# CHAPTER 10.
# AVALANCHE

## 10.1 GENERAL BACKGROUND

Avalanches can occur whenever a sufficient depth of snow is deposited on slopes steeper than about 20 degrees, with the most dangerous coming from slopes in the 35- to 40-degree range. Avalanche-prone areas can be identified with some accuracy, since they typically follow the same paths year after year, leaving scarring on the paths. However, unusual weather conditions can produce new paths or cause avalanches to extend beyond their normal paths.

In the spring, warming of the snowpack occurs from below (from the warmer ground) and above (from warm air, rain, etc). Warming can be enhanced near rocks or trees that transfer heat to the snowpack. The effects of a snowpack becoming weak may be enhanced in steeper terrain where the snowpack is shallow, and over smooth rock faces that may focus meltwater and produce “glide cracks.” Such slopes may fail during conditions that encourage melt.

Wind can affect the transfer of heat into the snowpack and associated melt rates of near-surface snow. During moderate to strong winds, the moistening near-surface air in contact with the snow is constantly mixed with drier air above through turbulence. As a result, the air is continually drying out, which enhances evaporation from the snow surface rather than melt. Heat loss from the snow necessary to drive the evaporation process cools off near-surface snow and results in substantially less melt than otherwise might occur, even if temperatures are well above freezing.

In a maritime climate, wind direction affects the humidity of the air (east winds bring dry air across the snow surface while west winds bring moisture from the ocean), and warm moist west winds can greatly enhance snowmelt, especially during cloud conditions that trap radiation and allow for condensation of moist air directly onto the snow surface. Drier easterly flows may enhance evaporation, taking heat from the snowpack and reducing melt.

**DEFINITIONS**

**Avalanche**—Any mass of loosened snow or ice and/or earth that suddenly and rapidly breaks loose from a snowfield and slides down a mountain slope, often growing and accumulating additional material as it descends.

**Slab avalanches**—The most dangerous type of avalanche, occurring when a layer of coherent snow ruptures over a large area of a mountainside as a single mass. Like other avalanches, slab avalanches can be triggered by the wind, by vibration, or even by a loud noise, and will pull in surrounding rock, debris and even trees.

**Climax avalanches**—An avalanche involving multiple layers of snow, usually with the ground as a bed surface.

**Loose snow avalanches**—An avalanche that occurs when loose, dry snow on a slope becomes unstable and slides. Loose snow avalanches start from a point and gather more snow as they descend, fanning out to fill the topography.

**Powder snow avalanches**—An avalanche that occurs when sliding snow has been pulverized into powder, either by rapid motion of low-density snow or by vigorous movement over rugged terrain.

**Surface avalanches**—An avalanche that occurs only in the uppermost snow layers.

**Wet snow avalanche**—An avalanche in wet snow, also referred to as a wet loose avalanche or a wet slab avalanche. Often the basal shear zone is a water-saturated layer that overlies an ice zone.

When the snow surface becomes uneven in spring, air flow favors evaporation at the peaks, while calmer air in the valleys favors condensation there. Once the snow surface is wet, its ability to reflect solar energy drops dramatically; this becomes a self-perpetuating process, so that the valleys deepen (favoring calmer air and more heat transfer), while more evaporation occurs near the peaks, increasing the differential between peaks and valleys. However, a warm wet storm can quickly flatten the peaks as their larger surface area exposed to warm air, rain or condensation hastens their melt over the sheltered valleys.

# 10.2 HAZARD PROFILE

## 10.2.1 Past Events

Avalanches in Washington State have killed over 200 people since 1900, and 47 between 1985 and 2009. This exceeds the death toll of earthquakes and floods combined. Records of large avalanches with loss of life or serious damage to property in or adjacent to Snohomish County include the following:

- 1910 Stevens Pass—96 dead, 2 trains derailed
- 1917 Monte Cristo—2 dead
- 1996 Mount Index—3 dead

Avalanches regularly close SR-2 above Index, as well as many of the smaller access roads at higher elevations. In addition, many miners and railroad workers were killed by an undocumented mixture of avalanches, rock falls and ***debris slides*** in the late 1800s, before the exodus of population from higher elevations as mines played out.

## 10.2.2 Location

The Cascade Range in the eastern half of Snohomish County receives extensive precipitation due to its size and orientation to the flow of Pacific marine air. In the local maritime climate, it is common for air temperatures to rise above freezing and for precipitation to change from snow to rain during mid-winter storm cycles. Temperatures can change several degrees within minutes, causing abrupt changes in precipitation type. These conditions frequently cause the release of avalanches. Figure 10-1 shows avalanche hazard areas in Washington State, including the easternmost portion of Snohomish County.

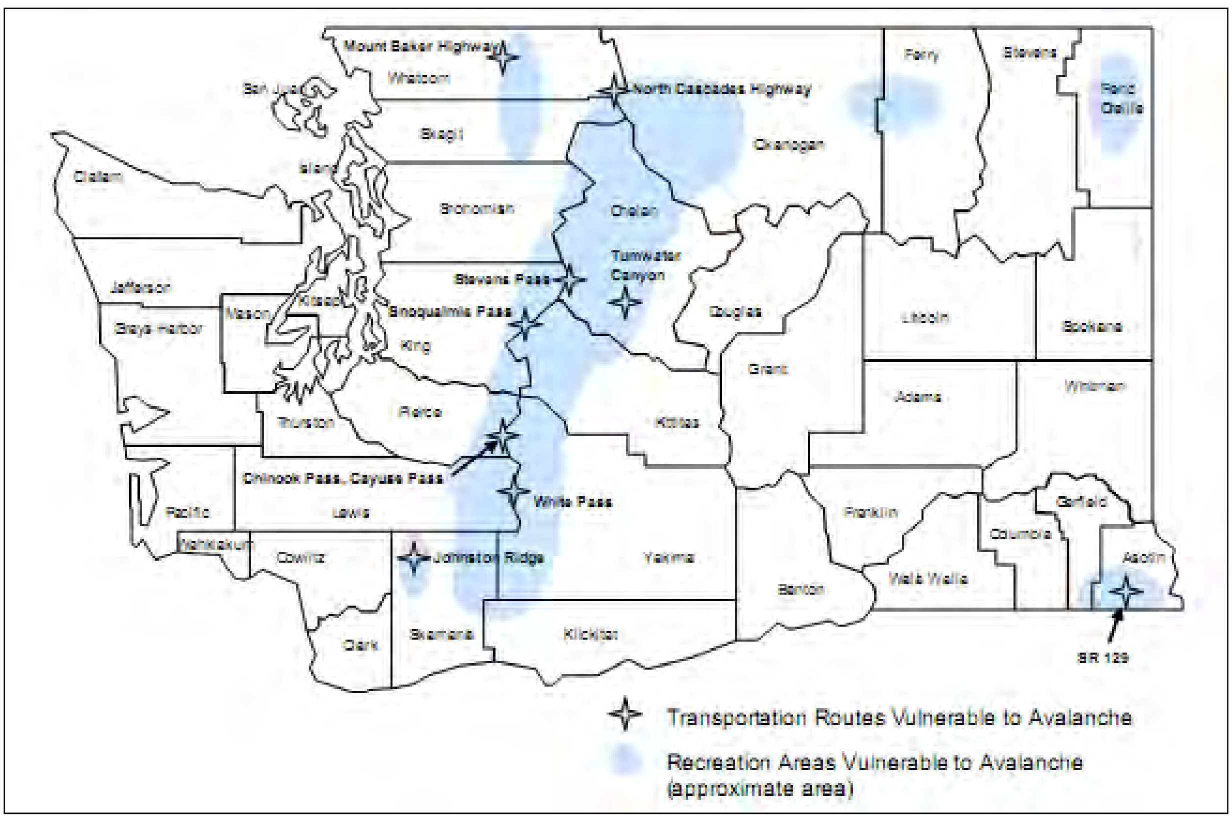



*Figure 10-1. Areas Vulnerable to Avalanche*

## 10.2.3 Frequency

At lower elevations of the Cascades, the avalanche season begins in November and continues until the last remnants of snow have melted in early summer. In the high alpine regions, the hazard continues year-round. Hundreds of thousands of avalanches are thought to occur each year in the Cascades.

## 10.2.4 Severity

A number of weather and terrain factors determine avalanche severity and danger:

- Weather:
  - Storms—A large percentage of all snow avalanches occur during and shortly after storms.
  - Rate of snowfall—Snow falling at a rate of 1 inch or more per hour rapidly increases avalanche danger.
  - Temperature—Storms starting with low temperatures and dry snow, followed by rising temperatures and wetter snow, are more likely to cause avalanches than storms that start warm and then cool with snowfall.
  - Wet snow—Rainstorms or spring weather with warm, moist winds and cloudy nights can warm the snow cover, resulting in wet snow avalanches. Wet snow avalanches are more likely on sun-exposed terrain (south-facing slopes) and under exposed rocks or cliffs.
- Terrain:
  - Ground cover—Large rocks, trees and heavy shrubs help anchor snow.
  - Slope profile—Dangerous slab avalanches are more likely to occur on convex slopes.
  - Slope aspect—Leeward slopes are dangerous because windblown snow adds depth and creates dense slabs. South-facing slopes are more dangerous in the springtime.
  - Slope steepness—Snow avalanches are most common on slopes of 30 to 45 degrees.

Experts say there are 12 common factors contributing to the avalanche hazard: old snow depth, old snow surface, new snow depth, new snow type, density, snowfall intensity, precipitation intensity, settlement, wind direction and speed, temperature, subsurface snow crystal structure, and tidal effect.

## 10.2.5 Warning Time

The time of an avalanche release depends on the condition of the snow pack; which can change rapidly during a day and particularly during rainfall. Research done at Snoqualmie Pass showed that most natural avalanches occurred less than 1 hour after the onset of rain; in these cases the snow pack was initially weak (Washington Emergency Management Division, 1996). In cases where the snow pack was stronger, avalanche activity was delayed or did not occur. Nonetheless an avalanche can occur with little or no warning time, which makes them particularly deadly.

# 10.3 SECONDARY HAZARDS

Avalanches can cause several types of secondary effects, such as blocking roads, which can isolate residents and businesses and delay commercial, public and private transportation. This could result in economic losses for businesses. Other potential problems resulting from avalanches are power and communication failures. Avalanches also can damage rivers or streams, potentially harming water quality, fisheries and spawning habitat.

## 10.4 CLIMATE CHANGE IMPACTS

Snow avalanches are mainly ruled by temperature fluctuations, heavy precipitation and wind regimes. Climate change is likely to modify the frequency and magnitude of both ordinary and extreme avalanche events. However, these possible changes are not taken into account in current engineering practice: reference scenarios and return periods for avalanche hazard management are always computed under the assumption of a stationary process. Unlike other phenomena such as tropical storms, snow avalanches are rarely used as indicators of climate change.

## 10.5 EXPOSURE

There is minimal development in the high Cascade Range, which makes Snohomish County's exposure to an avalanche small. Most mountainous areas in the County are part of the Mount Baker-Snoqualmie National Forest and other protected forests. There is threat to the development and users that do exist.

### 10.5.1 Population

There are no major populations exposed to avalanches in the County. Most of the avalanche hazard area is uninhabited or has minimal development. None of the ski resorts on Snohomish County's mountains are considered to be exposed to avalanches within their jurisdictional boundaries due to their ski slope maintenance protocols. Skiers who ski out of bounds in these areas are exposed to avalanches. People working in the mountains, such as miners and loggers, are exposed, as are recreational users, such as hikers and cross-country skiers.

### 10.5.2 Property

There is little property that is exposed to avalanches. Property and buildings exposed include National Forest huts and temporary structures belonging to mining and forestry operations.

### 10.5.3 Critical Facilities and Infrastructure

There are no critical facilities exposed to avalanches. There is a small amount of infrastructure that could be blocked by avalanches. These include hiking trails, fire roads and logging roads. SR-2 above Index is exposed to avalanches. The BNSF railroad passes through the mountains and could be exposed.

### 10.5.4 Environment

Avalanches are a natural event, but they can negatively affect the environment. This includes trees located on steep slopes. A large avalanche can knock down many trees and kill the wildlife that lives in them. In spring, this loss of vegetation on the mountains may weaken the soil, causing landslides and mudflows.

## 10.6 VULNERABILITY

In general, everything that is exposed to an avalanche event is vulnerable. More and more people are working and building in or using the high mountain areas of the Cascades in potential avalanche areas. These individuals often have little experience with, caution regarding, or preparation for, avalanche conditions. The increasing development of recreational sites in the mountains brings added exposure to the people using these sites and the access routes to them. The risk to human life is especially great at times of the year when rapid warming follows heavy, wet snowfall.

Snohomish County's transportation infrastructure is also vulnerable to avalanches. In most winters, snow slides can close any of the pass highways between western and eastern Washington. The avalanche threat was not a significant consideration in either the planning or construction of Washington's older mountain highways such as SR-2. Although costs associated with removing avalanches from SR-2 are borne by the state Department of Transportation, the County's road network and substantial commercial activity are also dependent upon the connectivity provided by this main highway. The BNSF Railway follows essentially the same east-west route as SR-2. Approximately 20 trains daily follow this route across the Cascades. The potential for rail service interruption, or for damage to a train carrying hazardous cargo in populated or environmentally sensitive areas, is of concern.

There may be an impact on Snohomish County's economy as a result of the avalanche hazard. The timber industry, power companies, recreational resorts, homeowners and recreational groups depend on relatively free access to wildland areas that may be restricted during periods of high avalanche threat.

## 10.7 FUTURE TRENDS IN DEVELOPMENT

Future trends in development cannot be determined until the avalanche hazard areas are accurately mapped. From review of the buildable lands analysis, which projects the location and density of development based on current land use regulations, there is no significant housing or employment capacity that has the potential to be developed in these areas.

## 10.8 SCENARIO

In a worst-case scenario, an avalanche would occur in the Cascade Mountains after a series of storms. Storms starting with low temperatures and dry snow, followed by rising temperatures and wetter snow, are more likely to cause avalanches than storms that start warm and then cool with snowfall.

## 10.9 ISSUES

The only issue of concern in the event of an avalanche is the threat to recreational users and property. The U.S. Forest Service, National Park Service, National Weather Service and Washington Department of Transportation currently have programs to monitor avalanche zones and forecast avalanche danger. However, there is no effective way to keep the public out of avalanche-prone areas, even during times of highest risk. A coordinated effort is needed among state, county and local law enforcement, fire, emergency management, public works agencies and media to provide winter snow pack and avalanche risk information to the public.

A national program to rate avalanche risk has been developed to standardize terminology and provide a common basis for recognizing and describing hazardous conditions. This United States Avalanche Danger Scale relates degree of avalanche danger (low, moderate, considerable, high, extreme) to descriptors of avalanche probability and triggering mechanism, degree and distribution of avalanche hazard, and recommended action in back country. Figure 10-2 shows key elements of the danger scale.

This information, updated daily, is available during avalanche season from the joint NOAA/U.S. Forest Service Northwest Weather and Avalanche Center and can be obtained from Internet, NOAA weather wire, and Department of Transportation sources. Avalanche danger scale information should be explained to the public and made available through appropriate county and local agencies and the media.

Measures that have been used in other jurisdictions to reduce avalanche threat include monitoring timber harvest practices in slide-prone areas to ensure that snow cover is stabilized as well as possible, and encouraging reforestation in areas near highways, buildings, power lines and other improvements. The development of a standard avalanche report form, and the maintenance of a database of potential avalanche hazards likely to affect proposed developments in mountain wilderness areas, would be of significant value to permitting agencies.

***Avalanche Safety Basics***

***Avalanches don't happen by accident*** *and most human involvement is a matter of* ***choice*** *not chance. Slab avalanches, which are triggered by the victim or a member of the victim's party, cause most avalanche accidents. However, any avalanche may cause injury or death and even small slides may be dangerous. Hence, always practice safe route finding skills, be aware of changing conditions, and carry avalanche rescue gear. Learn and apply avalanche terrain analysis and snow stability evaluation techniques to help minimize your risk. Remember that avalanche danger rating levels are only general guidelines. Distinctions between geographic areas, elevations, slope aspect and slope angle are approximate, and transition zones between dangers exist. No matter what the current avalanche danger is, there are avalanche-safe areas in the mountains.*

**UNITED STATES AVALANCHE DANGER DESCRIPTORS**

| **Danger Level (Color)** | Avalanche Probability and Avalanche Trigger | Degree and Distribution of Avalanche Danger | Recommended Action in the Back Country |
|---|---|---|---|
| **Low (Green)** | Natural Avalanches very unlikely. Human avalanches unlikely. | Generally stable snow. Isolated areas of instability. | Travel is generally safe. Normal caution advised. |
| **Moderate (yellow)** | Natural avalanches unlikely. Human triggered avalanches possible. | Unstable slabs possible on steep terrain. | Use caution on steeper terrain on certain aspects |
| **Moderate to High (orange)** | Natural avalanches possible. Human triggered avalanches possible. | Unstable slabs possible on steep terrain. | Be increasingly cautious in steep terrain. |
| **High (red)** | Natural and human triggered avalanches likely. | Unstable slabs likely on a variety of aspects and slope angles | Travel in avalanche terrain is not recommended. Safest travel on windward ridges of lower angle slopes without steeper terrain above. |
| **Extreme (red with black border)** | Widespread natural or human triggered avalanches are certain | Extremely unstable slabs are certain on most aspects and slope angles. Large destructive avalanches possible. | Travel in avalanche terrain should be avoided and travel confined to low angle terrain well away from avalanche path run-outs. |

*Figure 10-2. United States Avalanche Danger Scale (1996)*

# CHAPTER 11.
# DAM FAILURE

## 11.1 GENERAL BACKGROUND

Although numerous types of impounding facilities may be perceived as dams, not all are addressed or regulated equally by state and federal dam safety programs. WAEMD and FEMA do not consider dam failure as a "natural" hazard that falls under the mandatory requirements of 44CFR Section 201.6. According to 44CFR 201.6 (c)(2)(i), the risk assessment component of the local natural hazard mitigation plan is only required to include "a description of the type, location and extent of all *natural* hazards that can affect the jurisdiction." FEMA's guidance states that "while it is true that a Local Mitigation Plan does not require manmade hazards to be addressed in order to be approved…, FEMA supports jurisdictions that choose to consider *technological* and *manmade hazards* in their respective mitigation plans" (*Local Multi-Hazard Mitigation Planning Guidance*, July 1, 2008). Therefore, local governments have the discretion to determine whether dam failure hazards are to be included in natural hazard mitigation plans. The Steering Committee decided that including a profile on the potential risks associated with dam failures in Snohomish County would be prudent to this planning effort. Since it is not a required element, the Steering Committee was able to determine the scope and content for this chapter that would best meet the needs of the planning partnership.

**DEFINITIONS**

**Dam**—any artificial barrier and/or any controlling works, together with appurtenant works that can or does impound or divert water. (WAC 173-175-030)

**Dam Failure—**an uncontrolled release of impounded water due to structural deficiencies in the water barrier.

**Emergency Action Plan (EAP)**—a formal document that identifies potential emergency conditions at a dam and specifies preplanned actions to be followed to minimize property damage and loss of life. The EAP specifies actions the dam owner[1/] should take to moderate or alleviate the problems at the 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 the emergency management authorities of the critical areas for action in case of an emergency. (FEMA 64)

**High Hazard Dam**—dams assigned the high hazard potential classification are those where failure or mis-operation will probably cause loss of human life. (FEMA 333)

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

Dams considered in this plan are those facilities that meet the following criteria:

- The facility meets the federal definition of "dams" established by the Association of State Dam Safety Officials (ASDSO) Model State Dam Safety Program (National Inventory of Dams, July 2005):

  *"Any artificial barrier, including appurtenant works, which impounds or diverts water, and which (1) is twenty-five feet or more in height from the natural bed of the stream or watercourse measured 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 water storage elevation; or (2) has an impounding capacity at the maximum water storage elevation of fifty acre-feet or more."*

- The facility has an Emergency Action Plan (EAP) meeting FEMA specified requirements in response to the National Dam Safety Program, which was formally established by the Water Resources and Development Act of 1996. FEMA promotes EAPs for all dams with a hazard potential classification of significant or high and recommends dam failure inundation mapping. A recent FEMA survey indicates there are over 22,000 high or significant hazard potential dams in the United States, of which approximately 18,300, or 83 percent, do not have an EAP. The absence of EAPs at most state-regulated dams is recognized by FEMA as a deficiency in national emergency preparedness.

The National Dam Safety Program requires a periodic inspection and thorough engineering analysis of every major dam in the U.S. The goal of this FEMA-monitored effort is to identify and mitigate the risk of dam failure to protect lives and property. The Washington Department of Ecology's Dam Safety Office monitors the program at the state level. Dam failures typically occur as follows (see Figure 11-1):

- 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 or blockage of spillways, and by other means.
- Foundation defects due to differential settlement, slides, slope instability, uplift pressures, and foundation seepage 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 seepage, erosion along hydraulic structures such as spillways, erosion due to animal burrows, and cracks in the dam structure.
- Failure due to conduit and valve problems, 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.

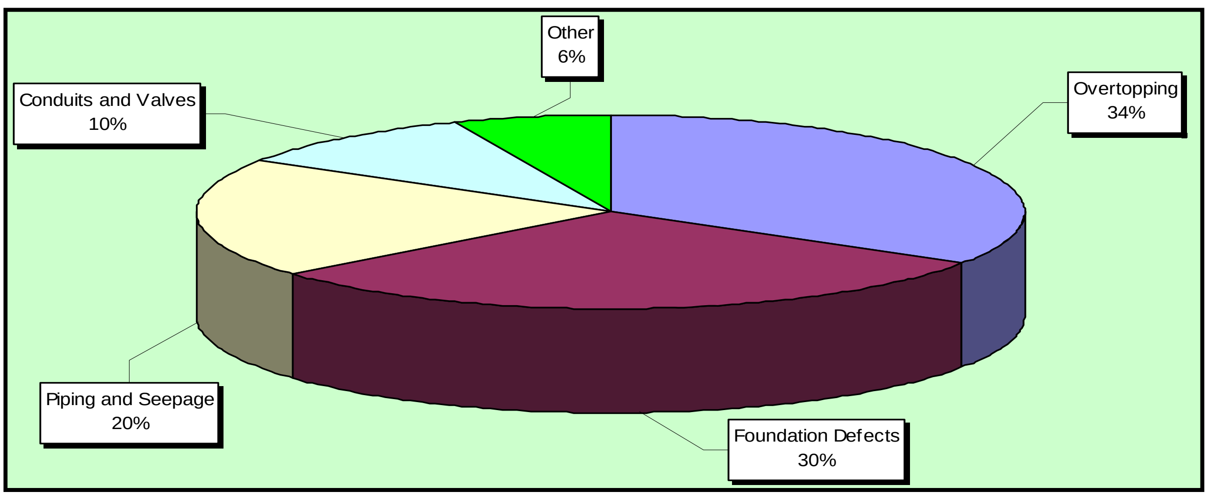



*Figure 11-1. Historical Causes of Dam Failure*

Many dam failures in the U.S. have been secondary results of other disasters, such as earthquakes, landslides, storms, snowmelt or sabotage. The most likely disaster-related causes of dam failure in Snohomish County 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.

Two federal agencies play significant roles in ensuring the safe operation and maintenance of dams identified under the National Dam Safety Program: the U.S. Army Corps of Engineers and the Federal Energy Regulatory Commission (FERC). Their dam safety programs are described below.

## 11.1.1 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 the design, construction, operation and maintenance of the dams; developed guidelines for the inspection and evaluation of dam safety; and formulated recommendations for a comprehensive national program (U.S. Army Corps of Engineers, 1997).

## 11.1.2 Federal Energy Regulatory Commission Dam Safety Program

The 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 are in the 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 projects on an unscheduled basis to investigate:

- 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 (10 meters), or with a total storage capacity of more than 2,000 acre-feet (2.5 million cubic meters).

Many FERC-regulated dams are in seismically active areas such as California and the Pacific Northwest. FERC staff monitors and evaluates seismic research in geographic areas where there are concerns about possible seismic activity. This information is applied in investigating and performing structural analyses of hydroelectric projects in these potentially affected 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. Additional chapters are being prepared and existing chapters are 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 are designed to serve as an early warning system if there is a potential for, or a sudden release of water from, a dam failure or accident to the dam. The plans include operational procedures that may be used, such as reducing reservoir levels and reducing downstream flows and procedures for notifying affected residents and agencies responsible for emergency management. These plans are frequently updated and tested to ensure that in emergency situations everyone knows what to do, thus saving lives and minimizing property damage.

# 11.2 HAZARD PROFILE

## 11.2.1 Past Events

The Department of Ecology Dam Safety Office maintains records of dam accidents in Washington. Between 1918 and 2003, 15 notable dam failure events occurred in Washington. Two of these events occurred in Snohomish County (see Table 11-1).

**TABLE 11-1.
NOTABLE DAM FAILURE INCIDENTS IN SNOHOMISH COUNTY**

| Project Name | Location | Date | Lives Lost | Nature of Failure |
|---|---|---|---|---|
| North Star Sand and Gravel Dam | Everett | 12/1967 | 0 | 40-foot-high dam was washed out by overtopping due to lack of a spillway. |
| North Star Sand and Gravel Dam | Everett | 12/1967 | 0 | A new 25-foot-high dam was built, which also failed, washing out railroad tracks and derailing a passing train. No casualties or fatalities were reported. |

## 11.2.2 Location

According to the Washington Department of Ecology, there are 58 dams in Snohomish County. Of these, six meet the parameters identified by the Steering Committee for discussion in this plan. Table 11-2 lists these facilities. The Tolt River Dam is in King County, but is included in the list because it has a significant inundation area within Snohomish County.

**TABLE 11-2.
HIGH HAZARD DAMS IN SNOHOMISH COUNTY**

| Name | Hazard Class[a] | Water Course | Owner | Year Built | Dam Type | Crest Length (feet) | Height (feet) | Storage Capacity (acre-feet) | Drainage area (sq. mi.) |
|---|---|---|---|---|---|---|---|---|---|
| Cedar Way Stormwater Detention Dam | 1B | Lyons Creek | Christopher T. Webber | 1985 | Earth Fill | 175 | 30 | 25 | 1.63 |
| Chaplin Lake North Dam | 1B | Woods Creek | City of Everett | 1940 | Earth Fill | 800 | 35 | 2200 | 2.6 |
| Chaplin Lake South Dam | 1A | Chaplin Creek | City of Everett | 1930 | Earth fill | 900 | 75 | 16,200 | 2.6 |
| Culmback Dam | 1A | Sultan River | Snohomish Co. PUD | 1965 | Rock Fill | 480 | 270 | 200,000 | 74.50 |
| Everett Reservoir #3 | 1B | Pigeon Creek | City of Everett | 1923 | Earth Fill | 1500 | 22 | 61 | 0.00 |
| Tolt River Dam | 1A | South Fork Tolt River | Seattle Public Utilities | 1962 | Earth Fill | 980 | 213 | 672,000 | 18.80 |

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

At this time, EAPs that include dam failure inundation mapping are not available for every dam in the County. Because of the stringent dam safety requirements for power projects with high hazard dams, examples of the best available data have been provided by the Snohomish County PUD for the Culmback Dam Inundation Zone and by Seattle City Light for the South Fork Tolt River Dam Inundation Zone. These were utilized to demonstrate the risk assessment possible with this type of information. The Culmback Dam Failure Inundation Map (Map 11-1) shows the approximate extent and location of downstream flooding should the Culmback Dam fail. The approximate location and extent of a probable maximum flood breach scenario for the Tolt River Dam is shown in Map 11-2. Snohomish County dams not considered in this plan include dams on the following rivers or tributaries:

- Chaplain Creek
- Cherry Creek Tributary
- Little Bear Creek
- Lyons Creek
- Lunds Gulch
- McCoy Creek Tributary
- Merrill and Ring
- North Creek Tributary
- Pigeon Creek
- Pilchuck River Tributary
- Possession Sound Tributary
- Powder Mill Gulch
- Powder Mill Gulch Tributary
- Quilceda Creek Tributary
- Sammamish River Tributary
- Sauk River (Off-stream)
- Siberia Creek Tributary
- Skykomish River
- Snohomish River (Off-stream)
- Snohomish River Tributary
- South Fork Stillaguamish Tributary
- Stillaguamish River Tributary
- Sultan River
- Tolt River (King County)
- Tulalip Creek
- Woods Creek Tributary

## 11.2.3 Frequency

Dam failure events are infrequent; their frequency coincides with that of the events that may cause them, including earthquakes, landslides and excessive rainfall and snowmelt. Two notable dam failure incidents have occurred in Snohomish County since 1918 as indicated in Table 11-1. Both of these events occurred well before federal and state dam safety programs were established. These types of events are not likely to occur in today's current regulatory and dam safety oversight environment.

## 11.2.4 Severity

Dam failure can be catastrophic to all life and property downstream. Past dam failure events in Snohomish County and Washington State have led to significant economic and environmental impacts. Table 11-3 shows the Corps of Engineers' classification for determining hazard potential of dam failures. These classifications are consistent with those defined by FEMA under the National Dam Safety program, which has established parameters for emergency action planning by dam operators.

## 11.2.5 Warning Time

Warning time for dam failure varies depending on the cause of the failure. In events of extreme precipitation or anticipated massive snowmelt, evacuations can be planned with sufficient time. Depending on the location of the population and critical facilities downstream, a structural failure due to earthquake may only allow very limited 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). For example, FERC standards require inundation maps to be developed based upon a 1-hour time of failure, while the 1976 Teton Dam failure occurred over the course of 2.5 hours.

**TABLE 11-3.**
**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

## 11.3 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.

## 11.4 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 could 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 to maintain the required margins of safety. These earlier releases of increased volumes of water can increase flood potential downstream.

Dams are constructed with spillways that allow controlled overflow if a reservoir fills too quickly. Spillway overflow events, often referred to as “design failures,” result in increased discharges downstream and increased flooding potential. The impacts of climate change may increase the probability of design failures. Throughout the Pacific Northwest, communities downstream of dams are already seeing the impacts from climate change due to increases in stream flows from earlier releases from dams.

## 11.5 EXPOSURE

The flood module of HAZUS-MH was used for a Level 2 assessment of dam failure risk and vulnerability in Snohomish County for facilities 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 the two principal dams of concern for which inundation data are available: Culmback Dam and Tolt Dam. Although the following discussions on exposure and vulnerability evaluate the data for each facility separately, it should be noted that there is an overlap in data between the two inundation areas.

### 11.5.1 Population

All populations within dam failure inundation zones would be exposed to the effects of a dam failure. The potential for loss of life is affected by the capacity of the dam, the number of evacuation routes available to populations living in areas of potential inundation, and warning time. For example, the population within the dam-failure inundation areas of the Culmback and Tolt River dams is approximately 17,421 or 2.47 percent of the total County population. Table 11-4 summarizes the at-risk population information.

**TABLE 11-4.**
**POPULATION AT RISK FROM DAM FAILURE**

| River System | Affected Population | % of County |
|---|---|---|
| Tolt | 4,379 | 0.62 |
| Culmback | 16,775 | 2.38 |
| **Total[a]** | **17,421** | **2.47** |

a. Represents the total population in the combined inundation areas for both dams.

### 11.5.2 Property

Based on Snohomish County Assessor parcel data, the HAZUS-MH model estimated that there are 5,064 structures within the combined inundation areas of the Culmback and Tolt River Dams. The value of exposed buildings in the planning area was generated using HAZUS-MH and is summarized in Table 11-5. This methodology estimated $1.98 billion worth of building-and-contents exposure to dam failure inundation in these areas, representing 3.16 percent of the total assessed value of the planning area. Since the Culmback and Tolt dam failure inundation areas overlie the mapped floodplain areas, the land use in these areas is the same as described for the flood risk assessment in Chapter 13.

### 11.5.3 Critical Facilities and Infrastructure

Table 11-6 summarizes the numbers and types of critical facilities exposed to possible inundation from dam failure. Failure of the less regulated dams of Snohomish County would affect fewer of the critical facilities of Snohomish County; however, quantifying for assessment is not possible without further development of inundation maps.

## 11.5.4 Environment

The environment would be exposed to a number of risks in the event of dam failure. Dam failure could introduce many foreign elements and debris into local waterways. This could result in destruction of downstream habitat and could have detrimental effects on many species of wildlife, especially endangered species such as salmon. Any facilities that house or process hazardous materials within the identified dam inundation areas may also threaten the environment.

**TABLE 11-5.**
**VALUE OF PROPERTY EXPOSED TO DAM FAILURE**

| Jurisdiction | Number of Buildings Exposed | Value Exposed: Building | Value Exposed: Contents | Value Exposed: **Total** | % of Total Assessed Value |
|---|---|---|---|---|---|
| Everett | 104 | $38,917,200 | $50,048,800 | **$88,966,000** | 0.56% |
| Marysville | 99 | $20,302,100 | $22,011,370 | **$42,313,470** | 1.01% |
| Monroe | 2,391 | $605,155,000 | $535,168,520 | **$1,140,323,520** | 50.12% |
| Snohomish | 137 | $26,247,400 | $22,419,960 | **$48,667,360** | 3.91% |
| Sultan | 1,236 | $189,487,700 | $152,775,150 | **$342,262,850** | 70.74% |
| Unincorporated County | 1,097 | $179,808,600 | $141,270,550 | **$321,071,950** | 0.83 |
| **Total** | **5,064** | **$1,059,918,000** | **$923,694,350** | **$1,983,605,150** | **3.16** |

**TABLE 11-6.**
**CRITICAL FACILITIES WITHIN SNOHOMISH COUNTY'S CULMBACK AND TOLT DAM INUNDATION ZONES**

| | |
|---|---|
| Medical and Health Services | 4 |
| Government Function | 8 |
| Protective Function | 3 |
| Schools | 11 |
| Other Critical function | 27 |
| Hazmat | 0 |
| Wastewater | 27 |
| Bridges | 124 |
| Communication | 2 |
| **Total** | **206** |

## 11.6 VULNERABILITY

### 11.6.1 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 may not have adequate warning.

### 11.6.2 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 this is where dam waters would collect.

The initial vulnerability analysis for property used HAZUS-MH, which requires detailed mapping that illustrates depth of flooding. Such mapping was available only for the Culmback Dam and Tolt River Dam. Therefore, the property initial vulnerability analysis addresses only these two facilities. These analyses are summarized in Tables 11-7 and 11-8.

**TABLE 11-7.**
**VALUE OF PROPERTY VULNERABLE TO CULMBACK DAM FAILURE**

| Jurisdiction | Buildings Impacted[a] | Loss | | | % of Total Exposure |
|---|---|---|---|---|---|
| | | Building | Contents | **Total** | |
| Everett | 78 | $11,073,845 | $27,358,651 | **$38,432,496** | 0.24 |
| Marysville | 0 | $0 | $0 | **$0** | 0 |
| Monroe | 1,749 | $119,060,100 | $145,090,151 | **$264,150,251** | 11.61 |
| Snohomish | 64 | $4,647,229 | $6,006,522 | **$10,653,751** | 0.86 |
| Sultan | 1,218 | $111,377,750 | $90,373,720 | **$201,751,470** | 41.70 |
| Unincorporated County | 1,016 | $73,253,093 | $51,977,653 | **$125,230,747** | 0.32 |
| **Total** | **4,125** | **$319,412,017** | **$320,806,697** | **$640,218,715** | 1.02 |

a. Buildings impacted are those exposed buildings expected to receive measureable damage from a dam failure event.

HAZUS-MH models estimated that 4,125 structures would receive measurable damage in the event of a Culmback Dam failure, with estimated losses of $640.2 million. For a Tolt River Dam failure, HAZUS estimated that 1,424 structures would receive measurable damage, with losses around $116.3 million. For this analysis, HAZUS-MH looked at finished floor elevations of structures within the inundation areas in relation to the projected water surface elevations. Buildings with finished floors above the projected water surface elevations were assumed by the model to have no measurable damage. These estimates should be viewed in context with the fact that the HAZUS-MH depth damage functions do not account for velocity flows or damage caused by impact from debris conveyed by high-velocity flows. Therefore, actual damage may be as much as double these estimates.

**TABLE 11-8.
VALUE OF PROPERTY VULNERABLE TO SOUTH FORK TOLT RIVER DAM FAILURE**

| Jurisdiction | Buildings Impacted[a] | Loss | | | % of Total Exposure |
|---|---|---|---|---|---|
| | | Building | Contents | **Total** | |
| Everett | 14 | $274,678 | $382,944 | **$657,622** | 0.004 |
| Marysville | 0 | $0 | $0 | **$0** | 0 |
| Monroe | 950 | $26,601,714 | $27,149,859 | **$53,751,572** | 2.363 |
| Snohomish | 24 | $1,693,769 | $1,171,664 | **$2,865,434** | 0.230 |
| Unincorporated County | 436 | $26,600,347 | $32,464,410 | **$59,064,557** | 0.160 |
| **Total** | **1,424** | **$55,170,508** | **$61,168,877** | **$116,339,185** | **0.124** |

a. Buildings impacted are those exposed buildings expected to receive measureable damage from a dam failure event.

## 11.6.3 Critical Facilities and Infrastructure

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.

HAZUS-MH was used to estimate the loss potential to critical facilities identified as exposed to dam failure inundation. Using depth/damage function curves to estimate the percent of damage to the building and the building contents, HAZUS-MH correlates these estimates to an estimate of functional downtime (the estimated time it will take to restore a facility to 100 percent of its functionality):

- On average, critical facilities within the inundation areas would receive 44.3 percent damage to the structure and 61.1 percent damage to the contents during a dam failure event.
- The estimated average time to restore damaged facilities to full functionality is 608 days.

## 11.6.4 Environment

The environment would be vulnerable to a number of risks in the event of dam failure. Inundation can introduce foreign elements and debris into waterways. This can result in destruction of downstream habitat and can have detrimental effects on many species of animals, especially endangered species such as salmon. The extent of vulnerability of the environment is the same as the extent of exposure.

## 11.7 FUTURE TRENDS IN DEVELOPMENT

Since the dam failure inundation areas overlie the mapped floodplain areas, the future trends for development in these areas are the same as described for the flood risk assessment in Chapter 13.

## 11.8 SCENARIO

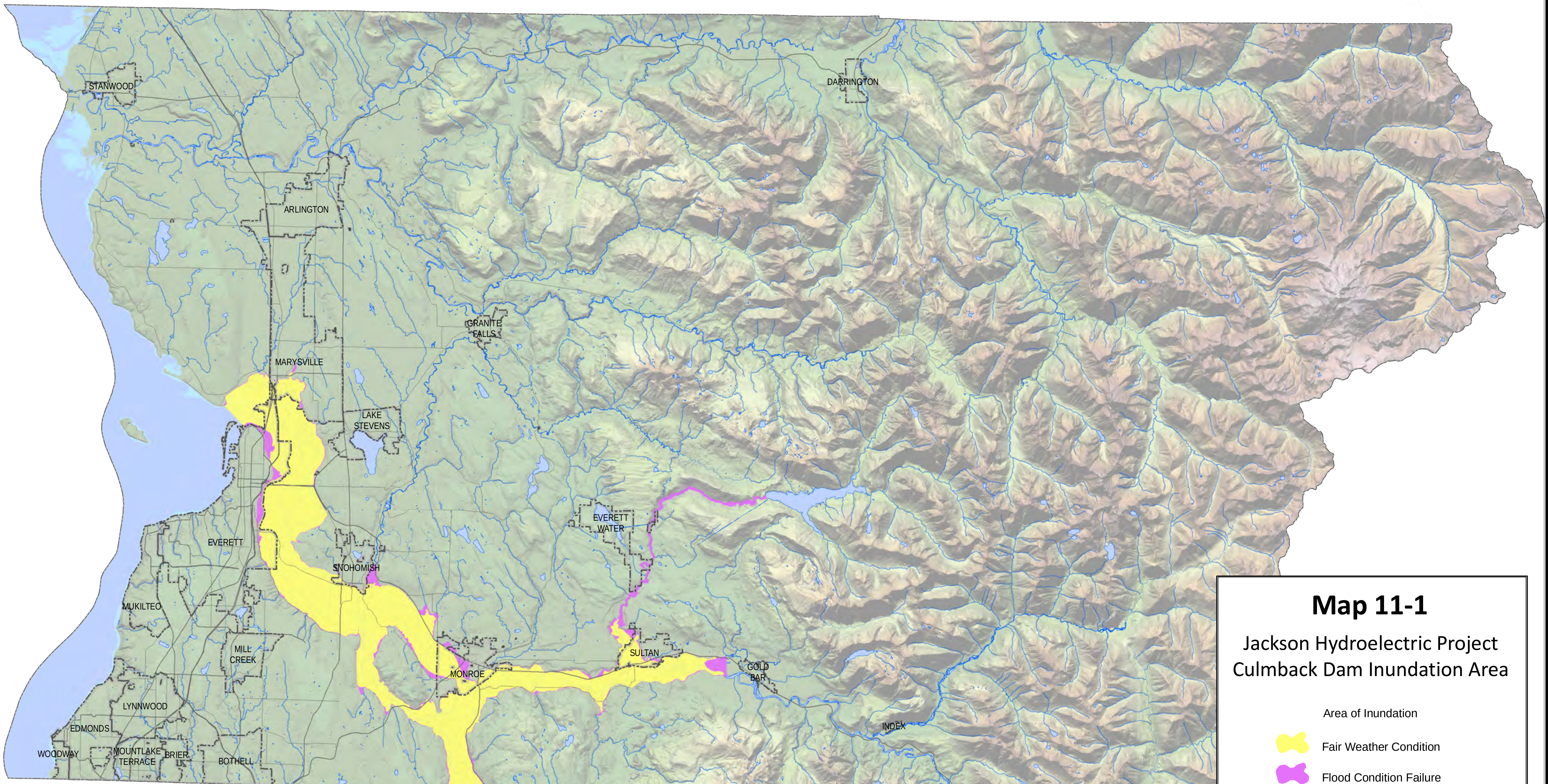
In a worst-case scenario, a shallow earthquake with a magnitude of 7.5 could be strong enough to cause a failure of some Snohomish County dams. An earthquake of this magnitude could lead to liquefaction of soils around the dams. This could occur without warning in the middle of the night when residents in river-front homes and campers are asleep and unprepared to evacuate. It should be noted that some of the more highly regulated dams within the County, such as the Culmback and Tolt, have been designed and certified to withstand a "maximum creditable earthquake" (MCE). The MCE for Culmback Dam has been determined to be a 7.5 magnitude event. Therefore, the probability of this worst case scenario impacting these higher regulated facilities would be less than those regulated to lesser standards.

Additionally, in light of recent concerns surrounding Howard Hanson Dam in King County, the inability of a dam to operate at 100 percent of its capacity is a major concern for dams that are used for flood control. Flood risk reduction infrastructure downstream of dams is designed using assumptions about the operation of the dams. Dams that are forced to release at rates higher than the design specifications of downstream infrastructure jeopardize the functionality of the downstream infrastructure. The impacts of climate change on dam operations could also have significant flood impacts downstream of these dams without there being any actual failure of the dam.

## 11.9 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, state regulated dams whose failure would pose a true threat to the people, property and economy of Snohomish County need to be clearly identified.
- Mapping for Federally regulated dams is already required and available; however, mapping for State 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 state and 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 State 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 high hazard 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.




# Map 11-1

## Jackson Hydroelectric Project Culmback Dam Inundation Area

Area of Inundation

Fair Weather Condition

Flood Condition Failure

Because of the method, procedures, and assumptions used to develop the inundation area, the limits of flooding shown and flood wave travel times are approximate and should be used only as a guideline for establishing evacuation zones. Actual areas inundated will depend on conditions during actual failure and may differ from areas shown on the map.

Snohomish County

Snohomish County disclaims any warranty of merchantability or warranty of fitness for any particular purpose of this map, either express or implied. Snohomish County makes no representation or warranty concerning the content, accuracy, currency, completeness, or quality of data depicted on this map. Any user of this map assumes all responsibility for its interpretation and use. Any user relying on any of the County's GIS products does so at his or her own risk. All critical information should be independently verified. Snohomish County shall not be liable to the user for damages of any kind, including lost profits, lost savings, or any other incidental or consequential damages related to the providing of data or its use. The user agrees to hold Snohomish County harmless from and against any damage, loss, or liability arising from any use of this map.

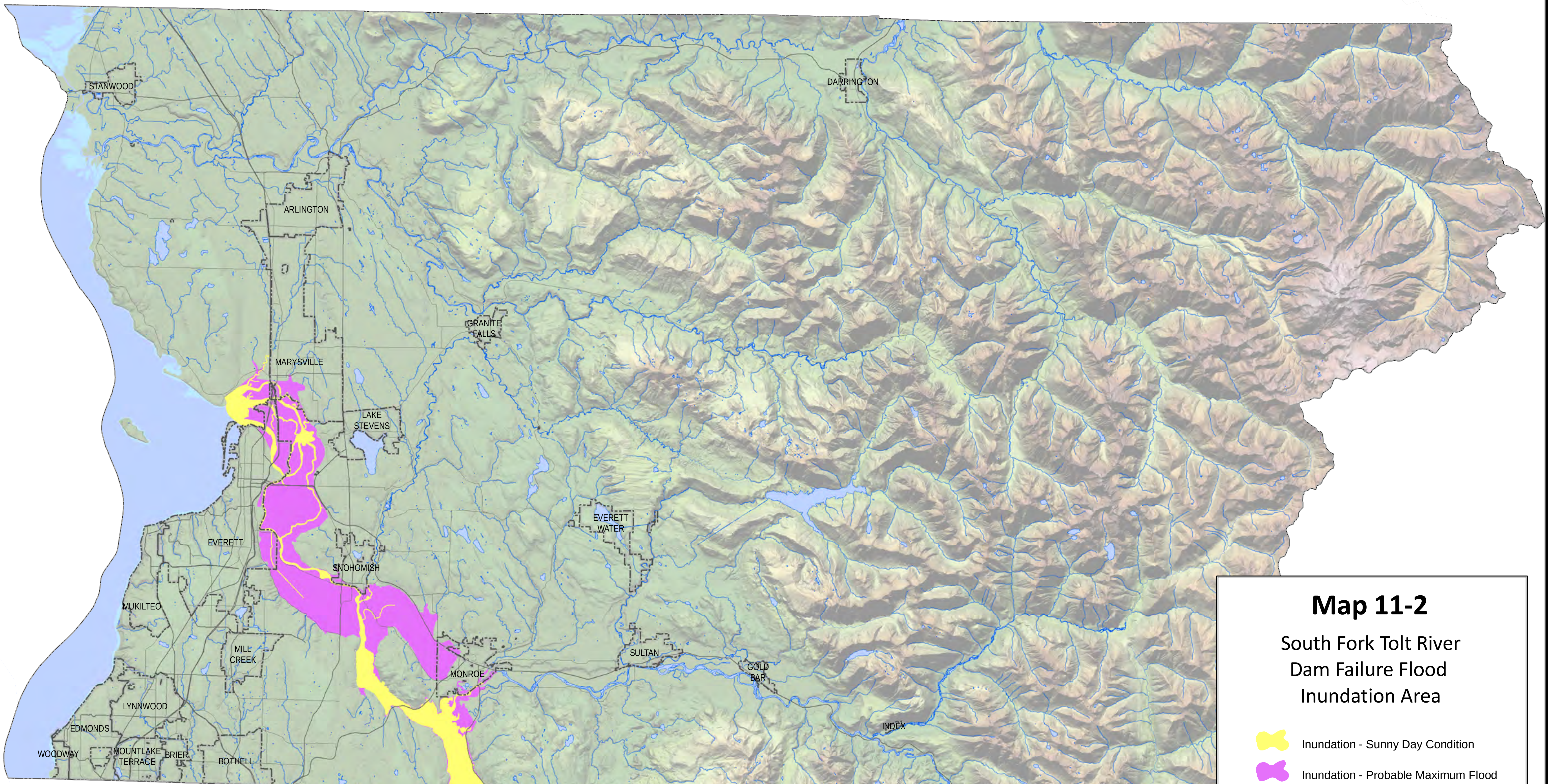
Tetra Tech, Inc.
May 2010

*Data Sources:*
*Snohomish County*
*US Geological Survey*
*Washington State Department of Natural Resources*
*Division of Geology and Earth Resources*
*Snohomish County Public Utility District #1*

0 2.5 5 10 Kilometers

0 2.5 5 10 Miles

N
W E
S




# Map 11-2

## South Fork Tolt River Dam Failure Flood Inundation Area

Inundation - Sunny Day Condition

Inundation - Probable Maximum Flood

The inundated areas shown on this map reflect events of an extremely remote nature. These results are not in any way intended to reflect upon the integrity of the South Fork Tolt River Dam.

Because of the methods, procedures, and assumptions used to develop the flooded area, the limits of flooding shown are approximate and should be used only as a guideline for establishing evacuation routes. Actual areas inundated will depend on actual failure conditions and may differ from areas shown.

*City of Seattle City Light Department*

**Snohomish County**

Snohomish County disclaims any warranty of merchantability or warranty of fitness for any particular purpose of this map, either express or implied. Snohomish County makes no representation or warranty concerning the content, accuracy, currency, completeness, or quality of data depicted on this map. Any user of this map assumes all responsibility for its interpretation and use. Any user relying on any of the County's GIS products does so at his or her own risk. All critical information should be independently verified. Snohomish County shall not be liable to the user for damages of any kind, including lost profits, lost savings, or any other incidental or consequential damages related to the providing of data or its use. The user agrees to hold Snohomish County harmless from and against any damage, loss, or liability arising from any use of this map.

Tetra Tech, Inc.
May 2010

*Data Sources:*
*Snohomish County*
*US Geological Survey*
*Washington State Department of Natural Resources*
*Division of Geology and Earth Resources*
*City of Seattle City Light Department*

0 2.5 5 10 Kilometers

0 2.5 5 10 Miles

N S W E