# 6. Natural Hazards

## 6.1. CRYOSPHERE

### 6.1.1. HAZARD CHARACTERISTICS

The "cryosphere" is defined as those portions of Earth's surface and subsurface where water is in solid form, including sea, lake, and river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground (e.g., permafrost) (Figure 6-1). The components of the cryosphere play an important role in climate. Snow and ice reflect heat from the sun, helping to regulate our planet's temperature. They also hold Earth's important water resources and therefore regulate sea levels and water availability in the spring and summer. The cryosphere is one of the first places where scientists are able to identify global climate changes.

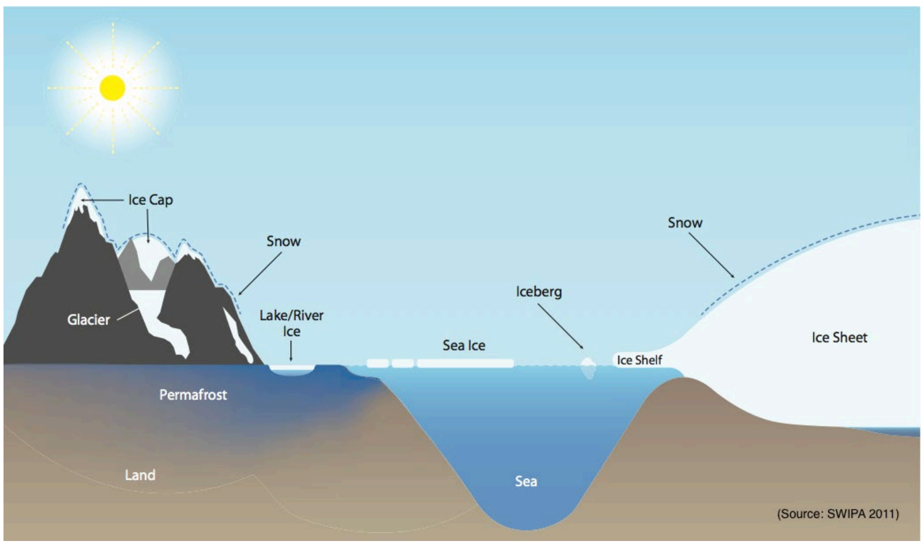



**Figure 6-1 Cryosphere Components Diagram**
*The diagram depicts cryosphere components. Source: Snow, Water, Ice, Permafrost in the Arctic (SWIPA)*

Hazards of the cryosphere can be subdivided into four major groups:

- Glaciers
- Permafrost and periglacial
- Sea ice
- Snow avalanche

Glaciers are made of compressed snow, which has survived summer and transformed into ice. Over many years, layers of accumulated ice build into large, thickened ice masses. Due to the sheer mass of the accumulated ice, glaciers flow like very slow rivers. Presently, glaciers occupy about 10 percent of the world's total land area, with most located in polar regions. Today's glaciers are much reduced from the last Ice Age, when ice covered nearly 32 percent of the land and 30 percent of the oceans. Most glaciers lie within mountain ranges that show evidence of a

much greater extent during the ice ages of the past 2-million years, and recent retreat in the past few centuries. Hazards related to glaciers include ice collapse (e.g., glacial calving and ice fall avalanche), glacial lake outburst flood, and glacial surge.

Permafrost and periglacial hazards are caused by the effects of changing perennially frozen soil, rock, or sediment (known as permafrost) and the landscape processes that result from extreme seasonal freezing and thawing (Figure 6-2). Permafrost is found in nearly 85 percent the state. It is thickest and most extensive in Arctic Alaska north of the Brooks Range; present virtually everywhere and extending as much as 2,000 feet below the surface of the Arctic Coastal Plain. Southward from the Brooks Range permafrost becomes increasingly thinner and more discontinuous, broken by pockets of unfrozen ground known as taliks, until it becomes virtually absent in Southeast Alaska, with the exception of pockets of high-elevation alpine permafrost.

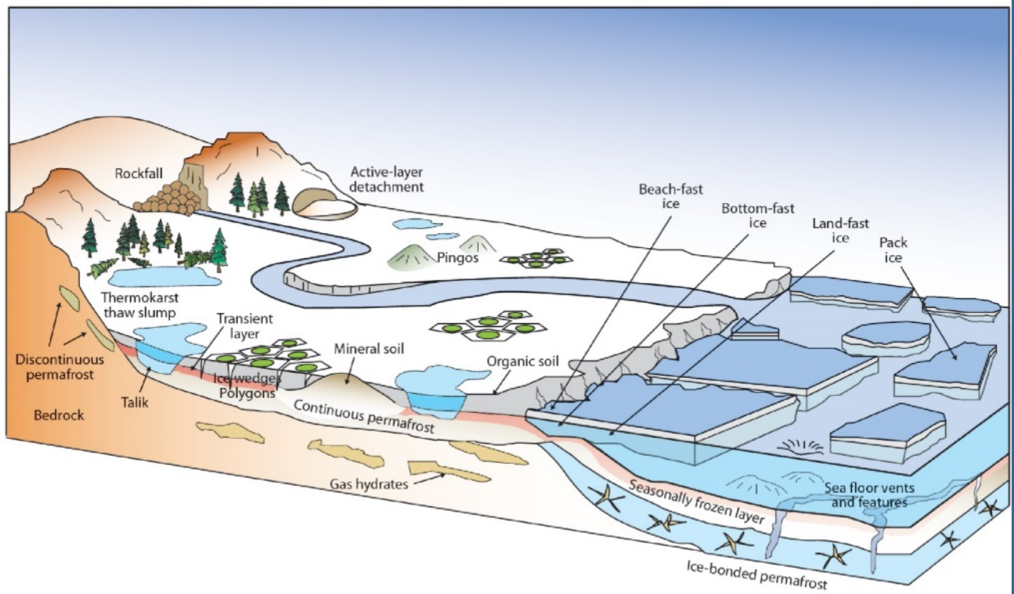



**Figure 6-2 Schematic Diagram Associating Landscape, Permafrost, and Sea Ice**

*These features are closely associated in northern latitudes. Source: SWIPA*

In the U.S., the presence of widespread permafrost results in classes of geologic hazards, which are largely unique to Alaska. Permafrost is structurally important to the soils of Alaska, and thawing causes landslides, ground subsidence, and erosion as well as lake disappearances, new lake development, and saltwater encroachment into aquifers and surface waters. *Usteq*, from the Yup'ik word meaning "surface caves in," is a catastrophic form of permafrost thaw collapse that occurs when frozen ground disintegrates under the compounding influences of thawing permafrost, flooding, and erosion.

Sea ice is frozen ocean water that forms, grows, and melts in the ocean (Figure 6-2). Sea ice grows during the winter and melts during the summer, but some sea ice remains all year in certain regions. Risks associated with human activities and ice processes are the greatest in the Arctic and sub-Arctic regions because of the prevalence of sea ice in those high latitudes. Hazards from sea ice include threats to shipping from running into ice; equipment or personnel breaking through ice when it is used as a seasonal platform for development activities; ice push (ivu) and gouging of the land or seafloor; and slush ice build-up that can clog intake valves. Lack

of sea ice during fall and winter increases the risk of coastal flooding and erosion from storms in northern and western Alaska because the ice is not there to protect the shore.

A snow avalanche is a mass of snow, ice, and debris that releases and slides or flows rapidly down a steep slope, either over a wide area or concentrated in an avalanche chute or track. Avalanches reach speeds of up to 200 miles an hour and can exert forces great enough to destroy structures and uproot or snap large trees. A moving avalanche may be preceded by an "air blast," which is also capable of damaging buildings. Snow avalanches commonly occur in the high mountains of Alaska during the winter and spring as the result of heavy snow accumulations on steep slopes.

Alaska is particularly vulnerable to cryosphere hazards, as much of its social and economic activity is connected to the existence of snow, ice, and permafrost.

### Glaciers

***Ice Collapse*** hazards result from large ice chunks breaking off from a glacier, either through glacial calving or as an ice fall avalanche. These hazards are almost impossible to predict and, in contrast to most other hazards in the cryosphere environment, they can happen independently of weather (e.g., heavy precipitation and rapid warming). In Alaska, ice collapses have on multiple occasions been triggered by earthquakes. Depending on the volume of ice collapse, these hazards can have tremendously devastating effects and can cause additional hazards, such as flooding and snow avalanches.

***Glacial Calving*** is the breaking away of a mass of ice from a near-vertical ice face along the terminus of a glacier, often into a large body of water (Figure 6-3). Glacier calving can be accompanied by a loud cracking or booming sound as the blocks of ice break loose and crash into the water. The entry of the ice into the water can cause large, sometimes hazardous, waves that can swamp boats and inundate nearby shores. In July 2015, a magnitude 6.3 earthquake occurred 120 miles west of Bear Glacier in Kenai Fjords, triggering a one-mile swath of ice to calve from the glacier and generating waves (a local tsunami) throughout the lagoon.

**Figure 6-3 Ice Calving From Glacier Front, Alaska**
*(Source: U.S. Geological Survey [USGS])*

***Ice Fall Avalanches*** are triggered by new or existing cracks (crevasses) in the glacier ice that allow chunks of a glacier to detach and fall down the slope as a mass of broken ice. Similar to cornice collapses (see Snow Avalanche), the mass of these ice falls often triggers snow avalanches on the slope below as they hit the snowpack. Ice fall avalanches are unrelated to precipitation, temperature, or other typical snow avalanche factors.

***Glacial Lake Outburst Floods***, also known as jökulhlaups, occur when water is rapidly released from a glacial lake due to the sudden failure of an ice or moraine dam, or to water overtopping the dam as a result of waves caused by mass wasting (landslide) of nearby unstable slopes that cause a landslide-generated tsunami. In the glacial system, ponds may form wherever water can be retained and drainage restricted, resulting in five glacial lake types (Figure 6-4):

A. *Ice-marginal lake:* forms alongside a glacier when a tributary valley or distributary glacier gets dammed by the main trunk of a valley glacier or outlet glacier
B. *Proglacial lake:* forms at the terminus of a valley glacier or outlet glacier
C. *Supraglacial lake:* forms in depressions on top of a glacier
D. *Englacial lake:* forms within a glacier in enlarged conduits and cavities in the ice
E. *Subglacial lake:* forms underneath a glacier in a topographic depression, or by damming by subglacial debris; subglacial volcanic or geothermal activity can also cause a subglacial lake to form

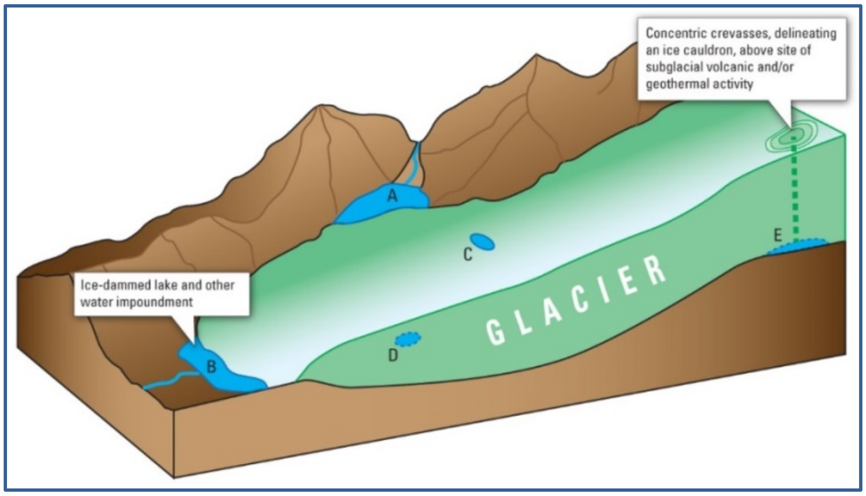



**Figure 6-4 Glacial Lake Formation Diagram**

*Shows the possible locations of impounded water that can form glacial lakes and potentially generate outburst floods. Source: USGS, 2018*

Outburst floods can be incredibly destructive; depending on the water volume released and downstream topography, outburst floods can cause extensive damage to downstream infrastructure and threaten public safety. Through collaboration between state agencies, universities, and local cities, a monitoring program has been established in Alaska for ice-dammed lakes at Bear Glacier in the Kenai Mountains, Valdez Glacier in the Chugach Mountains, Russell Lake at Hubbard Glacier in the Saint Elias Mountains, and the Suicide Basin at Mendenhall Glacier in the Coast Range.

***Glacier Surge*** is when a glacier periodically undergoes a brief phase (typically lasting 1–4 years) of rapid flow, called a surge. Surges are generally interspersed with longer periods (typically 10–100 years) of near-stagnation. During a surge, a large volume of ice is displaced downstream at speeds of up to several yards per hour into an ice-receiving area, and the affected portion of the glacier is chaotically crevassed (i.e. cracked). In the interval between surges, the ice reservoir is slowly replenished by snow accumulation and normal ice flow, and the ice in the receiving area is greatly reduced by ablation (i.e. the natural removal of ice through melting, calving, and sublimation). A surging glacier can advance quickly and override the ground in front of it, destroying anything in its path and potentially damming water flow to create a glacial lake that is a potential source of outburst flooding. Surging glaciers can also be particularly dangerous after surging because highly crevassed glacier snouts are unstable and subject to a higher incidence of calving and ice fall avalanches.

### Permafrost and Periglacial

In the periglacial environment, the effects of freezing and thawing drastically modify the ground surface. Types of modification include the displacement of soil materials, migration of groundwater, and the formation of unique landforms. Many periglacial regions are underlain by permafrost that strongly influences geomorphic processes acting in these parts of the world.

***Permafrost***, defined as ground with a temperature that remains at or below freezing (32°F or 0°C) for two or more consecutive years, can include rock, soil, organic matter, unfrozen water, air, and ice. Regions with permafrost are typically categorized by percent of surface area underlain by permafrost (Figure 6-5): continuous (>90 percent), discontinuous (50-90 percent), sporadic (10-50 percent), and isolated (<10 percent) permafrost. Bodies of ice can occur in permafrost, including pore ice, segregated ice, tabular ice, and ice wedges, among others. Large bodies of ground ice are referred to as massive ground ice. Permafrost with a high volume of ice is called ice rich permafrost.

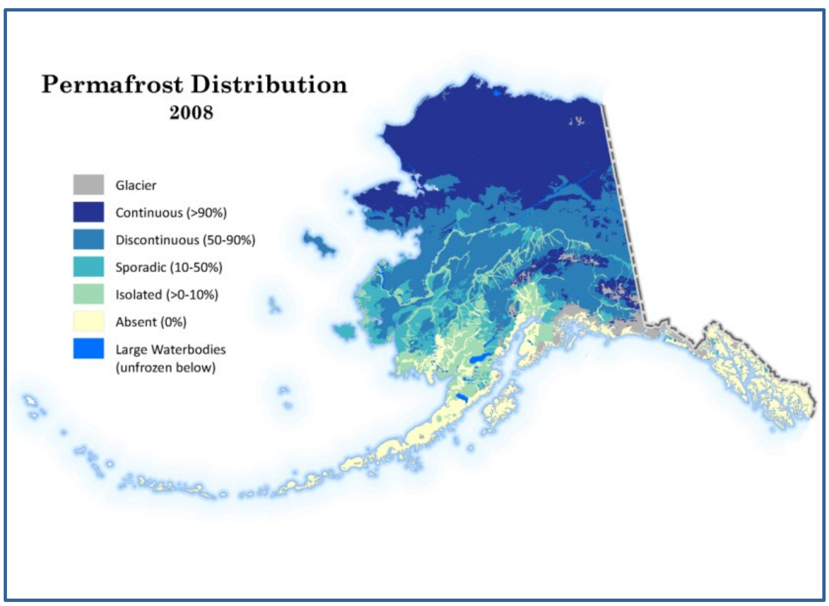



**Figure 6-5 Permafrost Distribution Map**
*Shows permafrost distribution in Alaska, 2008. Source: Jorgenson and others, 2008*

Permafrost provides a stable foundation for structures and infrastructure in cold-climate regions as long as the temperature of the frozen ground is well below freezing. A major hazard of warming and thawing permafrost is that ground ice degrades and the soil surface collapses. Fluctuations in temperature over the seasons also cause the ground to move as the upper layers freeze (i.e. ice lens formation) and thaw (i.e. loss of ice). Segregated ice lenses may form under wet conditions as the ground freezes, especially in fine-grained soils such as silt or clay. Upon thawing, ground ice can cause an excess of liquid water that cannot be stored in the soil and needs to flow out of the soil as gravity consolidates the soil after thawing.

***Aufeis*** (German for "ice on top"), or ***Icing***, occurs when a sheet-like mass of layered ice forms from successive groundwater flows during freezing temperatures. Groundwater is forced by hydraulic pressure to break through to the surface and flow on top of previously formed ice, which can occupy most or all of the river bed and causes the liquid to flow around or over the ice. This ice accumulation means that even small flows in winter can create large hazards as the icing impinges on roads and buildings (Figure 6-6). Aufeis can also cause a secondary hazard during snowmelt, when meltwater is unable to occupy the ice-filled river bed and instead flows unrestrained across the land and ice surface. The Dalton Highway aufeis flood described in the Flood and Erosion section of this report was exacerbated by meltwater.


**Figure 6-6 Aufeis at a Bridge Near Fairbanks, Alaska**
*Source: DGGS*

***Frost Cracking*** results from freezing soil contraction. This contraction can be forceful enough that the ground cracks in order to release tensile stress, similar to what happens when mud dries to form mud cracks. In extreme cases, polygons may form from thermal contraction in very cold environments and develop ice wedges within the cracks from meltwater and blowing snow accumulation. Frost cracking can be hazardous when it occurs in road surfaces, breaking pavement and road bed structure.

***Frost Heaving*** occurs when the soil surface is lifted with great strength from below by seasonal ice lens development in fine-grained soils (Figure 6-7). The temperature gradient from the freezing surface into the unfrozen ground drives liquid water to the freezing front, where it can

freeze into solid ice lenses. Buildings and roads are affected by the lifting force of the growing ice lenses, but the most destructive conditions occur when there is differential frost heave. Differential frost heave occurs when ice lens formation is non-uniform and only portions of the soil surface are pushed up—this can break building foundations and roads to pieces. A compounding effect of the seasonal ice lenses that cause frost heaving is that, upon thawing, the soil is left supersaturated, meaning that the liquid is carrying the weight of the soil. Pressure on the supersaturated soil, such as driving on a road across the thawed ice heave area, causes horizontal (lateral) movement of the soil and destruction of the overlying roadbed. This is the reason that roads can fail in spring, and why there are restrictions on axle weight.

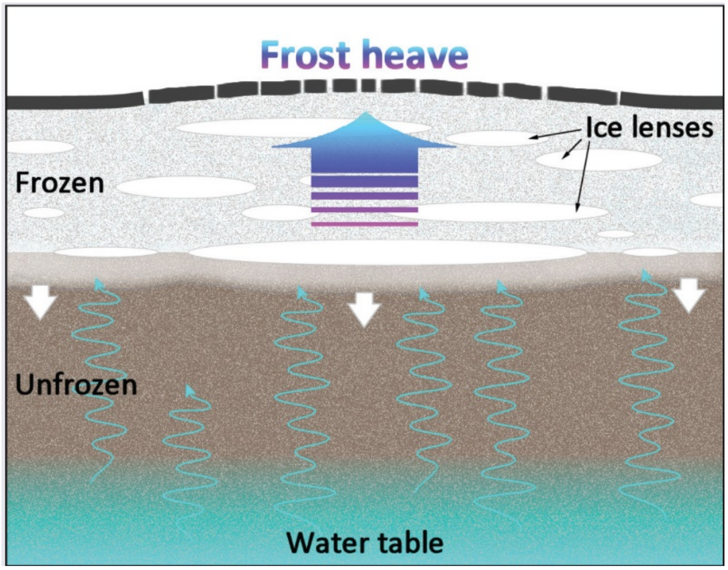



**Figure 6-7 Diagram of Frost Heave Formation**

*Freezing takes place from the surface down (white arrows). When conditions are favorable, an ice lens begins to form a short distance behind the freezing front. Fed by liquid groundwater from warmer zones deeper in the soil profile, the lens will continue to grow for as long as the controlling mechanisms allow. Multiple lenses reflect fluctuations in these controls due to changes in surface temperature, soil texture, and water availability. The amount of vertical displacement (heave) is roughly equal to the combined thicknesses of the underlying ice lenses. Heaving causes the pavement to crack.*

*Source: North Dakota Department of Mineral Resources*

***Frost Jacking*** occurs when a solid object, such as a fence post or foundation block, is incrementally jacked out of the ground due to ice lens formation within the soil during repeated freeze-thaw cycles. Two mechanisms are believed to be responsible for frost jacking:

- Freezing soil grips the object and heaves upward due to expanding ice, thereby lifting the object out of the ground; and
- Water trickles underneath a solid object and resultant ice growth during freezing pushes the object out of the ground. This process can cause foundations to break and buildings to collapse.

***Thermokarst*** is a form of periglacial topography resembling karst, characterized by irregular surfaces and hollows, produced by the selective melting of ice in ice-rich permafrost (especially permafrost with massive ground ice). Degrading ice-rich permafrost causes differential

settlement when voids are left behind by melting ice collapse. Sometimes this can form deep depressions (i.e. pits) when thick ground ice degrades and the soils above it cave in, or thermokarst lakes where continued thawing along the margins of the lake causes the surface to collapse further and the lake to expand over time.

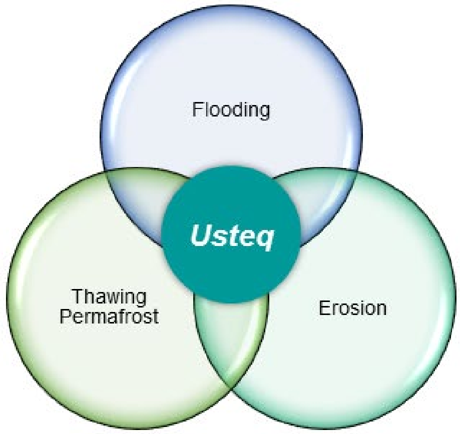
When permafrost is present on steeper slopes and the water released from melting ground ice is greater than the pore volume of the thawed soils, slope materials can become unstable and flow downhill. This is known as a retrogressive thaw slump or active layer detachment slide (see Ground Failure). These features can continue to grow as long as massive ice is present in the collapsing ground and the remaining slopes are sufficiently steep.

***Usteq*** is a catastrophic form of permafrost thaw collapse that occurs when frozen ground disintegrates under the compounding influences of thawing permafrost, flooding, and erosion (Figures 6-8 and 6-9). It is important to recognize that the compound hazard of usteq is much greater than the individual component processes; permafrost thaw, flooding, and erosion are parts of an escalating feedback loop. While permafrost degradation on its own can be a slow or moderately rapid process, in combination with flooding (including storm surge) and erosion, permafrost thaw can happen very quickly. During usteq, permafrost thaw that was previously a slow, developing hazard becomes a high-impact disaster as the ground caves in and collapses.

**Figure 6-8 Structure at Elson Lagoon, Alaska**
*Land lost to the ocean due to usteq. Source: USGS*

There are three critical permafrost characteristics that strongly affect susceptibility to usteq: thermal state, ice content, and soil characteristics. In practice, the thermal state of permafrost refers to the temperature of the frozen ground. Permafrost is a reflection of the long-term-thermal stability of atmospheric temperatures, combined with the dynamics of snow accumulation; and the stability of permafrost can be determined by measuring its temperature. When temperatures approach the melting point of ice in the ground, permafrost temperature remains more-or-less steady at that point until all ground ice has melted. During permafrost thaw, surface collapse can sometimes be measured instead of temperature to detect the progression of permafrost thaw. During wet summers, the effects of permafrost thaw can be accelerated because infiltrating water transports heat to the thawing front, and the additional water carries sediment away from ground ice in thaw slumps.

Individually, flooding, thawing permafrost, and erosion are persistent geologic hazards in Alaska. When combined, feedbacks effectively lower the threshold to each other's impacts and result in catastrophic permafrost thaw collapse known as ***usteq.***




## Thawing Permafrost

**Threshold Measure**
- Soil temperature above 0° C
- Increasing active layer thickness
- Collapsing land surface

**Natural Stressors**
- Temperature
- Ice content
- Soil character

**Anthropogenic Stressors**
- Building on permafrost
- Removing thermal insulator (vegetation) from ground surface

**Feedbacks**
- Thawing permafrost results in subsidence of the ground surface, lowering the threshold to flooding
- Thawed permafrost is less cohesive than frozen ground, lowering the threshold to erosion

**Documentation**
- Ground temperature
- Summer thaw depth
- Land surface levels

## Flooding

**Threshold Measure**
- Water levels exceed the elevation of a bank or shoreline

**Natural Stressors**
- Coastal/ocean storm surge and waves
- High precipitation
- Ice jam
- Snowmelt
- Glacial outburst
- Relative sea level rise

**Anthropogenic Stressors**
- Building on low-lying land
- Building damming structures

**Feedbacks**
- Flooding introduces warm or saline water into permafrost hydrology, increasing susceptibility to thaw
- Flooding physically erodes land through increased flow velocity over erodible materials

**Documentation**
- Level of water relative to a land-based datum

## Erosion

**Threshold Measure**
- Loss of land

**Natural Stressors**
- Waves, currents, and wind
- Soil character

**Anthropogenic Stressors**
- Boat wakes
- Vehicle and walking use
- Building structures in the nearshore coastal zone, disrupting longshore transport of sediment
- Removing vegetation

**Feedbacks**
- Erosion along rivers and coasts exposes permafrost to warm air and water
- Erosion of land can reduce the height of natural or built flood mitigation structures, or completely breach barriers to water flow

**Documentation**
- Position of the shoreline or riverbank

**Figure 6-9 Schematic Describes Usteq's Compounding Threat**

*A catastrophic form of permafrost thaw collapse that occurs when frozen ground disintegrates under the compounding influences of thawing permafrost, flooding, and erosion. Source: DGGS*

Permafrost temperatures throughout Alaska are showing warming trends (Figure 6-10); as permafrost approaches the freezing point (0°C/32°F), it becomes increasingly unstable and prone to collapse. Unstable permafrost requires very little trigger to initiate degradation.

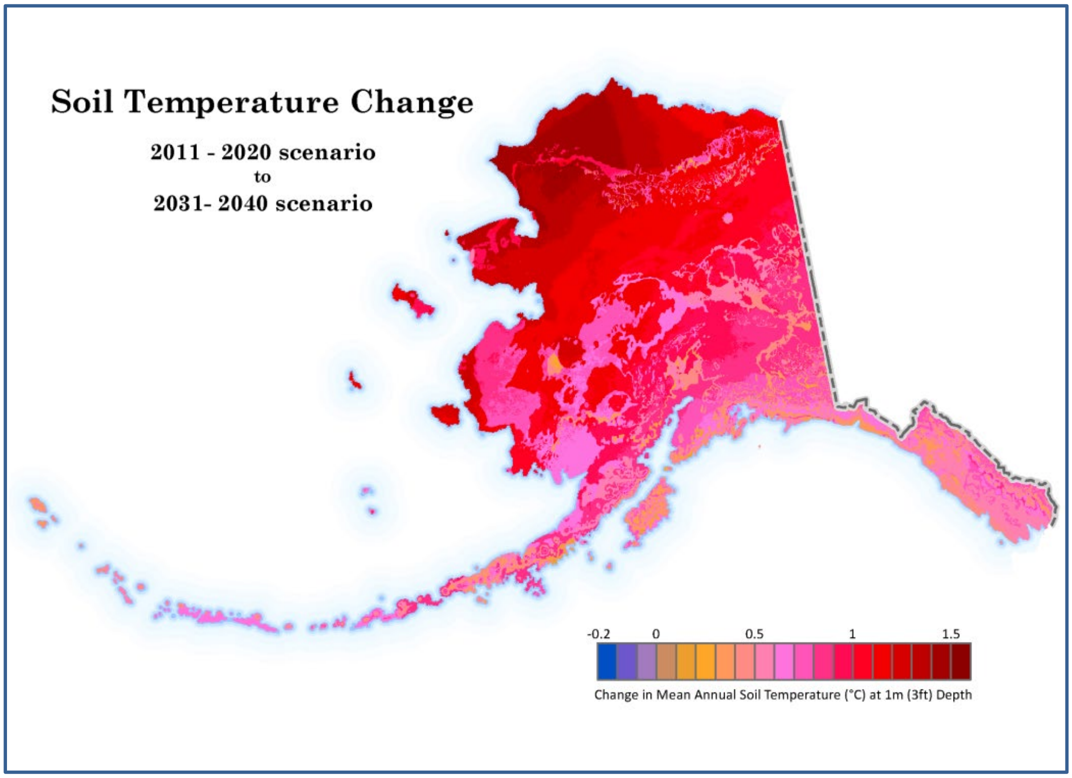



**Figure 6-10 Displays Modeled Soil Temperature Potential Changes**

*Scenarios span over the next 20 years. This is just one illustration of the many scenarios that scientists use to try to anticipate changes as climate warms; most models indicate that soil temperatures in Alaska are showing warming trends as global temperatures rise. Source: Denali Commission Threat Assessment, & UAF, 2018*

Ice content is the measure of frozen water in a given volume of permafrost (Figure 6-11). Because permafrost by definition is any earth material that remains below freezing for more than two consecutive years, permafrost composition is highly variable, ranging from solid rock to soils that are composed almost entirely of ice. Studies near Cape Halkett and Drew Point on the Arctic coast of Alaska have demonstrated that the rate of coastal erosion of ice-rich permafrost coast is much faster than non-ice-rich coast. In Alaska, yedoma that may be tens of feet thick occurs in the Arctic Foothills, in the northern part of the Seward Peninsula, and in interior Alaska; these areas will be particularly susceptible to catastrophic thaw collapse as temperatures warm. For example, the In'upiat community of Noorvik sits on 65 to 100 feet of massive ground ice that will be at risk of collapse if trends continue.

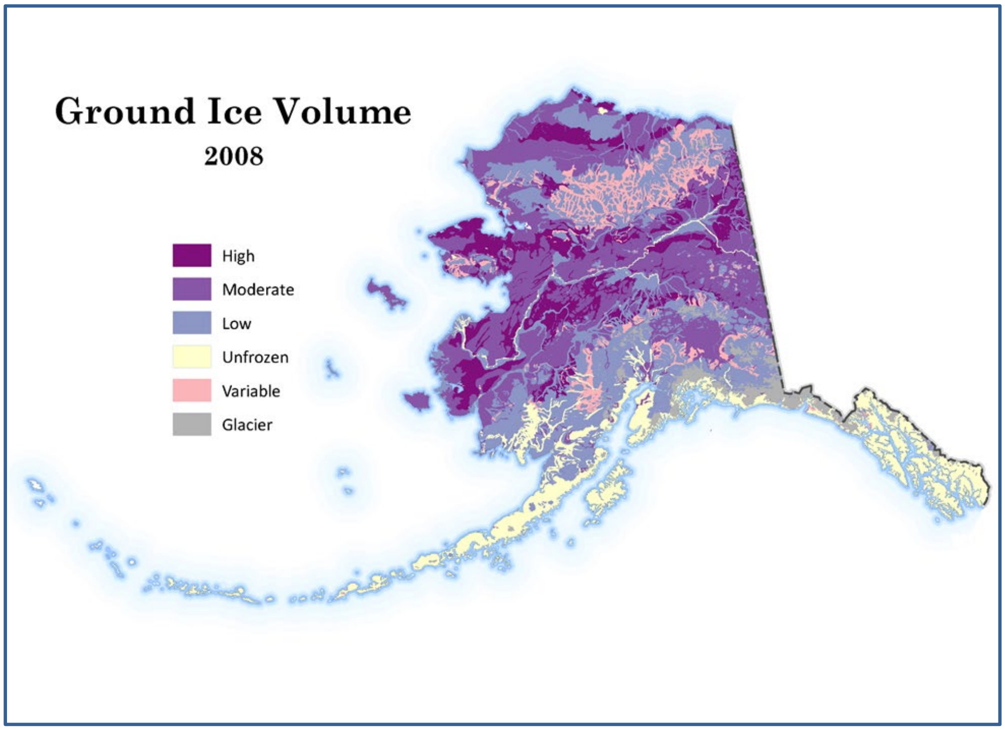



**Figure 6-11 Map Showing Ground Ice Volume of Permafrost in Alaska**

*A higher volume of ground ice, especially in fine-grained soils, can make soils more unstable upon thawing due to high pore water pressures in the supersaturated soils, and lead to extreme ground settlement due to voids left by melting ice. Source: Jorgenson and others 2008*

**Figure 6-12 Yedoma Exposed Along an Eroded Arctic Coast**

*Source: NPS*

The third factor is frozen soil or ground composition. Some soils (e.g., gravel) may have a very high ice content but are thaw stable when the ice melts, and other soil types (e.g., silt) will disintegrate and collapse when the supporting ice structure turns to water and saturates the soil material. When large areas of thick, ice-rich, fine-grained substrate thaw, there is potential for extreme consequences, including large-scale land surface lowering and collapse, sinkholes, and landslides.

Feedback mechanisms become particularly significant for affected communities in coastal and riverine environments, where river or ocean water from local flood events or storms can reach far inland and contribute to permafrost degradation. Warming temperatures initiate permafrost thaw, causing the land surface to sink (a form of ground subsidence). This lowered land surface is more vulnerable to storm surges and flooding, which exacerbate the hazard and lead to catastrophic hyper-erosion and inundation. Coastal storms that bring saltwater into contact with unstable permafrost can magnify thawing impacts, for example, at Kwigillingok on the Yukon-Kuskokwim Delta. Modeling shows that saltwater accelerates coastal permafrost thaw, even if temperature effects are ignored.

Permafrost is present and is collapsing throughout most of Alaska. Thawing permafrost alone is considered a specific hazard, but usteq is an additional unique, compound hazard. While some communities will have thawing with little or no flooding or erosion, it is when all three processes combine that the effects become catastrophic.

Elevated community risk factors for usteq include permafrost thermal state, soil ice content, soil characteristics, coastal vulnerability, and riverbank vulnerability. Measuring permafrost thaw vulnerability can be accomplished by:

- Measuring soil temperature, and evaluating whether it is approaching thaw vulnerability thresholds (in most cases 32°F);
- Measuring summer thaw depth and determining if this depth is increasing; and
- Monitoring ground surface levels to look for long-term subsidence.

Modeling and data sharing are critical to mitigating usteq threats to Alaska communities and infrastructure. On the ground observations, in conjunction with remotely sensed data, provide the necessary information required to develop realistic models of the interacting environmental hazards and how to integrate their effects into a unified understanding of the threat. Data inputs and results must be shared so that all stakeholders have equal access and can independently evaluate and use the information for diverse needs and priorities. Partnerships, which link local community observers with universities and government agencies researchers have already formed to create effective teams that contribute critical data to help understand and evaluate Alaska's thawing permafrost, flooding, and erosion challenges. These partnership networks include Alaska Native Tribal Health Consortium's Local Environmental Observer Network (LEO Network; http://www.aoos.org/alaska-community-based-monitoring/what-are-we-observing/leo-network); the Alaska Sea Grant-funded Shoreline Erosion Monitoring Project (https://seagrant.uaf.edu/research/projects/summary.php?id=1041); the UAF' Alaska Arctic Observatory and Knowledge Hub (AAOKH; https://arctic-aok.org); and a new community-based monitoring project initiated by the Alaska Institute of Justice, Woods Hole Research Center, and DGGS.

### Sea Ice

Sea ice hazards are common in the Arctic, where extreme cold weather conditions freeze the oceans' surface. Some of these hazards are also relevant for fresh water systems, such as rivers and lakes. The Arctic Ocean freezes over vast areas to ice thicknesses of more than 3 feet annually. A large portion of this area melts during the summer, but usually some of the annual ice remains to become multi-year ice that can freeze again and become much thicker. Sea ice and its associated hazards are complex and dynamic due to the interaction of wind, temperature, first-year ice, and multi-year ice with a variety of human activities related to transportation, subsistence living, coastal erosion, and resource extraction. *Source: Eicken & Mahoney, 2015*

Sea ice hazards have been present since the first people ventured out into the sea ice for hunting and travel. Population growth, demand for resources, and the warming climate of the last century have spurred more interest in arctic exploration and an increase in the number of cruises into high-latitude waters. Even the indirect consequences of sea ice activity can be hazardous to ship traffic; for example, in August 1996, the cruise ship "Hanseatic" ran aground in Simpson Strait near Gjoa Haven, Northwest Territories, because winter sea ice had moved a buoy that was supposed to be marking a shoal.

***Drifting Ice (Iceberg)*** is ice that has broken free of its source (sea ice or glacier) and floats in an ocean or lake. Icebergs come in all shapes and sizes, from ice-cube-sized chunks to ice islands up to 4,250 square miles (about the size of Connecticut). Icebergs pose a danger to ships traversing high-latitude waters.

A ***Grounded Floeberg*** is a massive piece of sea ice, composed of pressure ridges or hummocks, which has separated from the ice pack and become lodged in shallow water.

***Ice Push (Ivu)*** is a surge of ice from an ocean or large lake onto the shore. Ivus are caused by currents, strong winds, or temperature differences pushing ice onto the shore, creating immense ice piles that can be shoved far inland and are capable of moving and destroying infrastructure and buildings (Figure 6-13).

**Figure 6-13 Ivu Near Golovin, Alaska**
*Ivu seen after the 2011 Bering Sea storm. Source: DGGS*

***Landfast Ice Break-Out*** occurs when grounded pressure ridges that anchor sea ice to the shallow ocean bottom fail or unground, and previously stationary ice detaches from the coast and drifts away to form a floeberg.

***Slush Ice*** is a mixture of snow and ice crystals floating on the surface of the ocean. The ice crystals, called frazil, represent the first stages of sea ice growth. Slush ice can build up on vessels and equipment and clog intake valves.

With commercial shipping routes in the Arctic Ocean becoming more commonly traveled, ships are increasingly experiencing the impacts of sea ice. Even small amounts of ice can create problems for valves and water intake for jet propulsion. Icebreakers are typically used to break sea ice to reduce collision hazard, but multi-year ice can be too thick and pose a problem for ice breakers.

Oil pipelines and communication cables are typically laid upon or buried in sediment on the bottom of the ocean. Where sea water is shallow, iceberg gouging can be a problem when the ice thickness is greater than the water depth. Propelled by the wind, these ice masses push through the sediment and can disrupt cables or pipelines.

**Snow Avalanche**

A snow avalanche is a downhill mass movement of snow. Their size, run-out distance, and impact pressure vary. Large avalanches have the potential to kill people and wildlife, destroy infrastructure, level forests, and bury entire communities. Significant avalanche cycles (multiple avalanches naturally releasing across an entire region) are generally caused by long periods of heavy snow, but avalanche cycles can also be triggered by rain-on-snow events, rapid warming in the spring, and earthquakes.

An avalanche releases when gravity-induced shear stress on or within the snowpack becomes larger than its shear strength. Triggers can be natural (e.g., rapid weight accumulation during or just after a snowstorm or rain event, warming temperatures, and seismic shaking) or artificial (e.g., human weight or avalanche-control artillery). There are four distinct avalanche types in Alaska that occur under varying snowpack and weather conditions. Each avalanche type is named based on its snow release characteristics:

- Cornice collapse
- Loose snow avalanche
- Slab avalanche
- Slush avalanche/flow

***Cornice Collapse*** occurs when an overhanging snow mass breaks, separates, or is released. Cornices form on ridge crests or shoulders adjacent to gullies due to wind blowing the snow. The cornice is an indicator of predominant wind directions, as the cornice is formed on the lee (i.e., downwind) side of topographic features. Over time, the cornice can develop weaknesses in its structure and its attachment to the slope may fail. A cornice collapse often triggers a loose snow or slab avalanche as it adds sudden and significant stress onto the snowpack below.

***Loose Snow Avalanches***, also known as point releases, initiate with a small amount of non-cohesive (loose) snow and quickly grow larger as they move downhill and entrain more snow.

This type of avalanche typically carries relatively small amounts of powder snow and virtually no other debris. However, a loose snow avalanche may trigger a larger slab avalanche on the same slope.

A ***Slab Avalanche*** releases as a block of cohesive snow when snow particles have stuck together to form one or more resistant layers. There is a wide range of slab characteristics possible, running the gamut from “soft” slab (weakly cohesive snow) to “hard” slab (very cohesive snow), and from “storm” slab (release of recently deposited storm snow), to “persistent” and “deep persistent” slab (release of a slab that failed on a weak layer deeper down in the snowpack). Due to their large release masses, and because more snow is picked up along the way (snow entrainment), slab avalanches are the most destructive avalanche type. Human encounters with even small-sized slab avalanches are often fatal.

***Slush Avalanches*** are fast-moving mixtures of snow and water. They release in isothermal snowpacks (snow temperature throughout the snowpack is 32°F) when liquid water permeates the snowpack and dramatically weakens the intergranular bond. Slush avalanches therefore typically occur in northern Alaska during the spring when warm temperatures and strong solar radiation quickly warm up the snowpack. Slush avalanches can release on slopes as gentle as 20 degrees. Their release is often slower than other avalanche types, but as the slushy snow runs downhill they can reach speeds over 40 miles per hour. Smaller, more fluid avalanches with higher water content are commonly referred to as slush flows.

An avalanche path comprises three main parts: starting zone, track, and run-out zone (Figure 6-14). Local topography determines the shape and size of each part. Steep gullies that contain a stream or creek in the summer often function as avalanche paths in the winter, but avalanches also release and run on simple and complex open slopes.

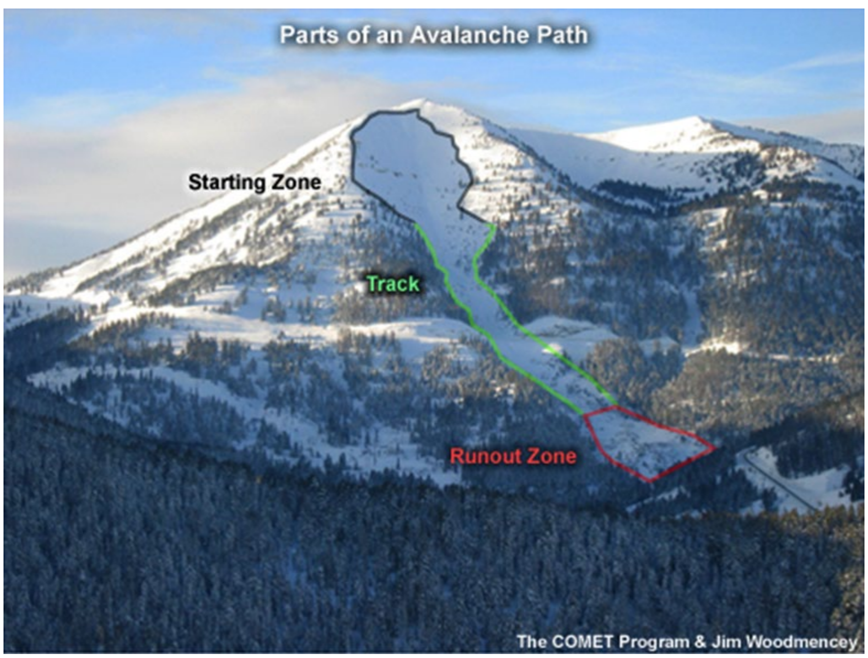



**Figure 6-14 Parts of an Avalanche Path**

*Source: Cooperative Program for Operational Meteorology, Education, and Training [COMET®]*
[http://www.comet.ucar.edu/who_about_us.php](http://www.comet.ucar.edu/who_about_us.php)

The *starting zone* is also called the release area. This is the upper part of the avalanche path, where snow accumulates (creating a slab or point source release area) and the avalanche begins its downhill movement. Starting zones are commonly located in the headwaters of a drainage where snow is accumulated on lee-side aspects of topographic features. Starting zones on open slopes are more difficult to identify. Sometimes multiple starting zones join into one track (e.g., several creeks funneling into one major gully).

The *track* is the middle part of the path, where the avalanche transports the released snow downhill to the deposition (runout) zone. The avalanche accelerates and reaches its maximum velocity in the track, and can also pick up more snow, adding to its mass. The track can be comprised of both confined gullies and unconfined open slopes. Tracks can also branch onto adjacent slopes, creating successive avalanches.

The *run-out zone* is the bottom part of the path, where the avalanche slows down and deposits debris. The avalanche impact pressure, which is a function of its snow density, volume (i.e., mass), and velocity, determines the amount of damage the avalanche could potentially cause. This measure is used for designing mitigation structures to protect infrastructure and buildings that are located in an avalanche risk zone.

Terrain factors that influence avalanche release are slope angle, aspect, and curvature, as well as topography (terrain roughness). Avalanches are also controlled by vegetation cover and elevation, which are both factors in getting enough snow accumulation on the slope. Avalanches typically release on slopes greater than 25 degrees and less than 60 degrees; this is the slope range where the snow can accumulate enough to build a slab, but also where snow tends to remain in place without sluffing off due to gravity. It is important to remember that avalanche run-out (deposition) can occur on all slopes. Figure 6-15 is a generalized avalanche-potential map of Alaska that was produced in 1980 by compiling and cross-correlating topographic relief, snow-avalanche regions, climatic zones, snowpack characteristics, and known and suspected avalanche activity. The map includes regions that had little or no snow avalanche occurrence data and is therefore provisional until better data are available and new analysis methods and avalanche modeling can be applied.

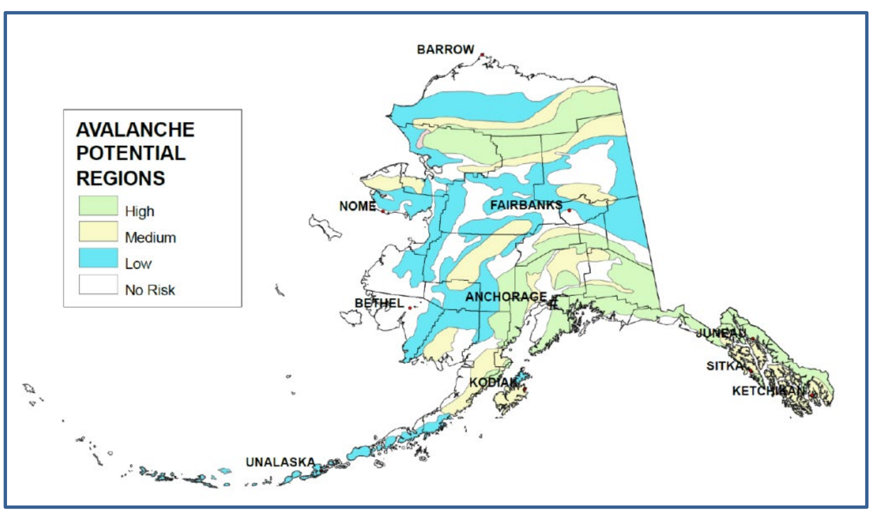



**Figure 6-15 Map Depicting Alaska's Potential Snow-Avalanche Areas**
*Source: Hackett and Santeford 1980*

New Alaska avalanche studies are currently being carried out by the State of Alaska Division of Geological & Geophysical Surveys and UAF. Figure 6-16 depicts potential snow avalanche release areas within a 6-mile buffer of roads in Alaska. The modeling uses digital topographic information as input and determines the potential release zones based on geostatistical parameters (e.g., elevation, slope, and curvature) and land cover (e.g., trees). This is a preliminary model result that does not include weather or snowpack parameters, but more advanced studies that will incorporate these elements are planned.

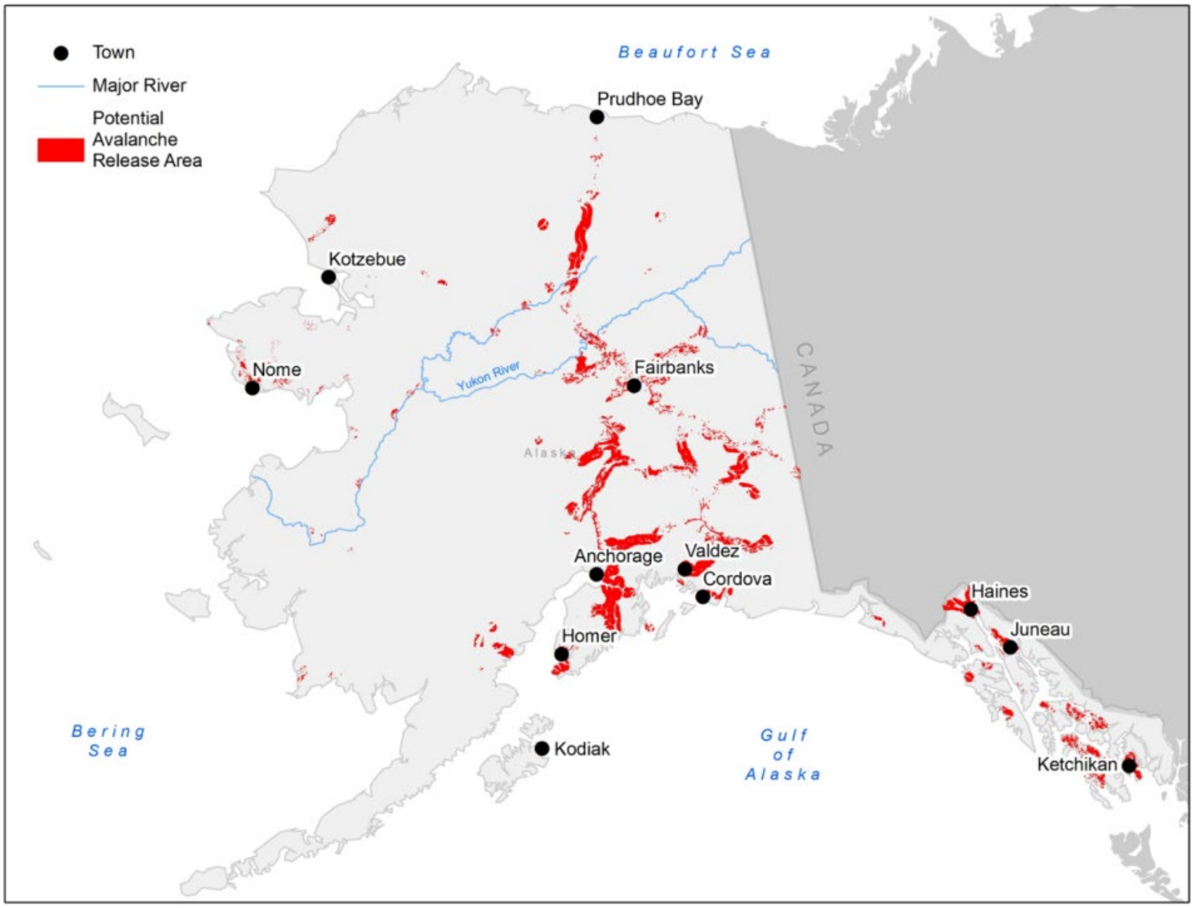



**Figure 6-16 Potential Snow-Avalanche Release Areas**
*Source: DGGS 2018*

Numerous snow avalanches occur in Alaska every year due to abundant avalanche-susceptible terrain and large amounts of snowfall. Many highways, the railroad, and multiple communities are at risk of avalanche hazards every winter, some of which can be particularly destructive. The most recent extreme avalanche event took place near Valdez in January 2014 after a mid-winter rain event that triggered many full-depth wet snow avalanches throughout Southcentral Alaska. This avalanche blocked the only road connection to Valdez and dammed a river in Keystone Canyon, Figure 6-17.


**Figure 6-17 Keystone Canyon Avalanche**

*An avalanche blocked the road and impounded a lake in Keystone Canyon near Valdez, 2014.*
*Source: DOT/PF 2017*

Alaska is sparsely populated with most development concentrated in relatively few areas. The exact number of avalanches release annually is undeterminable. However, snow avalanches cause more fatalities in Alaska than any other natural hazard (Figure 6-18). Alaska leads the nation in avalanche accidents per capita and experiences multiple fatalities each year due to this hazard. In addition to human risk, road closure due to avalanches is very costly. For example, a typical road closure with roughly 1,500 cubic feet of snow covering the road costs Alaska Department of Transportation & Public Facilities approximately $10,000 to remove. In the winter of 1999 to 2000, unusually high snowfall from the Central Gulf Coast Storm fueled avalanches in Cordova, Valdez, Anchorage, Whittier, Cooper Landing, Moose Pass, Summit, the Matanuska-Susitna Valley, and Eklutna. Damages in these communities exceeded 11 million dollars, resulting in the first presidentially-declared avalanche disaster in U.S. history.

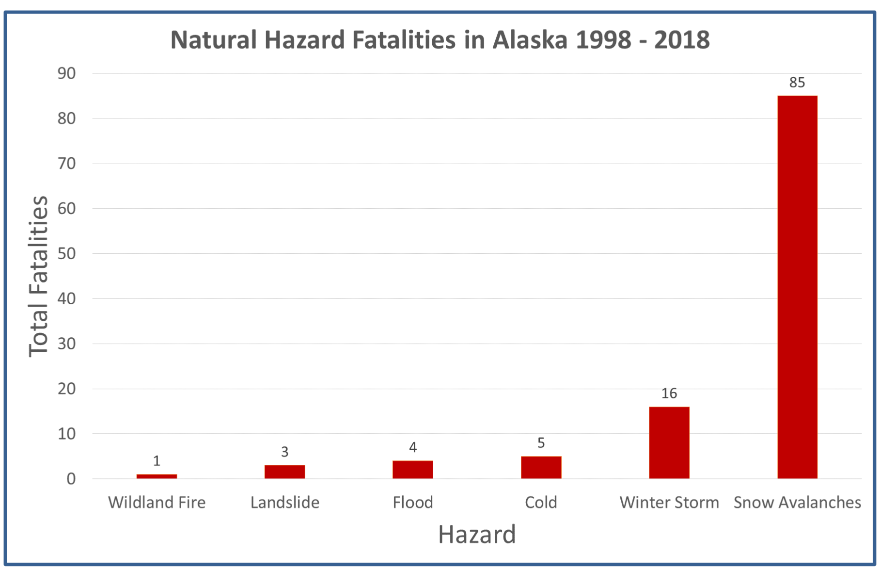



**Figure 6-18 Alaska's Weather Related Fatalities 1998–2018**

*Source: Data from NWS, [http://www.nws.noaa.gov/om/hazstats.shtml](http://www.nws.noaa.gov/om/hazstats.shtml)*

## 6.1.2. CLIMATE FACTORS

Climate has a major effect on cryosphere hazards because these hazards are so closely linked to snow, ice, and permafrost. Changes in climate can modify natural processes and increase the magnitude and recurrence frequency of certain geologic hazards (e.g., avalanches, floods, erosion, slope instability, permafrost thaw, and glacier lake outburst floods), which if not properly addressed, could have a damaging effect on Alaska's communities and infrastructure, as well as on the livelihoods and lifestyles of Alaskans.

During the last several decades, Alaska has warmed twice as fast as the rest of the U.S. Alaska's glaciers are in steep decline, and are among the fastest-melting glaciers on Earth. New ice-dammed lakes are being formed in valleys formerly occupied by glaciers, and as climate change continues on its current trajectory, more ice-dammed lakes can be expected. Glacier retreat also causes debuttressing and valley-wall unloading, potentially increasing rockfall and landslide incidences.

Permafrost is at an increased risk of thawing as a result of climate change. The major climatic factor leading to warming and thawing permafrost is an increase in air temperatures. Another important factor is the potential increase in snow depth predicted by the majority of climate models. Snow insulates permafrost from low winter temperatures, which leads to an increase in ground temperatures and diminishes permafrost stability. When soils are warm, permafrost becomes unstable and is sensitive to catastrophic collapse in conjunction with flooding and erosion. Even in non-ice-rich soils, process-driven models show more material is available for erosion and transport when the soil is thawed, which leads to increased exposure of underlying or adjacent frozen material to thermal and physical stressors.

Scientific data on the impacts of changing climate on the active layer (i.e., the surface layer above the permafrost that thaws each summer) is sparse, but on the decadal timescale (i.e., tens of years), the depth of the active layer looks to be increasing (Figure 6-19). This is potentially destructive to permafrost stability because the ground is not completely refreezing in winter, and leads to talik development. Taliks are areas of unfrozen ground within predominately frozen permafrost areas. Taliks exist over winter and have the potential to change many physical processes in the upper part of the soil, especially hydrology. If permafrost is ice-rich, taliks may greatly accelerate thawing. Critical thresholds are being approached in many parts of Alaska.

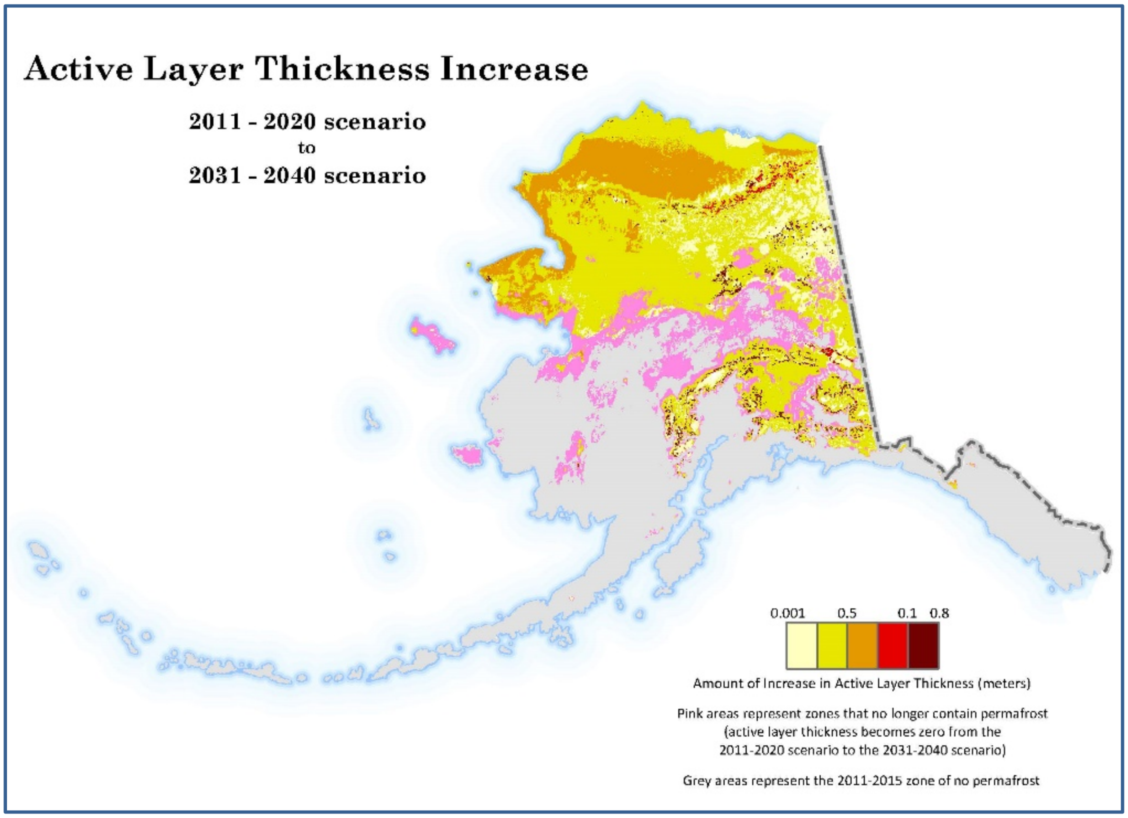



**Figure 6-19 Active Soil Thickness Layer Map**

*The map shows modeled potential change in the thickness of the active layer in Alaska over the next 20 years. Calculations indicate the active layer will thicken everywhere in Alaska as climate warms. Pink shows areas where existing permafrost will disappear. This is just one illustration of the many scenarios that scientists use to try to anticipate changes as climate warms. Source: Denali Commission Threat Assessment, and UAF, 2018*

Sea ice and climate are intimately linked. There are three timeframes to consider concerning the impacts of sea ice as climate changes:

1. Long-term concerns – regulation of the global climate;
2. Intermediate-term concerns – coastal erosion; and
3. Immediate concerns – transportation.

***Global climate:*** Sea ice plays an important role in the regulation of atmospheric temperature on a global scale. Snow and ice reflect a large portion of the incoming solar radiation back into space before this radiation can be converted into heat that would be trapped in the atmosphere. Without sea ice, the snow-covered area of Earth would be dramatically smaller and the dark ocean water would absorb short-wave radiation, resulting in a much warmer planet.

***Coastal erosion:*** Sea ice reduces wave development in the open ocean during winter months. Landfast ice can also mitigate wave action, nearshore ocean currents, and storm surge on the coastline by providing a physical barrier, minimizing coastal sediment transport. When waves and elevated water levels exceed beach elevations, relatively warmer, saline water can thermally destabilize coastal permafrost, and waves can mechanically erode coastal beaches, bluffs, and dunes. Many villages are located along Alaska's coastline and are threatened by eroding shores.

***Transportation:*** Many transportation forms can be affected by sea ice, both positively and negatively. Native people travel on sea ice to access subsistence hunting areas; reduced sea ice cover and thickness can create challenging and dangerous hunting conditions. Industrial development relies on sea ice routes to supply off-shore operations. These routes often make use of the more-stable landfast ice near the shore, but warming conditions reduce the annual duration and extent of landfast ice. Thinner ice, a consequence of warming climate, is vulnerable to being broken during storms, making sea ice roads impassable.

Climate warming affects sea ice in many different ways. As discussed above, sea ice and snow cool the planet by increasing albedo (i.e., reflecting solar energy) over polar regions. The current trends in atmospheric warming are causing a reduction in sea ice extent, which results in an increase in shortwave radiation absorption in the atmosphere. Delayed freezing in the fall allows longer periods of ice-free seas, and wave action can damage the shores for a longer duration, particularly in the fall when larger storms are typical. Direct use for transportation can be affected both positively and negatively: as arctic sea routes are open longer, they can be used for shipping during a longer season, but the timeframe during which surface travel is possible on the sea ice is reduced and thinner ice can break more easily in response to stress on the ice.

Ice gouging is potentially reduced due to a reduction in multi-year ice and reduced thickness of annual ice, but an increase in pressure ridges resulting from thinner ice could lead to much thicker ice locally, which in turn could lead to more gouging by icebergs.

Some studies suggest that warming climate may increase avalanche risk due to changes in snow accumulation and moisture content, as well as loss of snowpack stability because of changing air temperature. Increased rain-on-snow event frequency is leading to an increase in avalanche hazards all across Alaska. Rural and urban Alaska communities do not have many road options. Anchorage has the largest population. Yet it has one main road (north and south) connecting to the rest of the state’s road systems. Most Alaska communities have road choke points such as bridges and steep terrain that are susceptible to multiple natural hazard impacts from earthquakes, floods, and ground failure events such as landslides, mudslides, and avalanches.

Rural community road systems may experience the same threats. However, remote-rural locations have very limited road access to their immediate neighboring community via one road. If road access is blocked from natural hazard impacts these communities will be restricted to receiving resupply by boat, barge, or aircraft.

#### 6.1.2.1. RELATED HAZARDS

Related hazards include flooding, erosion, and ground failure.

### 6.1.3. CRYOSPHERE HAZARD HISTORY

- **Glacial Lake Outburst Floods**

  ***Bear Glacier Ice-Dammed Lake, Kenai Mountains***

  *The Bear Glacier ice-dammed lake in Kenai Fjords National Park is located in the Kenai Mountains at an elevation of approximately 900 feet on the east side of Bear Glacier, 8.8 miles up-glacier from the terminus. Bear Glacier ice-dammed lake is fed by meltwater from the glacier itself, and by water runoff (rain and snow meltwater) from upstream slopes. It generally empties in the late summer or early fall. The narrow strip of land that separates the*

*proglacial lake from the ocean, creating a lagoon, was formed during previous glacial retreat. The sand bar is a popular camping spot and the lagoon is a popular kayaking destination to watch calving icebergs. When the ice-dammed lake bursts, it may cause significant water level increase in the lagoon that could endanger campers and people recreating in the area.*

***Valdez Glacier Ice-Dammed Lake, Chugach Mountains***

*The Valdez Glacier ice-dammed lake is located at an elevation of approximately 720 feet on the east side of Valdez Glacier, 4.5 miles up-glacier from the current glacier terminus. The water from outburst floods exits Valdez Glacier and enters Valdez Glacier Lake subaqueously, causing a rapid rise in the proglacial lake level, localized flooding, and increased Valdez Glacier Stream discharge. The basin in which the lake forms was previously occupied by an unnamed tributary glacier to the east, and is repeatedly filled from glacier, snow, and rain runoff. The Valdez Glacier ice-dammed lake produces annual to bi-annual outburst floods of varying magnitude. One outburst event regularly occurs in June following spring snowmelt, and a second outburst event typically occurs in September-October in association with heavy rain from fall storms.*

***Russell Ice-Dammed Lake at Hubbard Glacier, Saint Elias Mountains***

*Hubbard Glacier and Russell Fjord are located north of Yakutat in the Saint Elias Mountains, Southeast Alaska. Earth's two largest recorded outburst floods occurred when the Hubbard Glacier ice-and-moraine dam breached, catastrophically releasing impounded water from Russell Lake. Hubbard Glacier is the largest tidewater glacier in North America, covering an area of ~1,460 square miles. In contrast to most glaciers in Alaska, Hubbard Glacier has advanced ~1.5 miles since 1895. Russell Fjord has no other outlet to the ocean than through Disenchantment Bay. Russell ice-dammed lake forms intermittently during times of glacial advance when Hubbard Glacier blocks the channel linking Russell Fjord and Disenchantment Bay at Gilbert Point. Outburst floods from Russell Lake have occurred when the ice dam has been breached, for example, in 1986 and 2002. Peak discharges during these events ranged from 1.9 million cubic feet per second to 3.7 million cubic feet per second. Glacial lake outburst floods from Russell Lake have the potential to cause major socio-economic consequences to the community of Yakutat, commercial and sport fisheries, and tourist and shipping industries, as well as impact sea life in the area.*

***Suicide Basin at Mendenhall Glacier, Coast Range***

*Suicide Basin ice-dammed lake is a sub-glacial lake that forms in an over-deepened basin carved by a now detached tributary glacier 2.2 miles up-glacier and on the east side of Mendenhall Glacier, ~10 miles northwest of Juneau in the Coast Range. Mendenhall Glacier terminates in the proglacial Mendenhall Lake, which drains into Mendenhall River. The river flows through a residential area and near critical infrastructure before reaching the ocean. The subglacial lake in Suicide Basin is fed by meltwater from surrounding glaciers and heavy rain in the early summer months. The ice-dammed lake in Suicide Basin has flooded annually since 2011; some years have multiple smaller floods and some years have only one large flood. The low-lying area along Mendenhall River is the most populated residential area of the City of Juneau, Alaska's capital. In 2014, an outburst flood from Suicide Basin caused the water level of Mendenhall Lake to gain 12 feet over the baseline and resulted in significant damage to riverside properties (Figure 6-20).*

**Figure 6-20 Juneau Area Flooding in the View Drive Neighborhood**

*Source: Eran Hood, UAS 2014*

*Flooding occurred along the Mendenhall River during the 2014 Suicide Basin outburst flood event.*

- **Permafrost**

***2016 Fall Usteq at Newtok***

*Usteq claimed at least 40 feet of ground between Newtok and the Ninglick River during this event, with blocks of tundra the size of minivans slumping and being carried away by floodwaters. The town is built on permafrost plateaus just 6-10 feet above river level, and the ground is disintegrating. The tribal government of Newtok declared a disaster, but the Obama administration declined to issue a Presidential disaster declaration.*

***2016 Spring and Fall Usteq at Kivalina***

*Repeated episodes of usteq, triggered by storms, struck Kivalina in 2016. The fall usteq threatened the Kivalina airport. The tribal government of Kivalina declared a disaster, but the Obama administration declined to issue a Presidential disaster declaration.*

- **Snow Avalanche**

***January 2014 Valdez "Damalanche"***

*In January 2014, the Richardson Highway was blocked by a huge avalanche that released above Keystone Canyon, near Valdez, due to heavy rain on top of snow (Figure 6-17). The snow became so saturated with water that the snowpack in the starting zone fractured all the way through to the ground, releasing a full-depth avalanche. The avalanche debris dammed Lowe River, and the local residents as well as the press took to calling it a "damalache." The dammed lake covered about 100 acres with an estimated 81 million cubic feet of water. The event blocked all transportation by road to and from Valdez (and the important Alyeska oil terminal) for 12-¼ days. 100,000 tons of snow (140 feet deep) were on the road, and the Alaska Department of Transportation & Public Facilities' round-the-clock cleanup work were estimated to have cost about $250,000.*

## 6.1.4. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location*

**Cryosphere hazards** can impact any place in Alaska where water occurs seasonally or permanently in solid form, including glaciers, ice caps, ice sheets, permafrost, sea ice, lake ice, river ice, and snow cover.

Glaciers and icefields currently occupy many of the mountain ranges in Alaska. Much of Alaska has been shaped by glaciation and deglaciation, and recent changes in climate are causing Alaska's glaciers to melt faster than most other places on the planet. These long- and short-term changes generate a range of glacier hazards, such as unstable water discharge rates, glacier lake outburst floods, glacier and slope instabilities, erosion and sedimentation, iceberg production, and glacier surges that can impact infrastructure and threaten public safety. Infrastructure and buildings located downstream of a glacier, for example low-lying residential areas along many rivers in coastal Southcentral Alaska, are at risk for flooding triggered by glacial lake outburst floods at higher elevations. In Alaska’s coastal areas, unexpected glacial calving can become dangerous for cruise ships and recreationists. Glacier hazards can also start a chain reaction of other hazards, such as snow avalanches and debris flows. Because of Alaska’s rapidly retreating glaciers, glacier hazard frequency is expected to increase, for example, more significant ice calving events during the summer, and greater flooding and erosion caused by outburst floods from lakes forming in valleys previously occupied by glacier ice.

### *Extent*

Permafrost is found beneath nearly 85 percent of Alaska (Figure 6-5). It is thickest and most extensive in arctic Alaska north of the Brooks Range, and becomes increasingly thinner and more discontinuous southward until it is virtually absent in Southeast Alaska except for pockets of high-elevation alpine permafrost. Permafrost can harbor ice in many forms, ranging from massive ice bodies to ice lenses to disseminated interstial ice crystals. Thawing causes landslides, ground subsidence, and erosion as well as lake disappearances, new lake development, and saltwater encroachment into aquifers and surface waters. Usteq—catastrophic permafrost collapse accompanied by flooding and erosion—is particularly destructive. Aufeis can form in low-lying areas such as along creeks. Periglacial hazards result from the effects of repeated freezing and thawing and include frost cracking, frost heaving, and frost jacking, and can occur anywhere in the state.

### *Impacts*

Permafrost and periglacial impacts include a full range of damage from comparatively minor bending or buckling of manmade features due to heterogeneous movement, to complete destruction of infrastructure and buildings due to catastrophic ground failure (usteq) and flooding (aufeis). Permafrost and periglacial processes have generated comparatively slow ongoing phenomena in the past, but warming climate is expected increase the magnitude and frequency of damaging permafrost collapse. Frost cracking, frost heaving, and frost jacking are annually occurring events.

Sea ice hazards are common in Alaska’s arctic oceans, where extreme cold weather conditions freeze the oceans’ surface. Some of these hazards are also relevant for fresh water systems, such

as rivers and lakes. Ice floes and ice break out events typically occur just off shore. Slush ice can be a problem anywhere on freezing water. Ice push (or ivu) is an on-land coastal hazard. The impacts from ice floes are on moving or fixed assets in the ocean such as shipping vessels, pipelines, and drill platforms. Ice break out events mainly affect sea ice transportation routes that supply offshore exploration operations, but could also affect subsistence hunters. Ivu is a major concern for onshore buildings or pipelines.

All sea ice hazards occur on an annual basis. Drifting ice bergs are more likely in summer and fall when ice is moving due to wind. Break out and ivu is most likely in the winter or spring when the ice warms up and winds are strong.

Snow avalanches are dangerous natural hazards that occur in mountainous areas. Approximately 30 percent of Alaska is subject to avalanche activity (Figure 6-15), and snow avalanche is the weather-related natural hazard that causes the most fatalities in the state (Figure 6-18). Driven by gravity, these hillslope mass movements of snow can release on slopes of 20–60°, but their run-out zones (where debris is deposited) can include slopes less than 20°, such as valley floors, and steep cliffs (slope > 60°). Large avalanches have the potential to kill people and wildlife, destroy infrastructure, level forests, and bury entire communities. In many areas of the state, avalanches lead to lengthy closures of important transportation routes. The economic impacts of such avalanches, from impeding traffic to removing avalanche debris blocking the transportation corridor, can be significant at both the local and state levels. Large avalanche cycles (multiple avalanches naturally releasing across a wide region) are generally caused by long periods of heavy snow, but avalanche cycles can also be triggered by rain-on-snow events, rapid warming in the spring, and earthquakes. Large avalanche cycles are more common in Alaska during pronounced climate events driven by changes in the Pacific Ocean, such as during La Nina/El Nino and the larger-scale Pacific Decadal Oscillation, that cause warmer air temperatures and heavier precipitation than normal. However, the effects on air temperature and precipitation during these climate abnormalities vary across the state, consequently the resulting likelihood of avalanche activity depends on region.

### *Recurrence Probability*

Return periods for snow avalanches, which are used to estimate avalanche risk of an avalanche to strike a position at least once in a specified time period, are typically categorized into 1, 5–10, 30, 50–100, and 200–300 years (McClung and Schaerer, 2006). Due to the incomplete historical record of avalanche occurrences in Alaska, longer return periods cannot be confidently stated. Some studies suggest that warming climate is increasing avalanche risk due to changes in snow accumulation and moisture content, and loss of snowpack stability because of changing air temperature. Increased rain-on-snow event frequency is leading to an increase in avalanche hazards all across Alaska.

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## 6.2. EARTHQUAKE

Alaska is one of the most seismically active regions in the world and is at risk of societal and economic losses due to damaging earthquakes. The 2002 Denali fault ruptured, causing the largest earthquake (Magnitude [M] 7.9) of its kind in North America in over 100 years. On average, Alaska has one "great" (M>8) earthquake every 13 years, one M 7-8 earthquake every year, and six M 6-7 earthquakes every year. Additionally, earthquakes that occur on tectonic plate boundary faults near the coast can generate tsunamis that impact coastal communities (see Tsunami). Earthquakes have killed more than 130 people in Alaska during the past 60 years, and as population centers near active faults and coastlines continue to grow it is imperative that Alaskans prepare for future events.

It is not possible to predict the time and location of the next big earthquake, but the active geology of Alaska guarantees that major damaging earthquakes will continue to occur and can affect almost anywhere in the state. Scientists have estimated where large earthquakes are most likely to occur, along with the probable levels of ground shaking to be expected. With this information, as well as information on soil properties and landslide potential, it is possible to estimate earthquake risks in any given area. It is also possible to estimate the potential for earthquakes to generate tsunamis, and to model the extent to which tsunamis will inundate coastal areas.

Alaska earthquake statistics:

- Alaska is home to the second-largest earthquake ever recorded (1964 Great Alaska Earthquake, moment magnitude 9.2)
- Alaska has approximately 11 percent of the world's recorded earthquakes
- Three of the eight largest earthquakes in the world were in Alaska
- Seven of the ten largest earthquakes in the U.S. were in Alaska

In addition to the previously mentioned large earthquakes, since 1900, Alaska has had an average of:

- 45 magnitude 5 – 6 earthquakes per year
- 320 magnitude 4 – 5 earthquakes per year
- 1,000 earthquakes located in Alaska each month

*Source: Alaska Earthquake Center (AEC)*

Figure 6.21 shows Alaska's typical annual earthquake distribution.

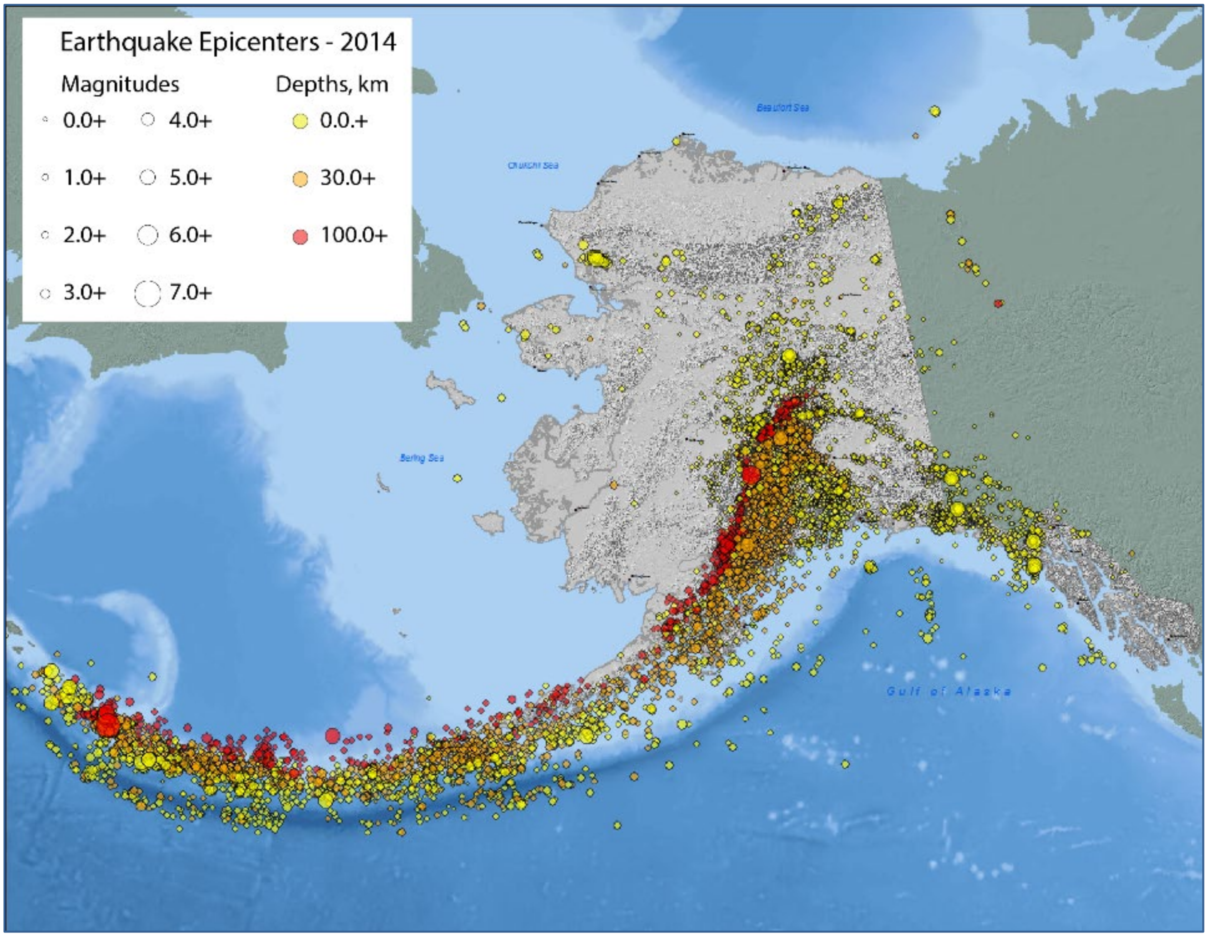



**Figure 6-21 Map of Reported Earthquakes in Alaska**
*Occurring for one typical year. Source: AEC 2014*

## 6.2.1. EARTHQUAKE CHARACTERISTICS

Earthquake shaking is caused by the release of elastic strain energy that has accumulated on faults within or at the boundary between earth's tectonic plates. Tectonic plates are thin, brittle pieces of the crust (the outer, rigid layer of earth) that move across the earth's surface relative to each other, like slabs of ice on a lake. The plates are constantly in motion because of forces originating from within the earth. The plates' motion causes energy buildup that is periodically released in earthquakes. Alaska is near a major tectonic plate boundary, known as the Alaska-Aleutian subduction zone, where one tectonic plate (the Pacific plate) is forced beneath its neighbor (the North American plate) (Figure 6.22). In addition to the major plate boundary, the subduction of one plate beneath the other causes distributed deformation on a network of faults extending more than 700 km north into the interior of Alaska (Figure 6-23).

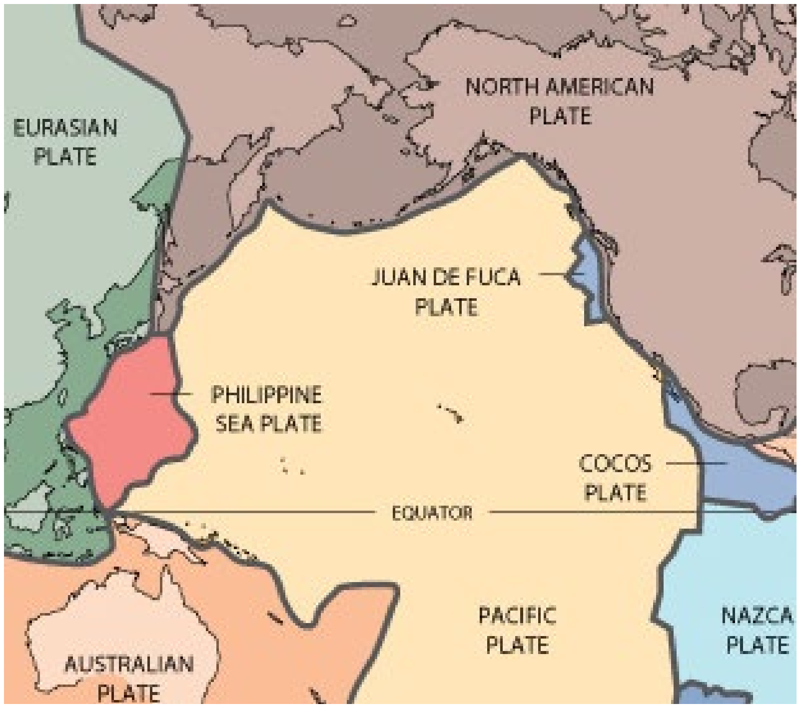



**Figure 6-22 Major Tectonic Plates of the Pacific Region**
*Source: USGS*

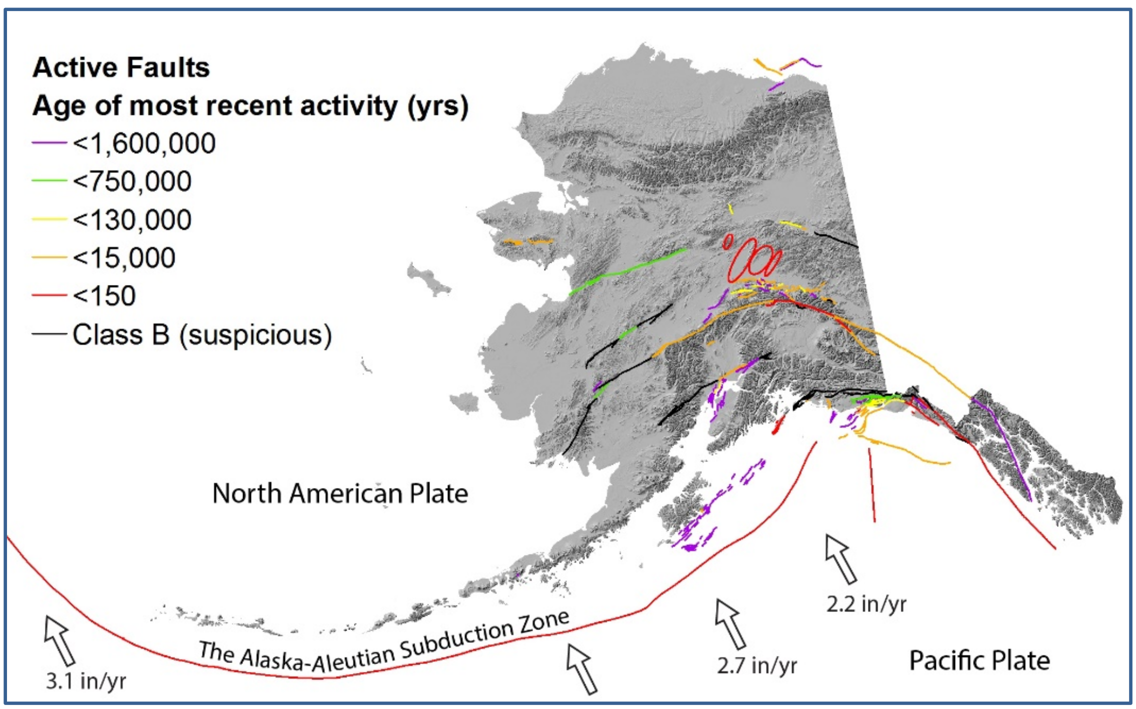



**Figure 6-23 Alaska's Known-Active Faults**
*Colored by activity recency. The North American plate and the Pacific plate are converging at the Alaska-Aleutian subduction zone at a rate of several inches per year. Source: DGGS 2018*

The point at the earth's surface directly above earthquake rupture begins is known as its "epicenter." While the epicenter usually experiences the most intense earthquake effects (e.g., shaking), the total area affected can cover hundreds of thousands of square miles, depending on the earthquake's magnitude. Scientists cannot predict earthquakes, and because damage can occur only seconds after rupture initiation, it is important for every Alaskan to know what to do to minimize risk posed by damaging earthquakes.

The moment magnitude scale ($M_w$) is used to describe the size of moderate to large earthquakes, and is objectively based on the amount of physical energy released in an event. The seismic moment of an earthquake (used to calculate the moment magnitude) is based on the area of fault that ruptures in the brittle crust, the average amount of slip (movement) that occurs between the two pieces of crust, and the force that was required to overcome the friction that was holding the pieces of crust together. The moment magnitude scale is logarithmic, meaning that each step up the scale corresponds to an increase of roughly 32 times the amount of energy released. For example, a M8 earthquake releases approximately 32 times more energy than a M7, and approximately 1,000 times more energy than a $M_w$ 6. Conversely, larger earthquakes are less common than smaller earthquakes, such that the smallest earthquakes are extremely frequent, while the largest earthquakes are relatively infrequent. The moment magnitude scale succeeds the Richter and Local magnitude scales, which were based on the amplitude of shaking recorded on paper seismographs.

Earthquakes are also classified by their felt effects (e.g., the perceived shaking intensity). However, the effects of an earthquake are directly related to the distance from the earthquake rupture, among other parameters (such as the type of crust where the earthquake occurs). In general, the closer one is to an earthquake epicenter, the more severe the felt effects and damage will be. An earthquake's intensity is described by the Modified Mercalli Intensity (MMI) Scale. As shown in Figure 6-24, the MMI Scale consists of 10 subjective intensity levels ranging from "not felt" to "extreme," with varying amounts of damage associated with each.

Figure 6-24 also depicts the relation of Modified Mercalli Intensity and ground acceleration, percent (%) *g*), which is a measure of shaking strength.

| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Mod./Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <0.05 | 0.3 | 2.8 | 6.2 | 12 | 22 | 40 | 75 | >139 |
| PEAK VEL.(cm/s) | ***<0.02*** | ***0.1*** | ***1.4*** | ***4.7*** | ***9.6*** | ***20*** | ***41*** | ***86*** | ***>178*** |
| MMI scale | **I** | **II–III** | **IV** | **V** | **VI** | **VII** | **VIII** | **IX** | **X+** |

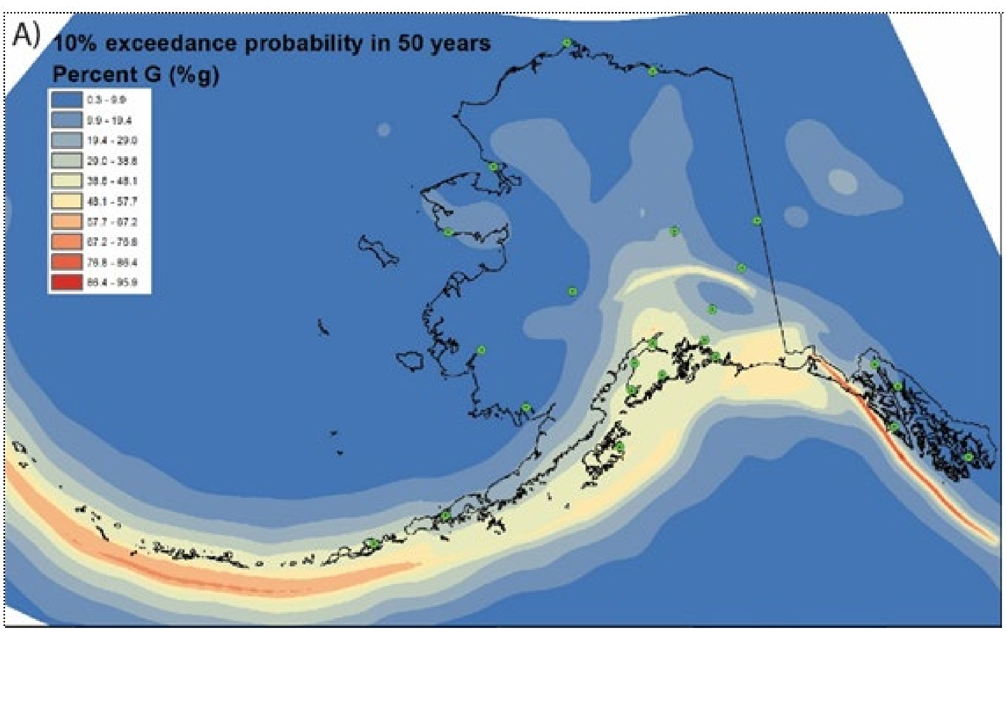
**Figure 6-24 Perceived Shaking, Potential Damage, and Peak Ground Acceleration**
*Associated with rating on the Modified Mercalli Intensity scale. Source: modified from Worden and others 2012*

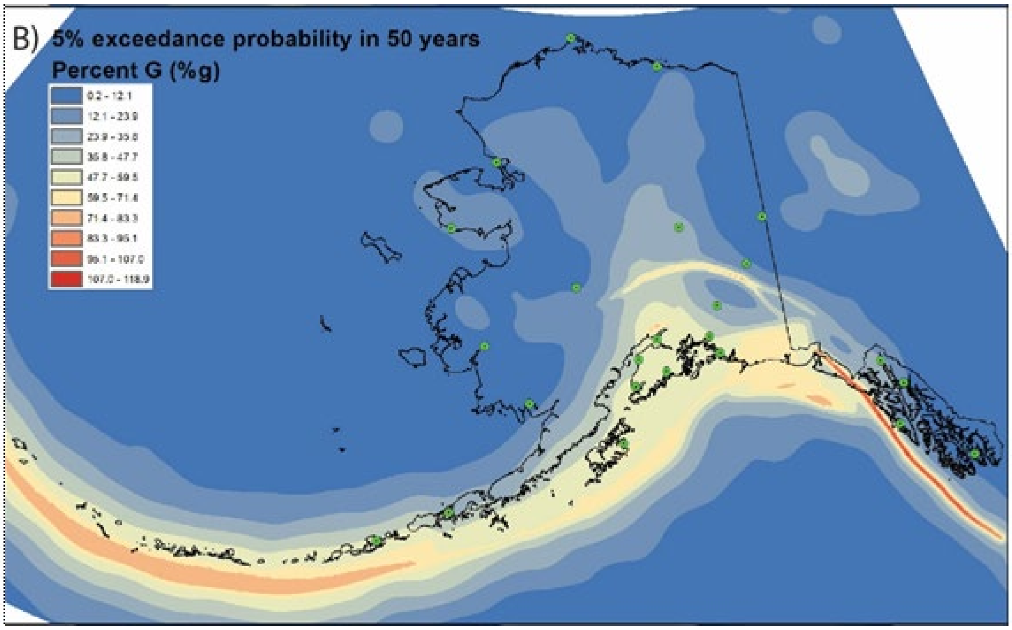
The varying degrees of damage associated with earthquakes are a direct result of the strong ground motions from seismic shaking. The objective classification of earthquake shaking at a point is based on ground accelerations. Ground accelerations (described as a percent of the acceleration of gravity, %g) are measured instrumentally and can be extrapolated between seismic stations after an earthquake occurs. Additionally, ground accelerations are described at different "spectral wavelengths" to describe the types of shaking that affect different building styles; for example, spectral wavelengths of 0.2 seconds affect short, rigid buildings whereas 1

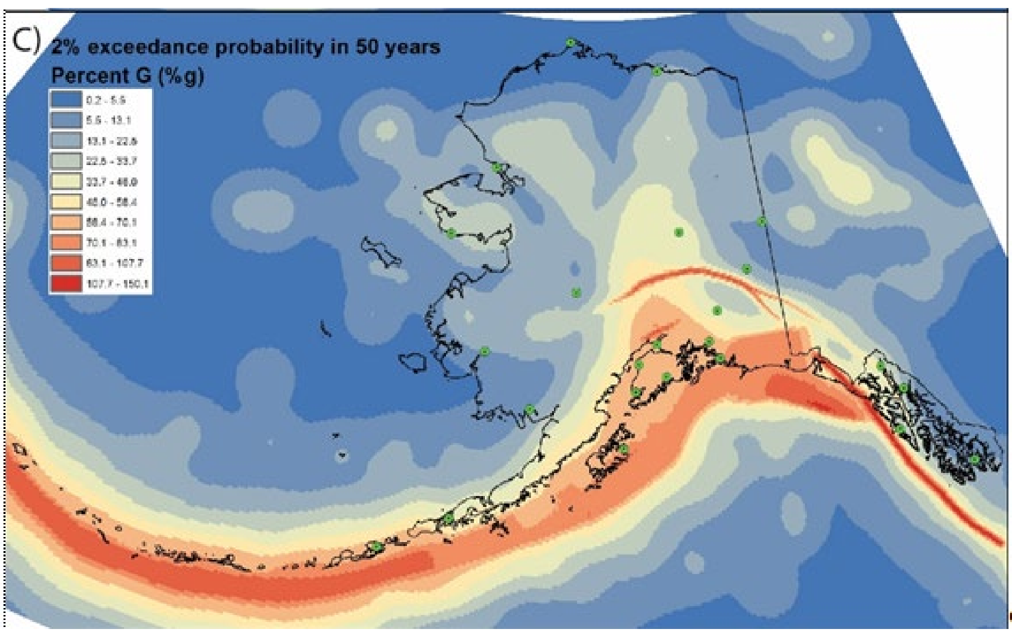
second wavelengths affect multi-story structures. The most universal metric used is the Peak Ground Acceleration (PGA) at a point.

Because earthquakes are impossible to predict, scientists must use a unique approach to describing the hazards posed by earthquakes. Probabilistic Seismic Hazard Analyses (PSHAs) describe earthquake shaking levels and the likelihood that they will occur in Alaska. PSHAs are based on known, mapped geologic faults throughout Alaska and all background seismicity from unknown faults. The result is a visual representation of the peak ground acceleration that has a certain percent chance of being exceeded in a given amount of time (usually 50 years). Figure 6.25 (includes three images) shows three peak ground acceleration maps, the 10, 5, and 2 percent probabilities that certain PGAs will be exceeded in the next 50 years in Alaska. The reason for three maps has to do with earthquake hazard characteristics and their magnitudes. Small earthquakes are frequent, and there is a higher percent chance that they will happen in any given year (a 10 % chance in 50 years means a 0.21% annual exceedance probability—there is a 0.21% chance that the earthquake will happen in a given year). Large earthquakes are infrequent, so there is lower percent chance that they will happen in a given year (a 2% chance in 50 years means a 0.04% annual exceedance probability—there is a 0.04% chance that the earthquake will happen in a given year). However, when the infrequent, large earthquakes occur, there are stronger ground accelerations.

To use these maps, first pick the type of earthquake in which you are interested. For infrequent, large, and destructive earthquakes you would use the 2% in 50 years exceedance probability (Figure 6-25 C). Next, choose your location, and note the color of the map there. For this example, choose Fairbanks, and see that the city is in the yellow zone. Look at the explanation on the map to see the range of ground accelerations that the color represents, in this case 34-53 %g for Fairbanks in Figure 6-25 C. That means that in Fairbanks, the peak ground acceleration that has a 2% chance of being exceeded in 50 years (or 0.04% chance in any given year) is 34-53 % g, which corresponds to shaking that is perceived as very-strong to severe, and may cause moderate to moderate/heavy damage (Figure 6-24).






**Figures 6-25 PGAs – 10, 5%, and 2% Percent Exceedance Probabilities in 50 Years.**

*Green dots show locations of significant population centers. Earthquakes with a high exceedance probability (e.g., 10% in 50 years) are common, and therefore are smaller earthquakes with less severe ground shaking. Earthquakes with a low exceedance probability (e.g., 2% in 50 years) are uncommon, but when they do occur, the earthquakes are large and have more severe shaking. Source: USGS*

The major earthquake hazards can be categorized as follows:

- Strong ground motion
- Surface rupture
- Subsidence and uplift
- Earthquake-related ground failure
- Seiche
- Tsunami

The most common and perceivable effect of an earthquake is ***Strong Ground Motion***, which is ground shaking. Strong ground motion intensity is directly correlated with earthquake magnitude (i.e., the larger the earthquake magnitude, the more intense and widespread the ground shaking will be). The strong ground motion severity is also dependent on distance from the energy source; the strongest shaking occurs near the earthquake epicenter. The damage extent at any given location is dependent on many factors: the magnitude of the earthquake; distance from the epicenter; local geology; and site-specific factors, such as building height and construction type.

A ***Surface Rupture*** occurs when the subsurface patch of fault that slips in an earthquake intersects the earth's surface. This causes discrete, differential ground movement during intense earthquake shaking. The relative crustal block motion is dictated by the rupture's fault type, which can be horizontal, vertical, or a combination of both. Earthquakes larger than M6.5 have sufficient energy to create surface ruptures, but whether or not this occurs is dependent on the earthquake's depth. The shallower a a depth at which a significant earthquake occurs, the more likely it is to create a surface rupture. The permanent displacement along faults can be substantial. For example, the 2002 Denali rupture (M7.9, right-lateral rupture) was roughly 211 miles in length and had maximum lateral offsets of 28.9 feet and maximum vertical offsets of 13.1 feet. Surface ruptures, as a product of intense strong ground motion, can cause severe damage to existing structures, including railways, highways, pipelines, and tunnels.

***Subsidence*** is a widespread downward shift of the earth's surface relative to a stationary datum (such as sea level), and ***Uplift*** is the opposite, an earth surface area's upward shift. Large earthquakes potentially cause widespread subsidence and uplift. This makes coastal areas more prone to tsunami inundation. For example, the Alaska-Aleutian subduction zone, where the Pacific plate dives beneath the North American plate along southern Alaska's coastline. In many cases, the vertical changes occur under the ocean, affecting the seafloor. Subsidence and uplift occur because of the enormous amount of slip (up to 150 ft.) that can occur on the dipping plate boundary fault. The 1964 Great Alaska Earthquake ($M_w$ 9.2) caused subsidence of more than 65,000 square miles (up to approximately 6 feet of lowering) and uplift of more than 55,000 square miles (up to approximately18 feet of uplift).

Earthquake strong ground motion heightens the possibility for ***Ground Failure***. Ground accelerations can de-stabilize materials or re-mobilize existing slide deposits. The most common phenomena include landslides, rock falls, debris flows, and avalanches. Of particular concern for coastal Alaska and communities on steep-sided lakes are subaerial (land-based) and submarine slope failures that may trigger local tsunami waves (see Tsunami).

***Liquefaction*** describes the phenomenon in which saturated or partially saturated soil materials lose significant stiffness because of an applied stress, in this case, earthquake strong ground motion. The sudden shaking causes the soil to behave like a viscous fluid. Liquefaction or plastic flow in underlying materials can lead to ***Lateral Spread***, creating subsequent soil or rock mass movement. Liquefaction and lateral spread can occur even in moderate earthquakes, and are responsible for a tremendous amount of damage in historical earthquakes worldwide.

A ***Seiche*** is a temporary oscillation in the water level of a fully or partially enclosed water body (e.g., a lake or fjord). "Seiche" literally means "to sway back and forth," and can be caused by a number of things. A seismic seiche is typically caused by earthquakes with vertical motions: the seismic waves from the earthquake pass through the area, creating standing waves in the water body. It may be difficult to isolate a particular causative mechanism near an earthquake epicenter, as seismic waves, landslides (submarine or subaerial), tsunamis, and tectonic tilting all may play a role in water level disturbance. At greater distances (i.e., over 600 miles), a seiche is mainly generated by seismic surface waves.

Earthquakes that occur at the subduction boundary between the Pacific and North American plates have a high likelihood of generating ***Tsunamis***. Such large megathrust earthquakes cause widespread vertical displacement along the seafloor, providing potential energy for a tsunami wave. See Section 6.5 Tsunami and Seiche for a more detailed discussion of Alaska's tsunami hazards.

### 6.2.1.1. RELATED HAZARDS

Related hazards include ground failure, tsunami, seiche, snow avalanche, landslides, and debris flows.

## 6.2.2. EARTHQUAKE HISTORY

The AEC states,

> *The Earthquake Center detects an earthquake every fifteen minutes, on average. In 2014, we reported an all-time high of over 40,000 earthquakes in Alaska. As our monitoring network expands we report more earthquakes because we are able to detect smaller earthquakes across more of the state. Thus, we expect to report more and more earthquakes as the Transportable Array project adds new seismic stations in previously unmonitored areas.*
>
> *The subduction zone produces very large earthquakes—as large as anywhere in the world—including three of the twelve largest earthquakes ever recorded. Magnitude six and seven earthquakes can nearly happen anywhere in Alaska.*
>
> *We reported over 150,000 earthquakes in Alaska over the last five years. Thirty-one of those had magnitudes of 6 or greater, and four had magnitudes of at least 7. Seventy-five percent of all earthquakes in the United States with magnitudes larger than five happen in Alaska (AEC 2018).*

This activity is typical for Alaska as described by AEC:

> *During July 2018, the Alaska Earthquake Center located 3,250 earthquakes within the state. Of these, 24 were larger than or equal to magnitude 4.0. 13 events were felt. The largest earthquake located in Alaska this month was a moderate earthquake of magnitude*

*5.8 that occurred on July 19 at 14:16:27.278 UTC (July 19, 06:16:27.278 AKDT), 64 miles SSW of Sand Point. Source AEC, 2018*

This screen capture (Figure 6-26) shows Alaska's "recent" earthquakes that occurred within the 30-days previous to April 15, 2018.

This activity is typical for Alaska as described by AEC:

*During July 2018, the Alaska Earthquake Center located 3,250 earthquakes within the state. Of these, 24 were larger than or equal to magnitude 4.0. 13 events were felt. The largest earthquake located in Alaska this month was a moderate earthquake of magnitude 5.8 that occurred on July 19 at 14:16:27.278 UTC (July 19, 06:16:27.278 AKDT), 64 miles SSW of Sand Point. Source AEC, 2018*

See figure 6-21 for a visual representation of one year of earthquakes in Alaska. Note that the majority of the earthquakes shown in 6-21 are small-magnitude events, as small earthquakes are exponentially more common than large, destructive earthquakes. For comparison, Figure 6-26 shows all Mw 5+ earthquakes from 1990 to mid-2018. There are significantly fewer Mw 5+ events.

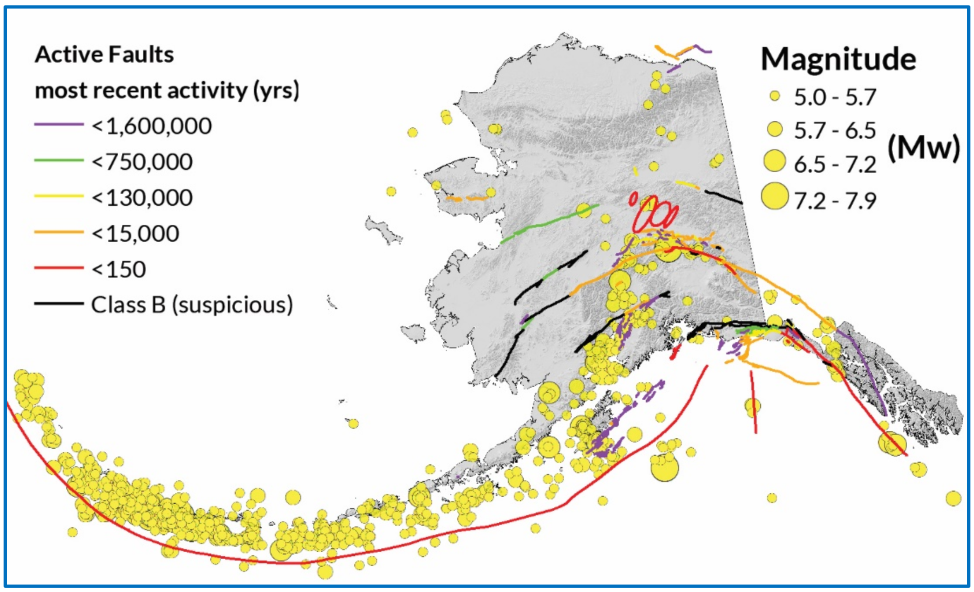



**Figure 6-26 Displays all Mw 5+ Earthquakes From 1990 to mid-2018**

*Source: DGGS and AEC*

Descriptions of Alaska's significant or notable earthquakes can be accessed via the AEC and the USGS. Some of the significant events include:

***1964 Great Alaska Earthquake (Good Friday Earthquake)***

*The largest earthquake ever recorded in North American history (second-largest earthquake ever recorded worldwide) occurred along the east end of the Alaska-Aleutian subduction zone on Good Friday in 1964. The earthquake had a moment magnitude ($M_w$) of 9.2 and shook for ~5 minutes. Damages were heavy in many towns, including Anchorage, Chitina, Chenega Bay, Glennallen, Homer, Hope, Kasilof, Kenai, Kodiak, Moose Pass, Portage, Seldovia, Seward, Sterling, Tatitlik, Valdez, Wasilla, and Whittier. The earthquake caused significant ground deformation, and the triggered landslides,*

*liquefaction, lateral spread, and tsunamis resulted in major damage throughout much of Southcentral Alaska (Figure 6.27). This great (M>8) earthquake and ensuing tsunamis took 128 lives (tsunamis 113, earthquake 15), and caused about $311 million in property loss. More than 200 bridges were destroyed or damaged due to lateral spread; flow failures damaged port facilities in Seward, Valdez, and Whittier; and ground failures (such as landslides and debris flows) were responsible for a large portion of the damage.*

**Figure 6-27 Government Hill Elementary School**
*Destroyed by earthquake-related ground failure in the 1964 Great Alaska Earthquake. Source: USGS 1964*

### *2002 M7.9 Denali Earthquake*

*A powerful ($M_w$ 7.9) earthquake struck Alaska on November 3, 2002, rupturing the earth's surface for ~210 miles along the Susitna Glacier, Denali, and Totschunda faults. Thankfully, this earthquake ruptured through a sparsely-populated region, and while it caused thousands of landslides, there was very little structural damage and no deaths. Although movement on the Denali fault caused right-lateral displacements of ~20 feet beneath the Trans-Alaska oil pipeline, the pipeline did not break, averting a major economic and environmental disaster (Figure 6.28). This was largely the result of stringent design specifications based upon geologic studies performed 30 years earlier. The pipeline is supported by Teflon coated beams that allow it to flex during lateral ground movement where it crosses the Denali fault. The Trans-Alaska Pipeline System (TAPS) transports about 17% of the domestic oil supply for the United States.*

**Figure 6-28 Trans-Alaska Oil Pipeline's Earthquake Mitigation Offset**

*Located where it crosses the Denali fault, 2012. Note how pipeline is shifted to left of center on the Teflon-coated beams.*

***2016 M7.1 Iniskin Earthquake***

*A $M_w$ 7.1 earthquake struck January 24, 2016, 53 miles west of Anchor Point and 161 miles southwest of Anchorage. The USGS reported an intermediate-depth strike-slip fault earthquake within the Pacific plate's subducted lithosphere. Intermediate-depth earthquakes have focal depths between 70 and 300 km and indicate movement within subducted plates rather than where plates meet. Thus, this earthquake was less damaging than would normally be associated with a shallow M 7.1. However, it did cause several power outages from Anchor Point to Willow, and opened a fissure in Kalifornsky Beach Road in Kasilof. In Kenai, a ruptured gas main was responsible for blowing the roofs off two homes, sending them 40 feet into the air. Two other nearby homes burned down. In Anchorage, the Anchorage School District's West High School and Romig Middle School sustained structural and non-structural damage. The Romig Middle School gymnasium was closed indefinitely due to a compromised roof, and the shared library with West High School was closed for a damaged ceiling.*

***1957 Andreanof Islands Earthquake***

*A $M_w$ 8.6 earthquake in Andreanof Islands occurred in 1957. This great (M>8) earthquake destroyed two bridges on Adak Island, damaged houses, and left an 18-foot-wide crack in a road. On Umnak Island, part of a dock was destroyed, and Mount Vsevidof volcano erupted after being dormant for 200 years. The seismic shock generated a 50-foot tsunami that smashed into the coastline at Scotch Cap, totally destroying the lighthouse; and a 26-foot tsunami washed away many Sand Point buildings and damaged oil lines. This tsunami continued to Hawai`i, where it destroyed two villages and inflicted about $5 million in property damage on Oahu and Kauai Islands. The tsunami also caused minor damage in San Diego Bay, California, before traveling to such distant countries as Chile, El Salvador, Japan, and other areas in the Pacific region. More than 300 aftershocks were reported along the southern edge of the Aleutians, from Unimak Island to Amchitka Pass.*

***Other Alaska Earthquakes***

*Many large earthquakes have affected other parts of Alaska. Since the early 1900s, three M>7 earthquakes have occurred within 50 miles of Fairbanks. Southeast Alaska also receives earthquakes from Queen Charlotte-Fairweather fault movement, including a $M_w$ 8.1 earthquake in 1949, and a $M_w$ 7.9 in 1958 that triggered a giant landslide-generated tsunami in Lituya Bay. Areas at greatest risk from earthquakes along this fault zone are communities along the outer coast of Southeast Alaska. Source: DGGS 2018*

## 6.2.3. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### Location and Extent

The entire geographic area of Alaska is prone to earthquake effects. The Alaska Seismic Hazard Safety Commission's website provides the following:

***Earthquake Risk in Alaska***

*Scientists have long recognized that Alaska has more earthquakes than any other region of the United States and is, in fact, one of the most seismically active areas of the world. The second largest earthquake ever recorded shook the heart of southern Alaska on March 27th, 1964, with a magnitude of 9.2. The 1964 earthquake was slightly larger than the magnitude 9.0 Sumatra-Andaman Islands earthquake that devastated northern Sumatra in December 2004 and generated a tsunami that killed more than 280,000 people. The largest on-land earthquake in North America in almost 150 years occurred on the Denali fault in central Alaska on November 3rd, 2002, with a magnitude of 7.9.*

*It is not possible to predict the time and location of the next big earthquake, but the active geology of Alaska guarantees that major damaging earthquakes will continue to occur. Scientists have estimated where large earthquakes are most likely to occur, and the probable levels of ground shaking to be expected throughout the state (see maps below). With this information, as well as information on soil properties and landslide potential, it is possible to estimate earthquake risks in any given area. It is also possible to estimate the potential for earthquakes to generate tsunamis, and to model the extent to which tsunamis will inundate coastal areas.*

*Alaska has changed significantly since the damaging 1964 earthquake, and the population has more than doubled. Many new buildings are designed to withstand intense shaking; some older buildings have been reinforced, and development has been discouraged in some particularly hazardous areas.*

*Despite these precautions, and because practices to reduce vulnerability to earthquakes and tsunamis are not applied consistently in regions of high risk, future earthquakes may still cause life-threatening damage to buildings, cause items within buildings to be dangerously tossed about, and disrupt the basic utilities and critical facilities that we take for granted.*

*The Federal Emergency Management Agency[1] estimates that with the present infrastructure and policies, Alaska will have the second highest average annualized earthquake-loss ratio (ratio of average annual losses to infrastructure) in the country. Reducing those losses requires public commitment to earthquake-conscious siting, design, and construction. The Seismic Hazards Safety Commission is committed to addressing these issues. Earthquake-risk mitigation measures developed by similar boards in other states have prevented hundreds of millions of dollars in losses and significant reductions in casualties when compared to other seismically active areas of*

> *the world that do not implement effective mitigation measures. The San Francisco (1989), Northridge (1994) and Nisqually (2001) earthquakes caused comparatively low losses as a result of mitigation measures implemented in those areas. Many of these measures were recommended by the states' seismic safety commissions.*
>
> *Source: 1. HAZUS 99 Estimated Annualized Earthquake Losses for the United States, Federal Emergency Management Agency Report 66, September 2000.*

Figures 6-25 for a visual representation of where earthquake shaking can be expected in nearly 100 percent of the Alaska.

### Impact

Impacts to communities such as significant ground motion, surface rupture, and ground failure may result in infrastructure damage or harm to Alaskans in nearly any part of the state. Again, Figure 6-25 depicts peak ground accelerations (PGAs) at three different exceedance probabilities.

### Recurrence Probability

As indicated, while it is not possible to predict when an earthquake will occur, the USGS has conducted Probabilistic Seismic Hazard Analyses for the state (Figure 6-25). This modelling effort incorporates what is known about Alaska's active faults and current and past seismicity to develop the most current map available.

The hazard maps depict the peak ground accelerations expected at a point with 10%, 5%, and 2% exceedance probabilities in 50 years. A useful way to think about these exceedance probabilities is that a 10% chance in 50 years means that statistically this earthquake happens on average every 500 years (Figure 6-25 A). A 5% chance in 50 years means that statistically this kind of earthquake happens every 1000 years (Figure 6-25 B). A 2% chance in 50 years, is the rare, large earthquake, and statistically it happens on average every 2,500 years (Figure 6-25 C). For each of these exceedance probabilities, the color on the map at your location corresponds to a shaking intensity in percent of gravitational acceleration. See figure 6-24 for a description of shaking at different percent gravity values.

See Section 8 Vulnerability Assessment for detailed recurrence probability analyses.

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# 6.3. Flood and Erosion

## 6.3.1. HAZARD CHARACTERISTICS

Approximately 6,600 miles of Alaska's coastline and many low-lying areas along the state's rivers are subject to severe flooding and erosion. The former U.S. General Accounting Office (now the U.S. Government Accountability Office [GAO]), reported in 2003 that flooding and erosion affect 184 out of 213 (86 percent) Alaska Native villages, most of which are coastal communities. Many of the problems are long-standing, although studies indicate that increased flooding and erosion are being caused in part by changing climate. *(Sources: Simmonds and Keay 2009; Terenziet al. 2014; Vermaire et al. 2013)*

**Flood** is the overflow of a body of water that inundates or submerges normally dry land. Water defeats natural or artificial barriers such as beaches, stream banks, and levees that would usually protect adjacent floodplains. Flooding is typically a natural event and considered a hazard only when people and property are at risk. Flooding is Alaska's most common disaster, often costing in excess of 1 million dollars annually, causing major disruptions to society and occasionally loss of life.

**Erosion** is the action of surface processes (such as from water or wind) that remove soil, rock, or dissolved material from one location and transport it to another location. Erosion can be gradual or occur quite quickly as the result of a flash flood, coastal storm, or other event. Most of the geomorphic change to a river system is due to peak flow events that can dramatically increase the erosion rate. Erosion is a problem in developed areas where disappearing land threatens development and infrastructure.

Alaska is unique in the U.S. because of how permafrost interacts with flooding and erosion to exacerbate the impacts of these hazards. Frozen ground can disintegrate under the compounding influences of permafrost thaw, flooding, and erosion in an escalating feedback loop that can result in damage that is much greater than would be expected from the individual processes alone. See "usteq" in the Permafrost section of this report for more information about this phenomenon.

**Flood Categories**

Flooding in Alaska occurs in riverine, coastal, and lake environments, with different processes and contributing factors. The major flood categories can be subdivided as follows:

**Table 6-1 Flood Categories and Subdivisions**

| | |
|---|---|
| • Riverine Flood | • Coastal Flood |
| ○ Overbank | ○ Storm Surge |
| ▪ Rainfall-Runoff | ○ Sea Level Rise |
| ▪ Snowmelt | • Fluctuating Lake Levels |
| ○ Alluvial Fan | • Glacial Lake Outburst |
| ○ Flash | • Groundwater |
| ○ Ice Jam | • Aufeis (Ice Overflow) |

Figure 6-29 shows the causes of 920 floods documented in Alaska between 1890 and 2017, as reported in local hazard mitigation plans, regional hazard mitigation plans, Alaska Pacific River Forecast Center (APRFC) River Notes, National Weather Service (NWS) Storm Database, NWS warnings and watches, and some site-specific reports.

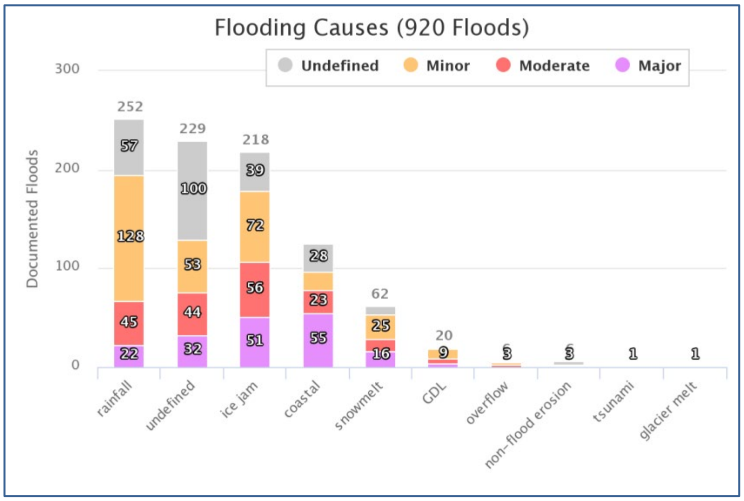


**Figure 6-29 Flood Cause Chart**

*Tabulates documented Alaska flood events since 1890, color-coded according to event magnitude. Undefined event magnitudes, shown in gray, are floods whose magnitudes are not known. Undefined flood causes are floods for which the cause is not known. Glacial-dammed lake (GDL) floods include glacial lake outbursts.*
*Source: NWS 2017*

Figure 6-30 shows the distribution of these flood hazards around the state. This map and chart may under-represent actual events, due to a general lack of documentation pertaining to these hazards in Alaska.

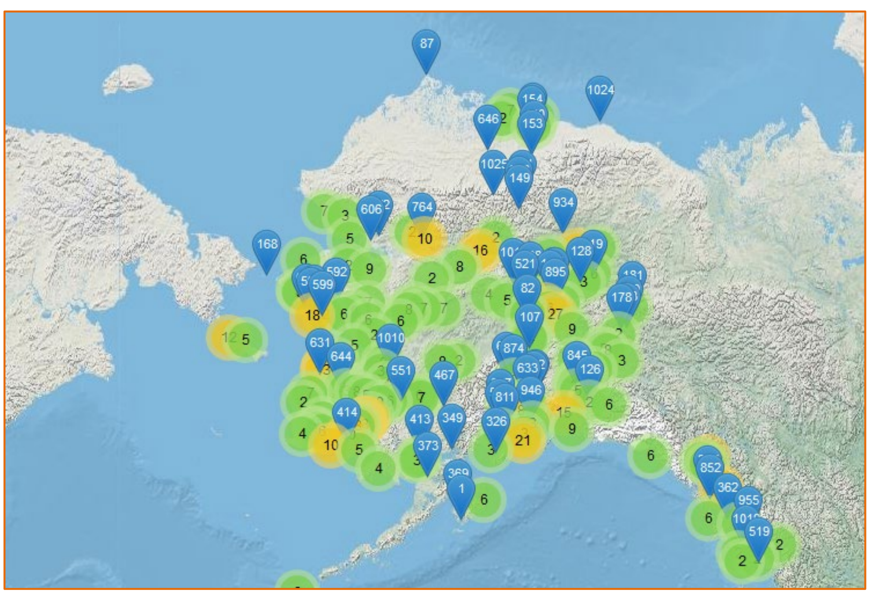

**Figure 6-30 Documented Flood Event Map**

*Documented Alaska flood events from all causes since 1890. Blue tags are locations of single events, with NWS event identification number displayed; green circles are locations with 2-9 documented flood events, with number of*

*events displayed; orange circles are locations with 10 or more documented flood events, with number of events displayed. Source: NWS 2018*

**Riverine Flooding** occurs when river levels rise and overflow their banks or the edges of their main channel and inundate areas normally above water level. The main driver of riverine flooding is rainfall, but additional factors may include temperature (for melting snow or ice), slope steepness, and the physical characteristics of the soil or rock forming the riverbed. The damage from a river flood can be widespread as the overflow affects smaller rivers downstream, often causing dams and dikes to break and inundate nearby areas.

**Overbank Flooding** is an umbrella term for when water rises and overflows the streambank. This is the most common form of riverine flooding world-wide, and can occur in any size channel, from small streams to huge rivers. Rainfall-runoff and snowmelt floods are examples of overbank flooding.

**Rainfall-Runoff Flooding** is the most common type of flooding in Alaska, typically occurring from late summer through the fall. These floods result from high rainfall amounts and accompanying high surface runoff rates. Rainfall intensity, duration, and distribution, as well as pre-existing soil moisture conditions and geomorphic characteristics of the watershed all contribute to a flood's magnitude.

**Snowmelt Flooding** occurs when the major source of water involved in a flood is from melting snow. Unlike rainfall, which can reach the soil almost immediately, snowpack can store water for an extended period of time until temperatures rise above freezing and the snow melts. This frozen storage can delay the arrival of water to the soil for days, weeks, or even months. Once the snow begins to melt, the water behaves much as it would if it had come from rain instead of snow by either running off, infiltrating into the soil, or both. Flooding occurs when there is more water than the soil can absorb or can be contained in the storage capacities of the soil, rivers, lakes, and reservoirs.

**Snowmelt floods** in Alaska typically occur from April through June, but are most common in the spring when rapidly warming temperatures quickly melt the snow. Snowpack depth, spring weather patterns, and geomorphic characteristics of the watershed determine the magnitude of flooding. Rainfall, high temperatures, and melting glacial ice can exacerbate snowmelt floods.

**Alluvial Fan Flooding** is flooding occurring on the surface of an alluvial fan or similar landform. An alluvial fan is a fan-or cone-shaped deposit of sediment that is built up by streams due to a decrease in the ability to carry material, typically where streams exit from a steep tributary valley onto a larger valley or flat plain. The floods originate at the valley or fan apex and are characterized by high-velocity flows; active erosion processes, sediment transport, and deposition; and unpredictable flow paths. When debris deposits fill the existing river channels on the alluvial fan, the water overflows the stream banks and floods land downstream. The overflow may establish new channels. Alluvial fan flooding frequently damages roads and infrastructure in the cities of Seward and Girdwood, and in communities along the Richardson, Haines, and Dalton highways (Figure 6-31).

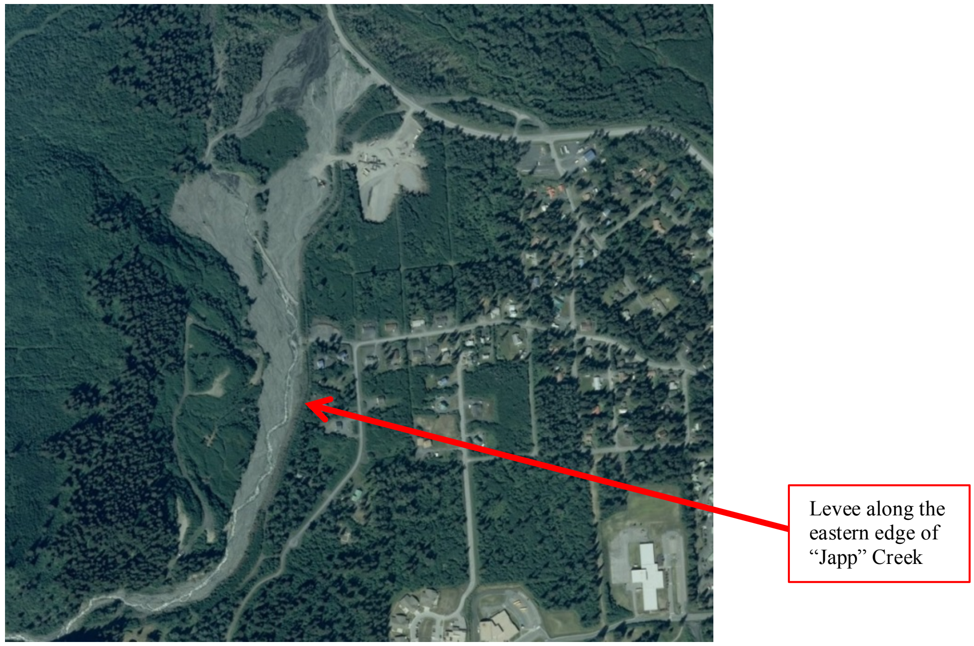


**Figure 6-31 Aerial Image of Japanese Creek**

*An alluvial fan in Seward, Alaska. [A] Levee has been constructed to direct the flow of water and sediment away from developed areas. Source: GeoNorth Information Systems*

**Flash Flooding** is a rapid and extreme high water flow into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event. Flash floods are usually caused by heavy rain associated with a severe thunderstorm, hurricane, tropical storm, or meltwater from ice or snow flowing over ice sheets or snowfields. They may also be caused by breaches in natural or manufactured dams. Usually swift moving, debris laden, and very destructive, these floods are sudden and potentially violent events. Topography such as narrow canyons and steep slopes are prone to flash flooding.

**Ice Jam Flooding** occurs when water backs up into surrounding areas because a river or stream is blocked by ice buildup or other debris blockage. Ice jams may occur any time when ice is present, but typically form during the following three seasons:

- Fall freeze-up.
- Midwinter, when stream channels freeze and form anchor ice.
- Spring breakup, when the existing ice cover weakens and breaks apart, flows downstream, and jams together at narrow sections of the stream channel where the ice blocks are forced to sink to the bottom from upriver water forces, forming a dam.

Ice jams commonly develop in areas of decreased channel slope, shallow sections, or constrictions, and frequently impede waterways during spring break-up. The water level rises upstream behind the ice jam. If the ice jam is higher than the riverbank, the adjacent land will flood. This effect is analogous to a dam, and if a community or development is nearby, low-lying structures will be subject to significant flooding and ice impact.

When the stream breaches the ice jam, the dammed water will drain rapidly and further damage structures as it flows back into its channel. The water level downstream will rise quickly and behave much like a flash flood, carrying large chunks of ice, trees, vegetation, and other debris.

A serious ice jam will threaten areas upstream and downstream of its location. Six inch-thick ice can destroy large trees and knock houses off their foundations. Many of the record flood events along major rivers in Alaska are the result of ice jams, including recent large and destructive floods along the Kenai, Susitna, Kuskokwim, and Yukon rivers (Figure 6-32).

**Figure 6-32 2013 Galena Ice Jam Flood**
*Source: NWS*

**Coastal Flooding** occurs along the coast when the combined effects of coastal storm surge, tides, waves (marine total water level) and sea level rise exceed local land elevations of beaches and coastal plains (Figure 6-33).

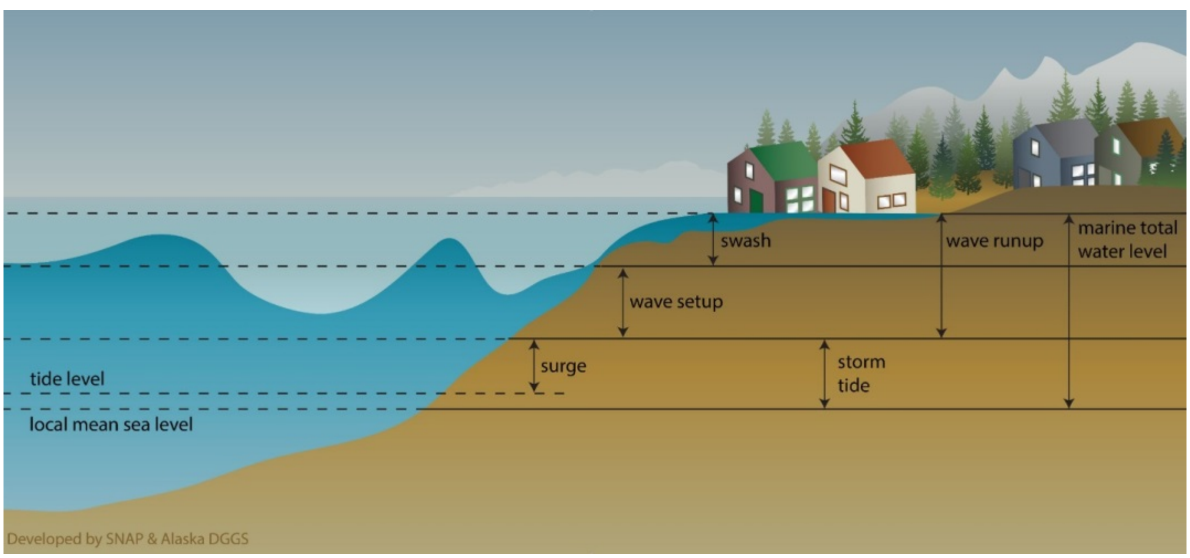


**Figure 6-33 Schematic of Coastal Water Levels Leading to Flood Inundation**
*Source: DGGS*

**Storm Surge** is caused by coastal storms, which start as low pressure weather systems moving across large bodies of water. These systems draw water toward the low pressure center, building a bulge of water that moves with the system; this bulge is called a storm surge. Flooding occurs when this storm surge reaches the coast and is driven landward. Storms also have high winds, which move across water bodies and generate wind-driven waves and "setup" (the increase in

water level due to the presence of breaking waves). The greater distance over which wind blows (i.e., fetch), the more wind energy can be converted into wave energy. Local tide fluctuations can result in increased or decreased flooding from a coastal storm, depending on their timing and magnitude (Figure 6-33).

The orientation and shape of the coast can result in variable amounts of flooding along the coastline. Shallow embayments, such as Kuskokwim Bay and Norton Sound, exert bottom friction on incoming storm surge, which enhances water elevation as it moves toward the coast. If the orientation of the storm is directly perpendicular to the coast (hits the coast straight on), the combined effects of storm surge and waves is translated directly onshore. Coastlines oriented slightly off-perpendicular may divert the high water levels to travel alongside the coast and hit it more obliquely, resulting in less flooding. Low elevation landforms such as deltas (e.g., the Yukon-Kuskokwim delta) is naturally more vulnerable to flooding, and even small events can cause substantial inundation. Low-lying sand spits and barrier islands, such as the islands on which Kivalina and Shishmaref are located, are also subject to flooding in the form of overwash events. Overwash is when storms push water, waves, and sediment over the top of the coastal landform, and results in net landward migration of the island.

In Alaska, coastal flooding primarily occurs on the northern and western coastlines. Storms (low pressure systems) from off-shore of Russia make their way across the Bering Sea to impact areas from the Alaska Peninsula to the northwest Arctic. Storm systems that move across the North Slope during ice-free ocean conditions can also result in flooding at North Slope communities. Coastal floods around the state have been identified using available data sources; however, many events go unreported due to the lack of observing systems and limited communication networks.

**Sea Level Rise** can impact the threshold for coastal flooding. Relative sea level change includes the combined effects of tectonically caused vertical land motion and changes in sea level due to changes in ocean water volume (Figure 6-34). Globally, sea level is rising due to ocean thermal expansion, caused by warming ocean water, and increased land-based ice melt, such as glaciers and ice sheets (National Oceanic and Atmospheric Administration [NOAA] 2018).

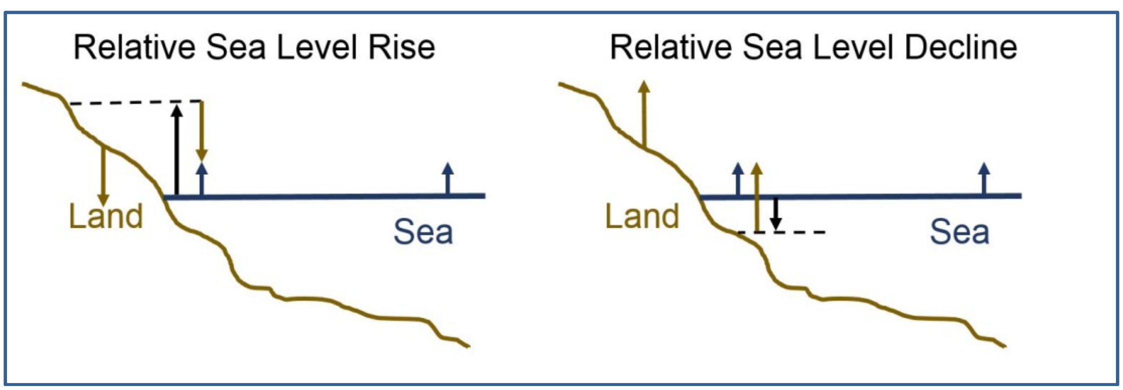


**Figure 6-34 Schematic of Relative Sea Level Change**

*Represents the combined effects of vertical land motion and changes to eustatic sea level. "Eustatic sea level" means sea level driven only by the mass or volume of the oceans. In the first case, sinking land level coupled with rising sea level leads to relative sea level rise; in the second case, rising land level coupled with the same amount of sea level rise as in the first leads to relative sea level decline.*
*Source: DGGS*

Relative sea levels in Alaska can either rise or fall, depending on local factors such as land subsidence, upstream flood control, erosion, regional ocean currents, variations in land height, and whether the land is still rebounding from the weight of glaciers from the last Ice Age (NOAA, 2018)(Figure 6-35). Regions of southeast Alaska are rebounding from the loss of their glacier ice faster than global sea levels are rising, resulting in relative sea level lowering. In contrast, sediment loading from the Yukon and Kuskokwim rivers is causing subsidence of the land relative to global sea levels on the Yukon-Kuskokwim delta. Actual rates for these processes were estimated using modelling and limited field data for northern and western Alaska *(DeGrandpre 2015)*, which had a high uncertainty of the calculated rates. Rates in the southeast, southcentral, and the Aleutian Islands, calculated using long-term ocean water level and land GPS observations, are better constrained (NOAA 2017).

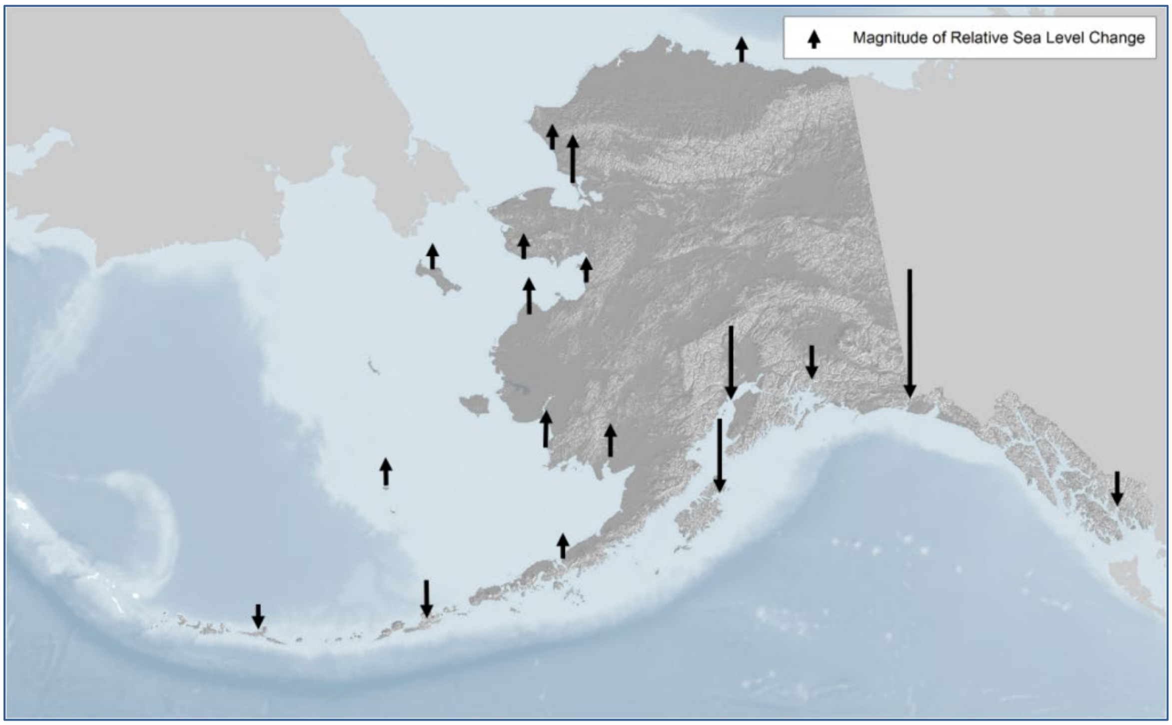


**Figure 6-35 Alaska's Relative Magnitude of Relative Sea Level Change Rates**
*Arrows show the direction and magnitude of relative sea level changes across Alaska. Source: NOAA 2017 and DeGrandpre 2015*

**Fluctuating Lake Levels** is flooding that occurs from overflowing lakes. Generally, lakes prevent downstream flooding by storing large amounts of runoff. However, the area around the lake may flood during periods of excessive inflow. The Kenai and Skilak lake areas occasionally flood due to excessive rainfall, snowmelt, and glacier-dammed lake releases.

**Glacial Lake Outburst Flooding** occurs when water is rapidly released from a glacial lake due to the sudden failure of an ice or moraine dam, or to water overtopping the dam as a result of waves caused by mass wasting (landslide) of nearby unstable slopes into the lake. Sub-glacial releases occur when enough hydrostatic pressure builds to float the glacial ice; water then drains rapidly from the bottom of the lake.

Glacial lake outburst flooding is possible in many parts of the state. A USGS study documented 750 glacier-dammed lakes with potential for outburst floods in Alaska and adjacent portions of Canada (Post and Mayo 1971). The Copper, Snow, Tazlina, and Kenai rivers all have periodic outbursts of approximately 2 to 5 year frequency, while the Kennicott Glacier at McCarthy and Valdez Glacier near Valdez outburst annually. See the Glacier Hazards section for a more detailed discussion of this hazard.

**Groundwater Flooding** occurs when water accumulates and saturates the soil. The water table rises to levels that flood low-lying areas, including structures, septic tanks, and other facilities. It has been a significant problem in Fairbanks, especially downstream of the Moose Creek Dam near Chena River Lakes. Additionally, the basements of structures along the Chena River may flood when the river stage remains high for more than a few days. Numerous rural or remote "boardwalk communities," such as Newtok and Atmautluak, experience dire living conditions due to groundwater flooding.

**Aufeis (Ice Overflow) Flooding** is caused by a surface ice mass (i.e., aufeis) that forms during the winter in a permafrost area by successive freezing of sheets of water that may seep from the ground or from a spring or river. Also known as "overflow ice," "glaciering," "icing," or "naled," most aufeis is less than a few hundred yards long; however, some can cover many square miles. Usually just a few feet thick, aufeis can reach a thickness of 30 feet or more. Aufeis in stream channels may force water up and over streambanks, resulting in flooding. In March of 2015, aufeis along the Sagavanirktok River caused flooding of the adjacent Dalton Highway (Figure 6-36). For more information about aufeis, see the Permafrost section.

**Figure 6-36 2015 Dalton Highway Flooding**
*Caused by aufeis on the Sagavanirktok River, 2015. Source: DOT/PF 2015*

### Erosion Classifications

The USACE's 2009 Alaska Baseline Erosion assessment found that many of state's communities are subject to erosion hazards – 178 communities along Alaska's rivers and coastline, mostly villages, reported erosion problems (Figure 6-37). There are three main erosion types in Alaska:

- Coastal erosion
- Riverine erosion
- Wind erosion

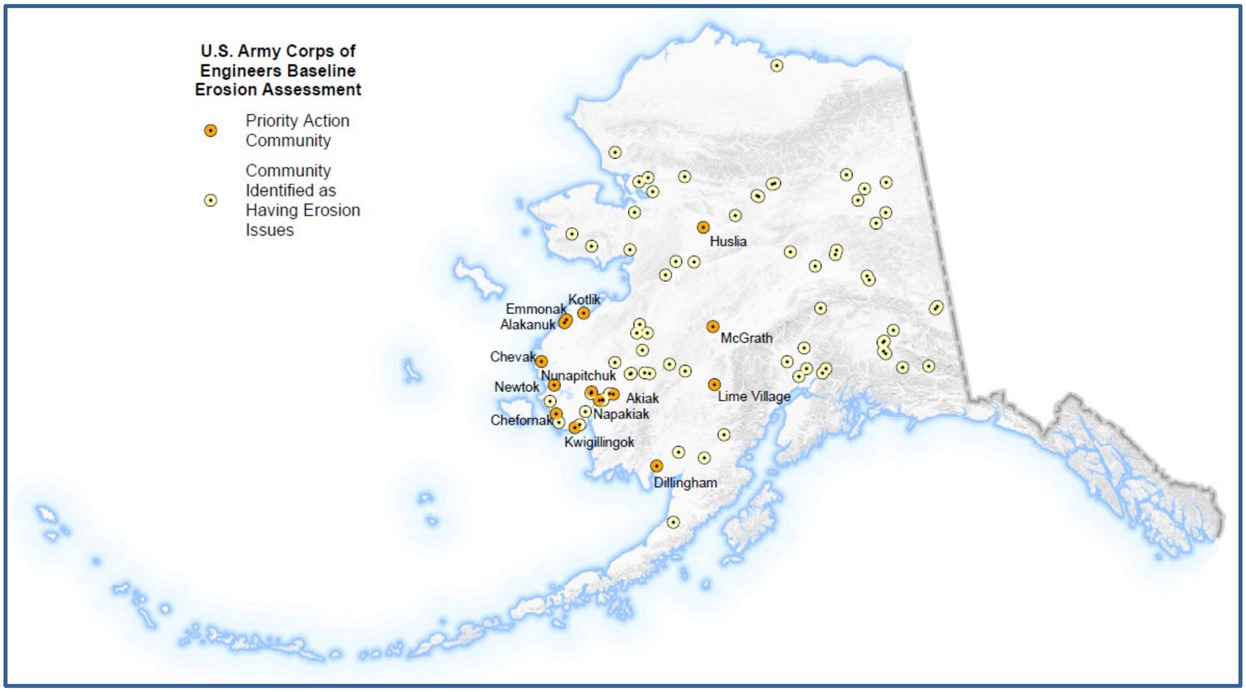


**Figure 6-37 USACE Baseline Erosion Assessment Map**
*Alaska communities with reported erosion problems. Sources: USACE, 2009; Map by DGGS 2018)*

**Coastal Erosion** (used interchangeably with scour) commonly occurs in Alaska because of the combination of hydrodynamic (waves and currents), physical (e.g., ivu [i.e., ice override] and human-caused), and thermal (e.g., permafrost thaw) processes that result in the transport of coastal sediments offshore or along the shoreline. Coastal retreat due to erosion can be significant and rapid.

Waves and currents act on the coastline on a wide range of time scales (from seconds to millennia). Coastal sediments are highly dynamic, shifting to respond to individual waves, tidal cycles, coastal storms, seasonal shifts in ocean currents and shelf circulation, relative sea level rise or fall, and others (Elko et al. 2014). Alaska's western and northern coastlines are subject to erosion from coastal storm waves and flooding (see Coastal Flooding). When sea ice is not present or is in low concentration, fall and winter storms can build storm surge and wave energy that significantly erode Alaska's coastline.

Engineered mitigation structures built in the nearshore zone (interface between ocean and land) work to:

1. Strengthen the shoreline to prevent erosion,
2. Capture sediment moving along the shoreline, or
3. Lessen wave energy as it moves toward the shoreline.

These structures can have both positive and negative impacts on the coastal sediment dynamics that drive coastal erosion. For example, coastal structures known as "groins" are built to capture sediment in the direction of dominant coastal currents and result in erosion on the leeward side. Other human activities, such as dredging and driving vehicles on beach surfaces, can work to erode coastal sediments. When sea ice is present in the nearshore, ice-pack movement can shift and result in ice override, or "ivu" (see Sea Ice). Ivus have been large enough to move buildings off their foundations and push nearshore sediments far inland.

Much of Alaska's coast also contains permanently frozen ground, or permafrost (see Permafrost). Permafrost is subject to thermal degradation from both air and ocean temperatures, greatly increasing its susceptibility to erosion. Coastal bluffs with high ice content (commonly found in northern and northwestern Alaska) develop thermoerosional niches from undercutting due to thermal degradation by waves at the bluff base, followed by collapse of entire blocks of frozen ground (Gibbs and Richmond 2015)(Figure 6-38).

**Figure 6-38 Aerial Photograph Showing a Typical Northern Alaska Coast**
*An example between the Staines and Sagavanirktok rivers. Note collapsing coastal bluffs and drained thermokarst lake (yellowish-brown area). (Source: Gibbs and Richmond 2015)*

Coastal erosion affects sand and gravel beaches and coastal bluffs throughout the state, but the regions impacted most dramatically are the North Slope, Northwest Arctic, Bering Strait, Yukon-Kuskokwim Delta, and Bristol Bay regions, as well as areas of southcentral Alaska. Much of Alaska, including regions in the Aleutian Islands, southeast, and southcentral, has rocky

coastlines. Rocky coastlines are much less vulnerable to coastal erosion as compared to sand and gravel beaches and coastal bluffs. Figure 6-39 shows coastal erosion rates from northern and western Alaska of which provides a visual of erosion hazards; the map is derived from analyses conducted by the DGGS, the National Park Service (NPS) (Manley and Lestak 2012), and the USGS (Gibbs and Richmond 2015). Shorelines were compared throughout time to determine how quickly they eroded; more negative means greater erosion. Shoreline change rates were calculated for some of the most vulnerable parts of the state, although some locations that experience erosion were not included because of limited availability or access to data.

Coastal erosion is also more likely to occur during sea ice-free conditions; normal fall and winter storms can have much greater impacts on a coastline unprotected by offshore and nearshore sea ice. Off-shore, sea ice mitigates wave and surge development, while nearshore ice provides a physical buffer to wave attack. In the future, sea ice in the Bering, Chukchi, and Beaufort seas is expected to form later in the year and break up earlier in spring (Douglas 2010). Sea ice concentration and thickness are also expected to decrease, allowing storms to more easily break up sea ice and thus impede its capability to reduce a storm's coastal impacts. Ice-free ocean conditions will also result in changing ocean processes, which will likely impact the distribution and behavior of coastal sediments.

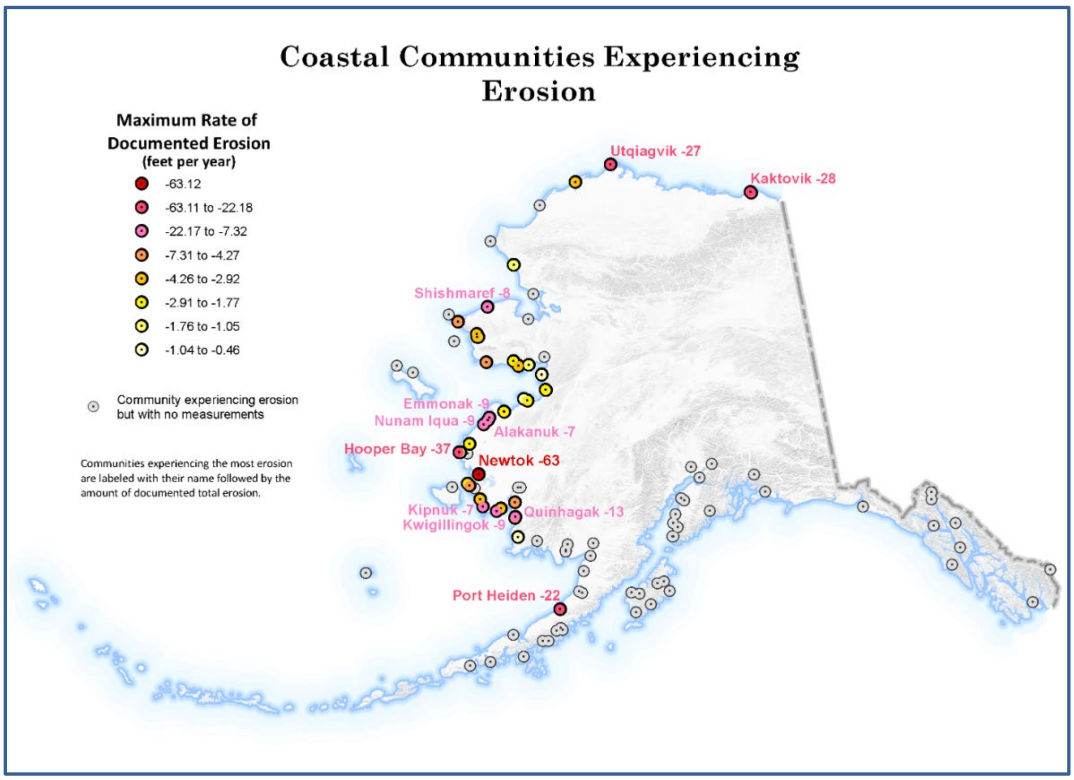


**Figure 6-39 Coastal Community Erosion Map**

*Showing maximum documented erosion rates (ca. 1950–2016) for Alaska coastal and tidally-influenced communities, where data or past studies were available. Coastal communities identified as possibly experiencing coastal erosion problems by the U.S. Army Corps of Engineers, but did not have measurements available, are shown as light gray circles. (Source: DGGS 2018)*

**Riverine Erosion** or scour occurs from high water flow forces and ice formations that wear away rock and soil along a riverbed and its embankments. This erosion also involves the breaking down of rock particles being carried downstream by the river. Eroded sediment is deposited in slower-moving sections of the river, such as the insides of river bends, places where the river widens, or where a river enters a lake or ocean. River erosion and deposition leads to lateral stream movement, with the streams meandering across the valley bottom by alternately eroding the sediment on the outsides of curves (cut banks) and depositing sediment on the insides of curves (point bars). Over time, the entire stream can move great distances across its floodplain and even cut into areas beyond the floodplain.

People in Alaska are losing the ground beneath their feet because of erosion (Figure 6-40). Not only do thawing permafrost and high river flow rates (such as during breakup) contribute to increased erosive scour, climate change has accelerated the normal process along Alaska's rivers; warmer temperatures degrade the permafrost that helped bind together the soil, and heavier rains produce more floods and swollen rivers that wash away the soil. Riverine erosion threatens many Alaska villages and major mitigation measures are needed whether these communities remain in place or relocate.

**Figure 6-40 Newtok Riverine Erosion**

*Newtok, Alaska's severely damaged bank reinforcement structures caused this steel shipping container to slide into the Ninglick River. Source: State of Alaska*

**Wind Erosion** moves soil from one location to another by wind power. Even a light wind can roll some soil particles along the surface, and strong winds can lift a large volume of soil particles into the air to create dust storms (Figure 6-41). Wind erosion is a relatively common occurrence in flat, bare areas; dry or sandy soils; or anywhere the soil is loose, dry, and finely granulated. The wind moves the finest particles (less than 0.1 mm in diameter) by suspending them in the air, and soil particles 0.1-0.5 mm in size are moved in a hopping or bouncing fashion, known as "saltation." Soil particles greater than 0.5 mm in size are generally moved by rolling.

Windblown sand creates sand dunes along beaches and in dune fields, such as the great Kobuk Sand Dunes of northwestern Alaska. Windblown silt, called "loess," can be carried many miles and redeposited on the ground as fertile loess soils, such as those covering large areas of Europe and North America (where highly productive farming has developed), and in the Matanuska-Susitna and Tanana River areas of Alaska.

While wind erosion is most common in deserts and coastal sand dunes and beaches, certain land conditions (e.g., bare soils) will exacerbate wind erosion in agricultural areas, where it can cause significant economic and environmental damage. Susceptibility to wind erosion is increased during drought periods, such as in the American and Canadian prairies in the 1930s during the Dust Bowl.


**Figure 6-41 Satellite Image of Windblown Dust from the Copper River Floodplain**
*Source: NASA Earth Observatory, https://earthobservatory.nasa.gov/IOTD/view.php?id=40973*

## 6.3.2. CLIMATE FACTORS

Climate and weather are the two primary drivers of flooding and erosion in Alaska. Weather (i.e., the day-to-day state of the atmosphere) affects these hazards on the short term with individual episodes of rainfall, wind, and temperature that initiate or intensify individual episodes of flooding or erosion. Climate is affecting the long-term incident rate and severity of these hazards, especially in Alaska, which is particularly vulnerable due to its high northern latitude and the unique importance of snow, ice, and permafrost. Longer sea ice-free seasons, higher ground temperatures, and sea level rise are expected to exacerbate flooding and accelerate erosion in many regions that ultimately increases risk.

In 2012 and 2013, Alaska's riverine communities experienced two of the quickest spring thaws on record. The Special Supplement to the Bulletin of the American Meteorological Society (published in August 2013) noted that the climate of the Arctic in 2012 was dominated by continued significant changes in the cryosphere, with new records for minimum sea ice extent

and permafrost warming in northernmost Alaska. Southerly airflow into the Arctic had a major impact on lake ice break-up, snow cover extent, and mass loss from Arctic glaciers and ice caps. Meltwater inundated many watersheds and the swollen rivers broke their ice cover prematurely, forming large ice dams downstream. The 2013 Spring Floods disaster (DR-4122) was one of the largest events of its kind in Alaska's history.

Global sea level rise is expected to continue due to increased glacier and ice sheet melting, which add water volume to oceans, and thermal expansion of the ocean as ocean water warms (NOAA, 2018). Sea level rise is location dependent. Figure 6-42 depicts this inconsistency along Alaska's coastlines. Sea ice that annually forms offshore of Alaska's western and northern coasts is expected to form later and break up earlier in the year (Douglas, 2010). The extent of sea ice is also expected to be reduced during winter months (Wang and Overland, 2009). Reduction of sea ice during fall and winter storms expose the coast and open ocean to storm surges and waves, and is expected to increase coastal flooding impacts (Simmonds and Keay 2009; Terenzi et al. 2014; Vermaire et al. 2013).

### 6.3.2.1. RELATED HAZARDS

Hazards related to flooding and erosion include glacier hazards (see Glacier Hazards), usteq (see Permafrost), sea ice hazards (see Sea Ice), and ground failure (see Ground Failure). Flooding and erosion commonly occur together because of increased water currents that get raised above the normal tide line or riverbank. Figure 6-42 illustrates how commonly coastal flooding and erosion occur together to threaten communities in western and northern Alaska.

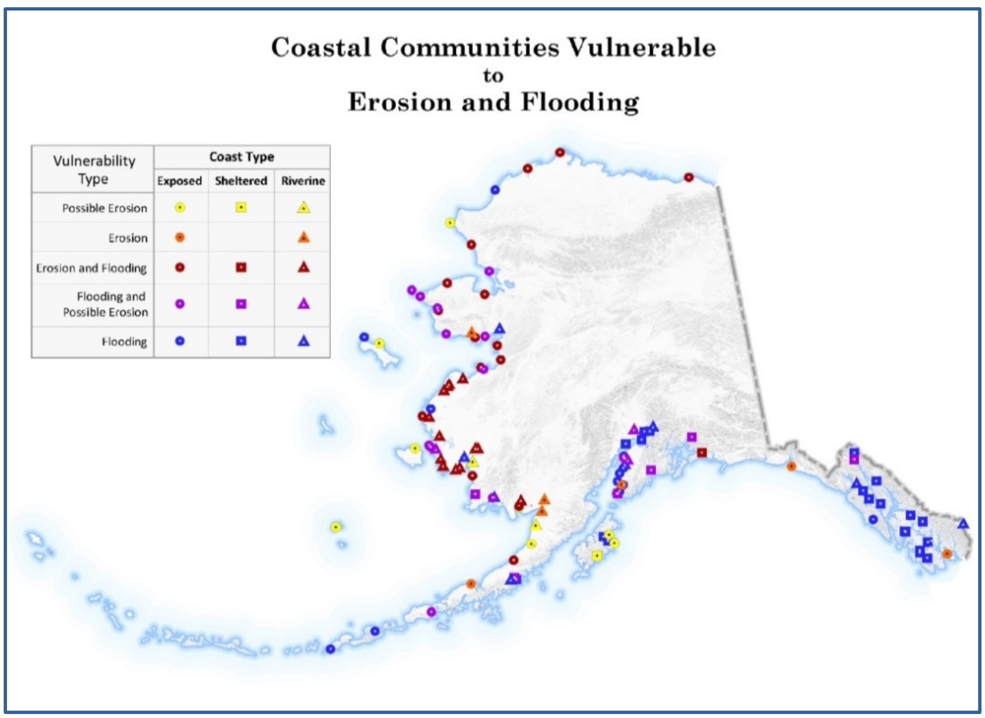


**Figure 6-42 Map of Alaska Erosion and Flood Threatened Coastal Communities**

*Experiencing known flooding (blue), erosion (yellow and orange), or both flooding and erosion (red and purple). The coasts of northern and western Alaska are particularly vulnerable to the combination of flooding and erosion. Source: DGGS 2018*

## 6.3.3. FLOOD AND EROSION HISTORY

Coastal and riverine communities throughout the state have lengthy flooding and erosion histories. Rapid snowmelt, ice jams, heavy precipitation, ice-free oceans, and seasonal variations all increase the risk. Flooding has overwhelmed wastewater treatment facilities, warranted entire community evacuations, inundated road systems, and forced agencies under considerable pressure to rebuild before winter. Given the limited highway infrastructure in Alaska, damaged runways, roads, and bridges may isolate communities for weeks and hamper disaster recovery projects for months or years.

- ***Rainfall-Runoff Floods***

***2013 October KPB Flood Disaster (DR-4161)***
*Beginning October 27, 2013, heavy rains inundated much of the Kenai Peninsula. Seward, Homer, Kenai, Anchor Point, and the Tyonek area along Beluga Road all reported major flood damage, prompting the Kenai Peninsula Borough to declare a local disaster and request state and federal assistance.*

***2012 September Storm (DR-4094)***
*On September 4, 2012, a strong weather system produced high winds and heavy rains, resulting in severe and widespread wind damage and flooding throughout much of Southcentral and Interior Alaska. The series of storms threatened life and property in the Matanuska Susitna Borough, Kenai Peninsula Borough, Alaska Gateway Regional Educational Attendance Area (REAA), and the Chugach area. The magnitude of the storm necessitated emergency protective measures enacted by the Rescue Coordination Center (RCC). Damages from wind and flooding were substantial and widespread.*

***2012 October Kuskokwim Delta Flood (AK-12-241)***
*On October 5, 2012, a strong fall storm moved north into the Bering Sea and produced severe winds, heavy rain, and storm surges up to 4 feet above mean tide levels in the Kuskokwim Delta, with severe impact to the Native Village of Napaskiak. The storm resulted in floodwaters surrounding the tribal-owned maintenance garage, undermining and shifting the building and foundation; damage to the driveway ramp to the maintenance yard; and substantial damage to community boardwalks.*

***2008 Tanana Valley Flooding (DR-1796)***
*From July 27–August 6, 2008, flooding from excessive storm activity destroyed property and threatened life in the interior region of the state. The most severely damaged were buildings and infrastructure near the City of Nenana* [Figure 6-43]. *In particular, the sewage lift stations required costly and extensive repairs. The lengthy unavailability of the sewer system created an unhealthy environment for the community. Following repairs, the City completed a hazard mitigation project to protect the sewer system from future flooding.*

*Additionally, the Alaska Railroad Company (ARRC) temporarily stopped all northbound freight and passenger rail service due to track failures in the City of Nenana and Healy Canyon. The ARRC completed a series of mitigation projects designed to prevent future flood damage and service interruption in the Nenana area.*

**Figure 6-43 Rainfall-Runoff Flooding in Nenana**
*Source: DHS&EM 2008*

- ***Snowmelt Floods***

***2015 Fort Yukon Flooding (AK-15-252)***
*Abnormally warm temperatures in mid-May 2015 rapidly melted snow in the highlands of northeastern Alaska and elevated water levels in the Yukon and Porcupine rivers. By May 20, the water levels overtopped the Porcupine River in some locations and inundated the Fort Yukon area with up to two feet of water.*

- ***Ice Jam Floods***

***2013 Spring Floods (DR-4122)***
*From May 17 through June 10, 2013, excessive snowpack and ice thickness, combined with rapid spring warming, resulted in ice jams and caused severe flooding throughout communities along the Yukon and Kuskokwim rivers* [Figure 6-44]. *Large ice jam floods severely damaged approximately 194 homes and much of the infrastructure, prompting evacuations. Loss and damage to personal property and multiple businesses, including loss of revenue, resulted from this event. Impacts to public infrastructure included: hazardous and non-hazardous debris removal; emergency protective measures (leading to ongoing mass care operations); and damage to city and state roads, bridges, water and sewer systems, electrical generation and distribution systems, recreation areas, and fuel storage facilities.*

**Figure 6-44 Ice Jam Flooding in Galena**
*Source: DHS&EM 2013*

***2009 Spring Ice Jam Flooding on the Yukon River (DR-1843)***

*The 2009 flood event was the largest disaster in Alaska in more than a decade, and involved communities along thousands of miles of the Kuskokwim and Yukon river systems. Ice jams formed along various points of the rivers, damming them and causing water levels to rise and flood nearby communities. Additionally, enormous ice chunks—some more than 15 feet thick—crashed into structures in the already-flooded communities of Eagle and Stevens Village* [Figure 6-45].

*Thirty-nine communities along the river systems, including the entire length of the Yukon River (1,980 miles long), sustained flood and ice damage in the month-long disaster. Challenges to the recovery teams were the remoteness of the communities and the fast-approaching winter season. The recovery effort included Public Assistance (PA), Individual Assistance (IA), SBA disaster loans, and temporary housing.*

**Figure 6-45 Ice and Flooded Structures in Stevens Village (left) and Eagle (right)**
*Due to the 2009 spring ice jam floods on the Yukon River. Source: DHS&EM 2009*

***2007 Kenai River Ice Jam Flood (triggered by glacial lake outburst flooding)***
*In the winter of 2007, the Skilak glacier-dammed lake breached and released a four-foot high surge of water into the Kenai River. The sudden rise in water level dislodged the river ice. The ice moved downriver and impacted public and private riverbank fishing platforms, stairs, and elevated walkways. Ice continued downriver and formed ice jams in multiple locations. Behind the ice jams, water and ice overtopped the riverbanks and flooded several public campgrounds, fishing parks, and residential homes* [Figure 6-46]. *Damage in the Kenai Peninsula Borough (KPB) extended from the community of Sterling to the City of Soldotna. Approximately 150 homes and riverside businesses reported damage to their buildings, fishing structures, and docks. Another 775 homes within the KPB sustained damage from the floodwaters and ice, and some roads became inundated and impassable.*

**Figure 6-46 Kenai River Ice Jam Flood**
*Triggered by a glacial lake outburst flood in its headwaters. Source: KPB 2007*

- ***Storm Surge Floods***

***2017 Alaska Severe Storm (DR-4369)***
*A storm from the Gulf of Alaska on December 4, 2017, resulted in heavy rain and a storm surge that caused significant damage to the Lowell Point area in the City of Seward on the Kenai Peninsula. High tides and a storm surge swept over the road and, along with waves, caused millions of dollars of damage* [Figure 6-47]. *Lowell Point Road was reduced to one lane of traffic in some locations, with the road edge on the ocean side suffering damage from storm water erosion in most areas. Rock slides triggered by the storm also deposited loose rock on the roadway.*

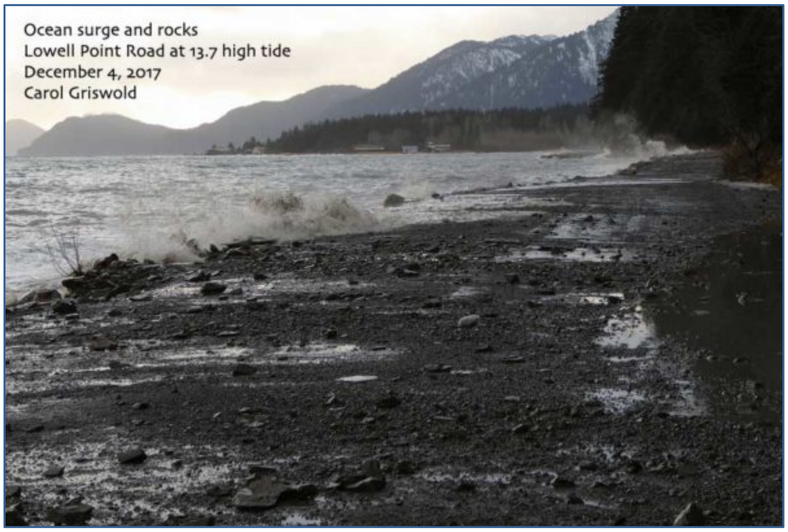


**Figure 6-47 Seward's Storm Surge Flooding of Lowell Point Road**
*Source: Carol Griswold, Seward City News 2017*

***2011 Alaska Severe Winter Storms and Flooding (DR-4050)***
*The November 2011 Bering Sea cyclone was one of the most powerful extratropical cyclones to affect Alaska on record. A 10-foot storm surge caused damage or flooding in some 40 villages across western Alaska. The storm shredded roofs, damaged portions of seawalls in Nome and Unalakleet, flooded homes in Golovin* [Figure 6-48]*, and knocked out electricity in several areas. The damage, though generally minor and likely underreported, was widespread, covering a nearly 700-mile swath.*

**Figure 6-48 Golovin Storm Surge Flooding**
*Source: Toby Anungazuk Jr., Chinik Eskimo Village [two photos spliced] 2011*

- ***Glacial Lake Outburst Floods***

*In Alaska, significant glacial lake outburst floods have been documented at Hubbard, Skilak, and Valdez glaciers, among others. See the Glacier Hazards section of this report for more information about glacial lake outburst floods.*

- ***Aufeis***

***2015 Dalton Highway Flooding (AK-15-253)***
*Beginning on March 13, 2015, the Sagavanirktok River on the North Slope experienced an unprecedented ice overflow flood between mileposts 390 and 415 of the Dalton*

*Highway, about 25–30 miles south of Deadhorse. Road clearing and overflow diversion efforts were hampered by very cold temperatures, high winds, and poor visibility.*

- ***Coastal Erosion***

***2017 Coastal Erosion at Shishmaref***
*The community of Shishmaref, located on a barrier island on the Chukchi Sea coast, experienced an erosion event from a fall storm in 2017. The storm did not result in significant flooding, but storm waves caused erosion of the community dump access road and land fronting the community's only airstrip* [Figure 6-49].


**Figure 6-49 Photos Showing Coastal Erosion**
*Occurring between 2012 and 2017at two sites in Shishmaref, Alaska. Colored arrows point to the same locations in each of the two series of photos. Far right photo shows aftermath of November 2017 erosion event, which washed out the road to the dump. Source: Photos include staff from DGGS and the Native Village of Shishmaref*

- ***Riverine Erosion***

Figure 6-50 shows riverine communities identified by the USACE as "priority action for erosion issues or as having erosion issues, but not priority action" (USACE, 2009). Some communities are located on tidally influenced rivers, so may experience both coastal and riverine erosion.

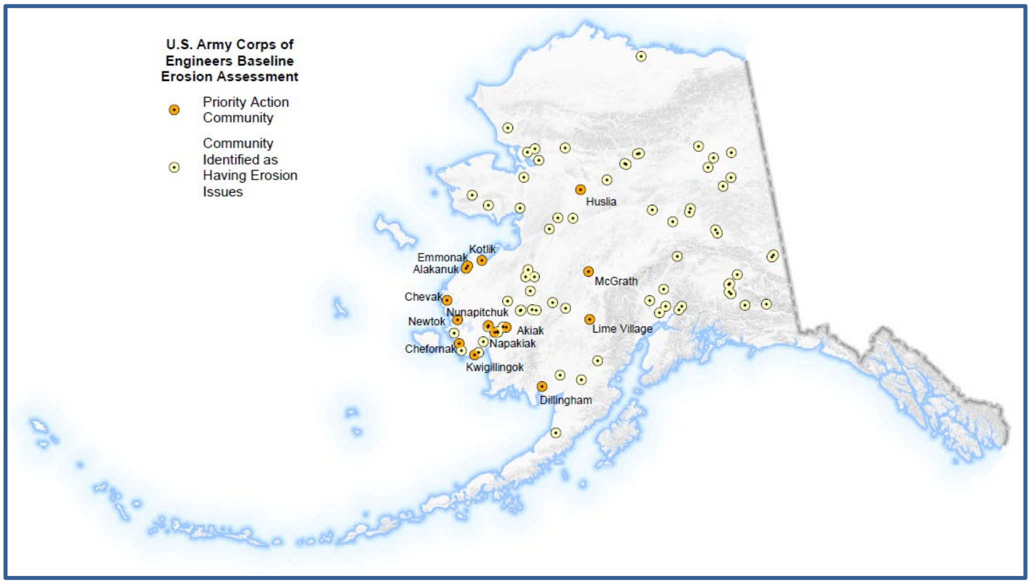


**Figure 6-50 USACE Riverine Erosion Prone Communities**

*Source: USACE 2009*

### *2016 Ninglick River Erosion at Newtok*

*An erosion event along the Ninglick River at Newtok in the fall of 2016 resulted in approximately 150 feet of lateral erosion, damaging residences and exposing a fuel header (Figure 6-51). Despite the amount of damage done in this and other events, FEMA denied the request for a major disaster declaration for the village.*

*Newtok has experienced many historic erosion events, with an average rate of erosion of 63 feet per year. The total amount of documented landward erosion between 1951 and 2015 is 3,680 feet; that is, in the last 66 years the riverbank has migrated almost three-quarters of a mile toward and into the town. Erosion has already claimed the community solid waste site, sewage lagoon, and barge landing site. The community anticipates the river will destroy the community water source, school, and airport by 2019.*

*Erosion is a particularly serious hazard in Newtok because the community is not only located on a riverbank and subject to typical riverine erosion, but coastal storms also enter the mouth of the river, raising the water level at town and exacerbating the destruction.*

**Figure 6-51 2016 Ninglick River Erosion at Newtok**
*Source: Romy Cadiente, Newtok Village Relocation Coordinator 2016*

## 6.3.4. EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Extent*

Flood and erosion hazards impact many communities around the state. As described in Section 8 Vulnerability Exposure Analysis, the extent of flooding and erosion has been defined as a 0.5 mile buffer along communities identified as threatened by coastal flooding (DGGS), community locations identified as experiencing coastal erosion (USACE), and a 0.25 mile buffer along riverine threatened communities (USACE). See Section 8 Vulnerability Exposure Analysis for detailed assessment.

### *Impact*

Nationwide, floods result in more deaths than any other natural hazard. Flooding is Alaska's greatest threat causing extensive property damage and losses, which include the following:

- Structure flood inundation, causing water damage to structural elements and contents.
- High water flow storm surge floods scour (erode) coastal embankments, coastal protection barriers, and result in infrastructure and residential property losses. Additional impacts can include roadway embankment collapse, foundations exposure, and damaging impacts.
- Damage to structures, roads, bridges, culverts, and other features from high-velocity flow and debris carried by floodwaters. Such debris may also accumulate on bridge piers and in culverts, decreasing water conveyance and increasing loads which may cause feature overtopping or backwater damages.
- Sewage, hazardous or toxic materials release, materials transport from wastewater treatment plant or sewage lagoon inundation, storage tank damages, and/or severed pipeline damages can be catastrophic to rural remote communities.

Floods also result in economic losses through business and government facility closure; utilities such as energy generation, communications, potable water, and wastewater; and transportation service disruptions. Floods result in excessive expenditures for emergency response, and generally disrupt the community's normal function and quality of life.

Impacts and problems also related to flooding are deposition as well as embankment, coastal erosion, and/or wind. Deposition is the accumulation of soil, silt, and other particles on a river bottom or delta. Deposition leads to the destruction of fish habitat, presents a challenge for navigational purposes, and prevents access to historical boat and barge landing areas. Deposition also reduces channel capacity, resulting in increased flooding or bank erosion. Embankment erosion involves material removal from the stream or river banks, coastal bluffs, and dune areas. When bank erosion is excessive, it becomes a concern because it results in loss of embankment vegetation, fish habitat, and land, property, and essential infrastructure. *Source: BKP 1988*

### *Recurrence Probability*

Alaska has historically experienced flood and erosion events. Many of these events are under-reported or not measured and very few communities have a 100-year flood analysis. For this reason, recurrence probabilities are not easily computed for coastal flood and erosion hazards. Section 8 Vulnerability Assessment provides a rough recurrence probability analysis.

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# 6.4. GROUND FAILURE

## 6.4.1. HAZARD CHARACTERISTICS

Ground failure results when rock and soil lose their mechanical stability, leading to failure, collapse, and/or material movement. “Mass wasting” and “mass movement” are terms used for events that include downslope movement from the originating location. Topography (i.e., slope), geologic setting, lithology (i.e., rock or sediment type), vegetation, and water content are important factors that influence the movement type (i.e., style) and speed as well as the amount and type of damage that may result from failure. Ground failure can occur due to natural processes, human activities, or a combination of the two.

### Ground Failure Types

***Landslide*** is a catch-all term that describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. “Landslide” is often used interchangeably with “slope failure” or “mass movement.” Anything that alters the slope gradient, vegetation cover, surface drainage, or groundwater infiltration can potentially destabilize vulnerable slopes and lead to landslides. In Alaska, degrading permafrost, steep slopes, heavy rain, retreating glaciers, and ground shaking from earthquakes are some of the important natural mechanisms that can trigger devastating landslides. Human activity—such as construction that undercuts or overloads dangerous slopes, or redirects surface or groundwater flow—can trigger landslides, as can forest clearing or tundra vegetation disturbance.

In general, landslides are classified based on the type of material being transported and the mechanics material movement (Table 6-2). Transported materials include rock, soil (fine-grained material), and debris (coarse-grained materials). The materials may move by falling, toppling, sliding, spreading, or flowing.

**Table 6-2 Landslide Classifications**

| Type Of Movement | | Type Of Material | | |
|---|---|---|---|---|
| | | Bedrock | Engineering Soils | |
| | | | Predominantly coarse | Predominantly fine |
| Falls | | Rock fall | Debris fall | Earth fall |
| Topples | | Rock topple | Debris topple | Earth topple |
| Slides | Rotational | Rock slide | Debris slide | Earth slide |
| | Translational | | | |
| Lateral spreads | | Rock spread | Debris spread | Earth spread |
| Flows | | Rock flow (deep creep) | Debris flow (soil creep) | Earth flow |
| Complex | | Combination of two or more principal types of movement | | |

*Source: Varnes, 1978*

Landslides are often complex, involving multiple movement and material types, and they may begin as one mass movement type and evolve into another as materials collect and continue to move downslope. The most common landslide types can be categorized as listed in Table 6-3 and displayed in Figure 6-52.

**Table 6-3 Landslide Types**

- Rotational Landslide
- Translational Landslide
- Directed Blast
- Rockfall
- Topple
- Debris Flow
- Debris Avalanche
- Earthflow
- Creep
- Lateral Spread

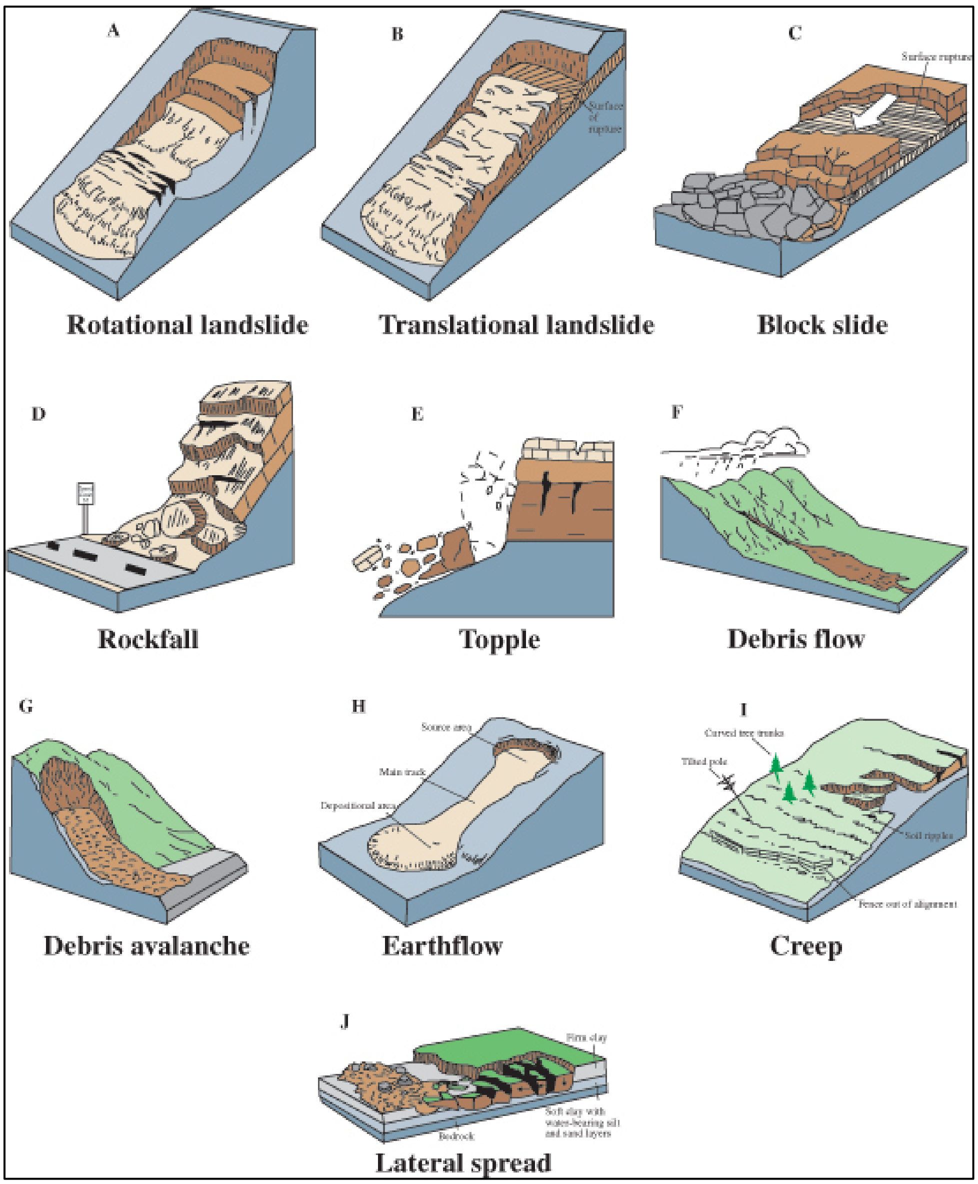



**Figure 6-52 Diagram – Most Common Types of Landslides**

*Source: USGS*

A ***Rotational Landslide*** is a landslide in which earth material slides on a failure surface or thin failure zone that curves upward. The slide movement is more-or-less rotational about an axis that is parallel to the slope contour. Rotational landslides generally occur on steep slopes (greater than 20 degrees).

A ***Translational Landslide*** moves downslope along a relatively planar failure surface, and has little rotational movement or backward tilting. Translational landslides commonly occur along geologic discontinuities, such as faults, joints, bedding surfaces, or at the contact between rock and soil. If the failure surface slope is steep, these slides can have considerable run-out distances. In Alaska, the top of permafrost can form the failure surface for a translational landslide; the frozen layer is impermeable to water, which accumulates on top of the permafrost and acts as a lubricant that facilitates sliding of overlying unfrozen materials. These types of translational landslides are called “active layer detachments.”

***Block Slides*** occur when material remains relatively coherent as it moves downslope, with little or no internal deformation. The sliding surface may be curved or planar.

***A Rockfall*** is an abrupt, downward rock movement that detaches from a steep slope or cliff. Falling material may bounce or break on impact and then continue to roll downslope. Rockfalls can occur where natural processes (such as weathering and erosion) or human activities (such as digging or blasting) have resulted in an over-steepened slope.

***A Topple*** describes the forward rotation of a mass of soil or rock about a pivot point that separates it from adjacent material. Toppling can be caused by natural processes, for example, stress from the weight of upslope material or freeze-thaw action in cracks or fractures. Columnar-jointed rocks are notably susceptible to toppling.

A ***Debris Flow*** is a rapid mass movement in which a saturated slurry of loose soil, rock, organic matter, air, and water flows downslope. Debris flows are commonly composed of a large proportion of silt- and sand-sized material, and are triggered by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. This landslide type is prevalent in areas with steep canyons and gullies, de-vegetated areas, and in volcanic regions with weak soils. Debris flows may develop from other types of landslides (such as rotational or translational) as they increase in velocity and the internal mass loses cohesion and/or gains water. A special form of debris flow that occurs on the slopes of volcanoes is called a “lahar” (see Volcano).

***Debris Avalanches*** are very fast-moving debris flows. Debris avalanches occur in steep terrain from collapse of weathered slopes, or when bedrock disintegrates during a rotational or translational landslide as material moves downslope at high velocity.

***Earthflows*** occur on moderately steep slopes, usually under saturated conditions, when earth materials lose shear strength and behave like a liquid. The flows are elongate and commonly occur in fine-grained soil (e.g., marine clay [quick clay] or silt) but granular materials or weathered bedrock with high clay content are also susceptible. Earthflows grow in size through a process known as “head scarp retrogression,” which is erosion of the upper portion of a failure surface, and may evolve from slides or lateral spreads (described below) as they move downslope. Earthflows can destroy large areas and flow for several miles.

***Soil Creep*** is a slow earthflow that is characterized by almost imperceptibly slow, steady, downslope movement of the uppermost few feet of soil or rock. Creep can pull apart or crack pipelines, highways, and other manmade structures. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges. Creep may be seasonal, where movement within the soil is affected by changes in moisture or temperature, or it may be continuous. In some cases creep may progressively increase and produce other landslide types.

***Solifluction*** is soil creep resulting from alternating cycles of freezing and thawing. It occurs when fine-grained soil thaws, becomes oversaturated due to poor drainage, and then begins to flow. If sufficient water is present, debris flows may develop. In areas of permafrost and deep seasonal freezing, the near-surface material (active layer) thaws seasonally and moves slowly downslope over the underlying frozen material; this process is called **gelifluction**.

***Lateral Spread*** is the extension or disruption of a normally coherent upper rock or soil layer on top of a softer, weaker layer that has liquefied or flowed. During a lateral spread event the stronger upper unit may subside into the weaker lower unit, or material from the lower unit may be squeezed into the upper unit. This mass-movement type generally occurs on flat or very gentle slopes. Lateral spreads can be prevalent in seismically active areas with liquefiable soils (see Earthquake). For example, the Bootlegger Cove Clay (quick clays) in the Anchorage area is particularly susceptible to liquefaction, resulting in catastrophic lateral spreading during the 1964 Good Friday Earthquake.

A ***Slump*** is a form of mass wasting that occurs when a coherent mass of loosely consolidated materials or rock layers moves a short distance down a slope. Slumps often occur as material drops off an eroding surface, for example, on the cutbanks of rivers or along undercut coastal bluffs.

***Subsidence*** is any sinking or settling of the earth's surface, often due to removal of subsurface material. Subsidence is common in areas of thermokarst (see below). Other causes include underground mining; groundwater and petroleum extraction or movement; and degassing and other changes in hydrothermal systems. Tectonic subsidence occurs when the ground surface is lowered by sinking of the Earth's crust as crustal plates move. In Alaska, sediment compaction, thawing ice-rich permafrost, and earthquakes are common subsidence causes.

***Thermokarst*** describes the land surface, landforms, and processes that result from thawing ice-rich permafrost. Ice-rich soil and ice lenses become exposed and thaw as surface material warms and erodes during summer, resulting in abundant water that mobilizes sediment to flow or slide downslope along the surface of the frozen permafrost; ice becomes exposed in steep headwalls, melting causes material to slump. ***Retrogressive Thaw Slumps*** and ***Retrogressive Thaw Slides*** form as permafrost ice continues to melt, scarps migrate upslope, and material continues to slump and slide (Figure 6-53). This process persists until displaced vegetation buries and insulates the ice-rich head scarp, slowing further degradation.

**Figure 6-53 Large Retrogressive Thaw Slump on the Noatak River**
*The top of the slump is 900 ft. above the river. (Source: NPS)*

***Frozen Debris Lobes*** (FDLs) are a unique kind of slow-moving landslide, which have recently been recognized in permafrost-affected mountainous regions of Alaska, particularly the Brooks Range (Figure 6-54). Frozen debris lobes are lobate or tongue-shaped features consisting of soil, rock, organic debris, and massive ice from infiltrating water. The largest FDLs measured in Alaska are almost 100 feet wide and 0.75 miles long. Some are more than 80 feet high—as tall as an eight-story building. These masses of material move at rates of up to 165 feet per year, and one is threatening to overrun the Dalton Highway because they cannot be slowed or stopped, the only viable solution is to move the road.

**Figure 6-54 Frozen Debris Lobe next to the Dalton Highway**
*Source: DGGS*

Many regions of Alaska are especially prone to landslides. For example, the U.S. Forest Service has identified hundreds, if not thousands, of landslides just within the Tongass National Forest area of Southeast Alaska. Landslide maps help raise awareness and promote public safety, but very few landslide maps exist for the state.

## 6.4.2. CLIMATE FACTORS

Studies show that changing climate conditions can increase the frequency of fast-moving, catastrophic landslides. Alaska's warming surface temperatures and thawing permafrost are impacting slope stability and increasing a variety of ground failures risks. Warming climate has caused many areas to become unstable, and future warming will increase landslide risk throughout the state, especially in permafrost and glacial regions. Increases in tsunami-producing landslides in Southeast Alaska can be attributed to retreating glaciers and thawing permafrost. Rock-ice face collapse is most common in areas with glaciers and steep topography, frequently the same areas that attract tourists. At the same time, population growth and the expansion of settlements and lifelines over potentially hazardous areas are increasing the likelihood of landslide impacts.

Increased permafrost thaw causes thermokarst and subsidence due to loss of ground ice. Additionally, increased water from thawing amplifies potential for ground failure slides, flows, and creep. Degrading alpine permafrost in the Haines area is causing increased debris flow incidents that repeatedly inundate and block the highway, making it one of the most expensive maintenance stretches in the state for DOT/PF (Figure 6-55).

**Figure 6-55 Aerial View of Haines Highway Debris Fan**

*Haines highway crosses a debris fan that is repeatedly inundated by debris flows near milepost 19 from the Takshanuk Mountains. Source: DGGS*

Glacial retreat due to warming climate increases ground failure potential as steep slopes are exposed and become unstable due to glacier ice overburden or lateral support removal. This is believed to have contributed to the June 28, 2016, landslide at Lamplugh Glacier, Glacier Bay National Park, where more than 100 million tons of rock, snow, and ice slid down a mountainside and sent debris 6 miles across the glacier surface (Figure 6-56).

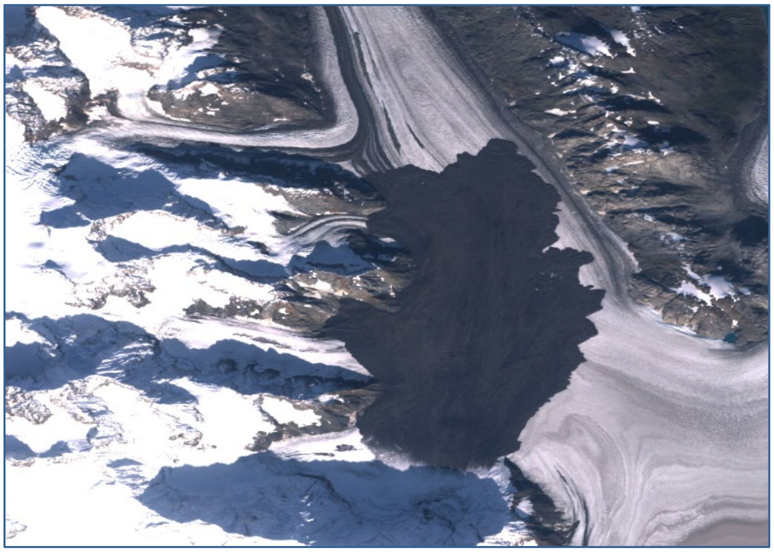


**Figure 6-56 2016 Lamplugh Glacier Landslide – via Satallite**

*The dark mass of the landslide extends 6 miles across the white ice of Lamplugh Glacier, Glacier Bay National Park. Source: European Space Agency, Copernicus Sentinel 2016*

Permafrost temperatures changes measured across the North Slope Borough and much of western and interior Alaska reveal they are clearly rising in direct relation to rising air temperatures. Alaskan communities depend upon a stable permafrost layer to support their buildings and infrastructure. Built on once-stable permafrost, the Dalton Highway has also been damaged by both frost heaving and subsidence (Figure 6-57).

**Figure 6-57 Dalton Highway, Alaska, June 2015**

*Thawing permafrost caused significant damage to the Dalton Highway in the North Slope of Alaska in June 2015. Source: DOT/PF and Climate Central 2015*

### 6.4.2.1. RELATED HAZARDS

Ground failure is associated with many other hazards because these hazards can directly initiate mass movement, or else destabilize slopes, making them more susceptible to failure. For example,

- Flooding can add weight to a surface (through water and sediment), causing it to be overloaded and unstable
- Erosion can remove material at the base of a steep slope, resulting in loss of lateral support
- Thawing permafrost can leave voids in the ground, resulting in subsidence
- Ground motion (shaking) from earthquakes commonly initiates a variety of ground failures

## 6.4.3. HISTORY

The DGGS Hazard profile project lists the following ground failure events:

***2015 Sitka Landslides***

*On August 18, 2015, heavy rainfall resulted in more than 70 landslides in the vicinity of Baranoff Island, Southeast Alaska. Four debris flows impacted roads and infrastructure in Sitka, including one on Harbor Mountain that was more than 1,200 feet long and resulted in the death of three people and massive property damage on Kramer Avenue* [Figure 6-58].

**Figure 6-58 South Kramer Landslide in Sitka, 2015**
*This landslide took the lives of three people. Source: DGGS 2015*

***Ground Failures of the 1964 Great Alaska Earthquake***
*Some of the most dramatic ground failure events in Alaska were associated with the 1964 Great Alaska Earthquake, which triggered a wide variety of falls, slides, flows, and lateral spreads throughout Southcentral Alaska. Anchorage was heavily impacted because of failures in the Bootlegger Cove Clay Formation. Significant failure events occurred at Fourth Avenue, L Street, Government Hill, and Turnagain Heights, with several less-devastating slides in other areas, such as at Point Woronzof and Potter Hill.*

*The Government Hill Elementary School was severely damaged by a complex translational slide where the south wing of the school dropped ~30 feet while the east wing split lengthwise and collapsed. Part of this slide became an earth flow spreading 150 feet across the flats into the Alaska Railroad yards. The Turnagain Heights landslide was the largest and most complex translational slide, and likely began as a block slide*

*that evolved to include lateral spreading, slumping, and possibly other movement types. This landslide caused serious damage to a housing development in which three people died.*

*The earthquake caused at least one rock avalanche. A slab of rock became detached from the mountain peak overlooking Sherman Glacier. The rock slab disintegrated as it moved downhill, helping it achieve great velocities and extend a large distance over the glacier.*

*The 1964 Great Alaska Earthquake also caused extensive subsidence. The subsidence zone covered about 110,000 square miles, including the north and west parts of Prince William Sound, the west part of the Chugach Mountains, most of Kenai Peninsula, and almost all the Kodiak Island group. In some areas, subsidence exceeded seven feet. Part of the Seward area is about 3.5 feet lower than before the earthquake, and portions of Whittier subsided more than five feet. The village of Portage, at the head of Turnagain Arm of Cook Inlet, subsided six feet, partly due to tectonic subsidence and partly due to sediment compaction during the earthquake.*

***2009 Alaska Severe Storms, Flooding, Mudslides, and Rockslides (DR-1865)***
*In October 2009, the remnant of a typhoon brought the Kodiak Islands their second largest rainfall event ever recorded. More than 9.5 inches of rain fell in five days, resulting in mudslides and rockslides that damaged roads and infrastructure. The event was declared a federal disaster and included the Kodiak Island Borough and the Kodiak Electric Association.*

***Ground Failure Events in Juneau***
*Multiple mass movements have affected Juneau in the past 100 years. One of the most destructive occurred on November 22, 1936, when prolonged heavy rainfall triggered a debris flow that struck a residential area and caused numerous injuries and deaths. On July 16, 1984, heavy rain fell on already-waterlogged soils and triggered a debris avalanche/flow that destroyed a small hydroelectric dam, damaged two houses, and left debris on the Glacier Highway and inside several local businesses.*

***Other Ground Failure Events in Alaska***
*On November 29, 1969, a debris flow caused by the overflow of an emergency spillway destroyed Ketchikan's Upper Lake Silvis powerhouse, plunging the city into partial darkness.*

*A rock avalanche on April 11, 2009, blocked the tunnel connecting the town of Whittier to the main highway system. The avalanche deposited a 300-foot-long by 30-feet-tall pile of rubble on the solitary access road, completely isolating Whittier. The town has no commercial airstrip, so the slide completely stopped all transportation and commerce until the rubble pile was removed days later. Falling rock inside the tunnel contributed to Whittier isolation in June 2014.*

## 6.4.4. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location*

Ground failure can occur anywhere in Alaska where soil conditions, geology, slope, and weather (especially rain events) combine to destabilize the ground surface. Degrading permafrost, steep slopes, heavy rain, retreating glaciers, and ground shaking from earthquakes are some of the important natural mechanisms that can trigger devastating landslides in Alaska. Human activity—such as construction that undercuts or overloads dangerous slopes, or redirects surface

or groundwater flow—can trigger landslides, as can forest clearing or tundra vegetation disturbance.

### *Extent*

Damage from ground failure could range from minor—with some repairs required and little to no damage to transportation, infrastructure, or the economy—to major if a critical facility (such as an airport) were damaged and transportation was affected.

The extent of ground failure impacts throughout Alaska will vary (depending on the type of failure, its size or extent, and location). Impacts can occur quickly or over time with warning signs. This hazard could cause injuries or death, or shut down critical facilities and services without foreknowledge, and property could be severely damaged.

### *Impact*

Impacts associated with ground failure include surface subsidence or upheaval, and infrastructure, building, and/or road damage. Ground failure can pose a sudden and catastrophic hazard in the event of a large landslide. Most ground failure damage from non-landslide causes occurs from improperly designed and constructed buildings that settle as the ground subsides, resulting in structure loss or expensive repairs. It may also impact buildings, communities, pipelines, and airfields, as well as road and bridge design costs and location. To avoid costly damage to these facilities, careful planning and location and facility construction design is warranted.

### *Recurrence Probability*

Communities may experience annually recurring landslides (debris flows) and other ground failure damages to residential and public structures, roads, harbor areas, and airports. The probability for ground failure is location specific.

## 6.5. TSUNAMI AND SEICHE

A tsunami is a series of waves in a water body caused by large, sudden water displacement (Figure 6-59). Subduction zone earthquakes, subaerial (land-based) and submarine landslides, volcanic eruptions, calving glaciers, underwater explosions, and even meteorite impacts have the potential to generate tsunamis. In Alaska, subduction zone earthquakes pose the primary tsunami threat.

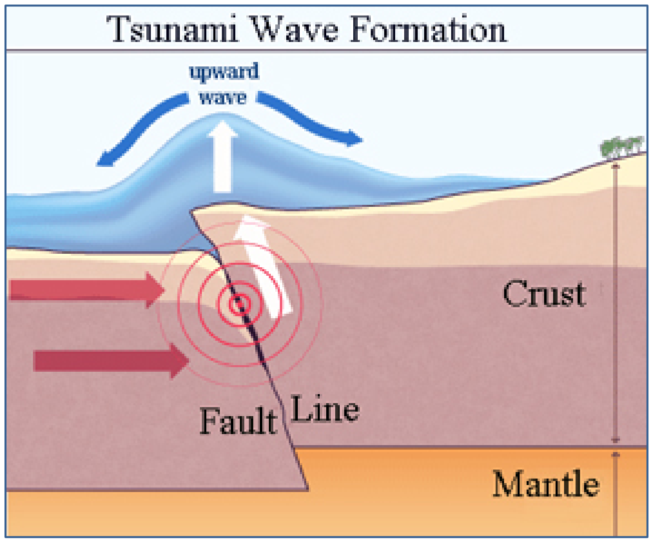



**Figure 6-59 Most Tsunamis Occur from Underwater Earthquakes**
*Source: California Seismic Safety Commission, modified from How Stuff Works*

A seiche is a series of standing waves sloshing in a semi- or fully enclosed water body, typically caused when strong winds, rapid atmospheric pressure changes, earthquakes, tsunamis, or severe storm fronts “pile up” water on one end of the basin (Figure 6-60). When the driving force stops, the water rebounds to the other side of the enclosed area. The water then continues to oscillate back and forth for hours or even days. Because they are standing waves, they move vertically more than horizontally.

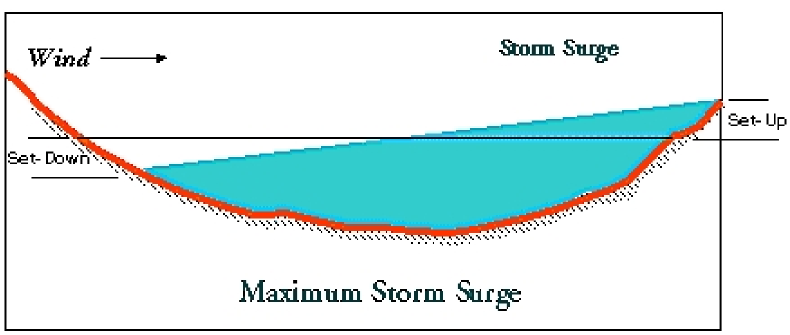



**Figure 6-60 Storm Surges Can Cause Seiches in Large Lakes**
*Strong storm winds blow across the lakes and pile up water on the downwind shore of the lake, resulting in wind set-up. On the opposing upwind shore, the storm surge lowers the water the exact amount that has risen at the downwind shore, resulting in a wind set-down. When the wind stops, the water sloshes back and forth.*
*Source: Michigan State University Department of Geography*

Tsunamis are far more destructive than seiches in Alaska. In the last 60 years, Pacific plate subduction under the North American plate has resulted in numerous great earthquakes, and is the source of locally generated tectonic tsunamis that have killed more than 100 people and destroyed entire towns. Some previously inhabited areas are now permanently abandoned because of this threat. Alaska has an enormous amount of coastline and, in addition to local and distant tectonic tsunamis, there are other tsunami triggers that may occur without warning.

### 6.5.1. HAZARD CHARACTERISTICS

Many potential tsunami causes are present in Alaska. For example, submarine landslide-generated tsunamis threaten numerous communities where nearby rivers deliver fine-grained sediment into the ocean e.g. Valdez, Seward, Whittier, Skagway, Haines, Juneau, Wrangell. These locally generated tsunamis can make community landfall within minutes.

The National Tsunami Warning Center (NTWC), University of Alaska Fairbanks, Geophysical Institute (UAF/GI), and emergency management offices primarily focus on seismically-induced tsunami waves because there is typically sufficient time to warn communities of the potentially pending danger. Tectonic tsunamis originating in the vicinity of the Aleutian Islands, Alaska Peninsula, and the Gulf of Alaska are of particular concern to Alaskans because waves can reach coastal communities within minutes to hours after the earthquake that caused them.

Tsunamis generated by subsea earthquakes exhibit long wave periods, can have wavelengths extending up to several hundred miles, and travel at speeds that can exceed 500 miles per hour in the open ocean. In contrast, a typical wind-generated wave may have a period of ~10 seconds and a wavelength of ~300 feet. A main difference between the tsunamis and wind-generated waves is that the latter are only surface disturbances and do not cause movement of water at the ocean bottom. Rather than resembling normal sea waves, a tsunami is similar to a rapidly fluctuating tide and, depending on the area in question; the fluctuations can persist for ~24 hours. In the open ocean, the amplitude (height) of a tsunami may only be a few feet and, combined with wavelengths of hundreds of miles, is practically imperceptible to boaters. The word “tsunami” is Japanese for “harbor wave,” because fisherman on the open ocean would not perceive a tsunami but would return to their harbors to discover they had been destroyed.

The energy of a tsunami wave train affects the entire ocean column from sea surface to sea floor. As the tsunami enters shallow water, the wave is forced to slow down, resulting in increased amplitude (height). The two mechanisms by which tsunamis cause damage are:

- The smashing force of incoming water as land is inundated; and
- The destructive force of water draining off the land while carrying a tremendous amount of debris (even knee-deep tsunami water contains enough debris to make walking impossible).

Note that is also important to consider the natural tidal fluctuations in an area: a 3-foot tsunami on a very low tide may go unnoticed, but the same 3-foot tsunami on a very high tide may cause significant damage.

Tsunamis are categorized according to the distance from source mechanism to inundation zone:

- Local Tsunami
- Regional Tsunami
- Distant Tsunami

A ***Local Tsunami*** is any tsunami inundation that occurs near the source. The total elapsed time from the source event to the community is usually less than 1 hour. Alaska local tsunami event sources include:

- Subduction zone earthquakes
- Volcanic eruption or edifice collapse
- Landslides
- Glacial calving
- Rockfalls, or
- Any combination thereof.

Recall that strong earthquake shaking can increase gravity-driven mass movement potential. If the source event is not immediately observed (e.g., underwater slope failure), there may be no warning. A local tsunami is likely to reach coastlines before an official evacuation notice can be made by the Tsunami Warning Center or local authorities. If a causative source event is observed or experienced (such as an earthquake so strong residents can barely remain standing), coastal residents and visitors will need to quickly self-evacuate.

A ***Regional Tsunami*** may travel 1 to 3 hours before reaching the community. This tsunami type allows for more accurate and timely evacuation notices.

A ***Distant Tsunami***, also referred to as tele-tsunami or ocean-wide tsunami, usually takesg more than 3 hours to arrive. In many cases, tele-tsunamis allow for sufficient warning time and evacuation. Most tele-tsunamis reaching Alaska are not damaging. For example, Massacre Bay on Attu Island has historically received tele-tsunamis with less than one foot recorded amplitudes. In one rare instance, the 1960 Chilean earthquake, Massacre Bay recorded a tsunami wave more than 6 feet in amplitude. This same tsunami damaged docks and pilings at MacLeod Harbor, Montague Island, and Cape Pole, Alaska.

A ***Seiche** as* summarized on page 6-75 and depicted in Figure 6-60, is a temporary water level oscillation within a fully or partially enclosed water body (e.g., a lake or fjord). "Seiche" literally means "to sway back and forth." Seismic seiches are typically caused by earthquakes that result in vertical motions. It may be difficult to isolate a specific causative mechanism near an earthquake epicenter, as seismic waves, landslides (submarine or subaerial), tsunamis, and tectonic tilting all may play a role in water level disturbance. At greater distances (i.e., over 600 miles), seiches are generated mainly by seismic surface waves.

Seismic waves from the 1964 Great Alaska Earthquake were so powerful that they caused water bodies to oscillate at many places in North America. Although they had rarely been reported following previous earthquakes, seiches were recorded at hundreds of surface-water gaging stations; in fact, four seiches were observed in Australia. Some of the 1964 seiches were very

large, waves as high as 6 feet were reported on the Gulf Coast of the U.S., probably because they were generated in resonance with the seismic surface waves.

## 6.5.2. TSUNAMI AND SEICHE HISTORY

Given the extent and dynamic Hazard Characteristics of Alaska's coastline, there are far too many tsunamis to document here. Instead, here are some of the most notable and destructive historical tsunamis.

***1883 Augustine Volcanic Tsunami***

*In 1883, a debris flow from the Augustine volcano inundated Port Graham with >20 foot tsunami waves.*

***1946 Unimak Island Earthquake Tsunami***

*A M 8.6 earthquake occurred near Unimak Island on April 1, 1946. The resulting tsunami had a run-up of approximately 100 feet and totally destroyed the Scotch Cap lighthouse, a reinforced concrete structure. All five occupants and the lighthouse washed out to sea. The tsunami caused about $250,000 in damages in Alaska, with widespread effects elsewhere. Relatively minor damage was reported in Washington and Oregon, as well as in French Polynesia and Chile. California suffered $10,000 in damages and one death. Hawai'i was heavily impacted, with $26 million in damages and 159 fatalities.*

***1957 Andreanof Islands Earthquake Tsunami***

*AM 8.6 earthquake west of Unalaska generated <75 foot tsunami waves along Aleutian shores and a distant tsunami in Hawaii with maximum run-up of 53 feet. The tsunami event destroyed two bridges on Adak Island and damaged houses. On Umnak Island, tsunami waves destroyed part of the community dock. Additionally, Mount Vsevidof volcano erupted after being dormant for more than 200 years. The northwestern side of the Island of Kauai, Hawai'i, experienced more inundation and damage than the 1946 tsunami. The tsunami damaged boats and docks in San Diego Bay, California, and reached Chile, El Salvador, and Japan. Although there were no reported fatalities from this event, the Hawaiian Islands suffered more than $5 million dollars in damages.*

***1958 Lituya Bay Tsunami***

*A M 7.8 earthquake on the Fairweather fault triggered a landslide into the head of Lituya Bay in Glacier Bay National Park and generated a devastating tsunami. The wave traveled up the adjacent mountainside to a height of more than 1,720 feet* [Figure 6-61]. *Two fishing vessels anchored in the bay were sunk, killing two people. A third boat was swept over the La Chaussee Spit and back into the bay, landing upright. Lituya Bay is a tsunami-prone area, and at least three other fatal, landslide-generated tsunamis have occurred there in the past. The 1958 earthquake triggered at least eight separate landslide-generated tsunamis, including the Yakutat Bay tsunami that caused three fatalities.*

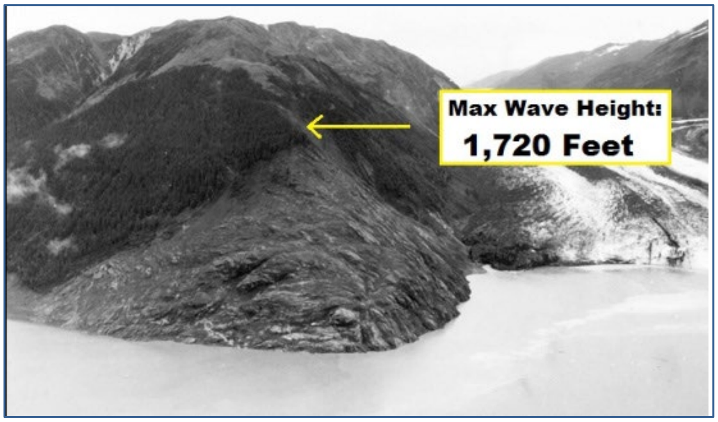



**Figure 6-61 The 1958 Landslide-Generated Tsunami Wave in Lituya Bay**
*Trimlines along the bay that are still visible today. Source: USGS*

***1964 Great Alaska Earthquake Tsunamis***

*The 1964 Great Alaska Earthquake in Southcentral Alaska triggered several tsunamis, including one major tectonic tsunami and about 20 local submarine- and subaerial-landslide tsunamis. The tectonic tsunami hit 20–45 minutes after the earthquake, depending on location. The locally-generated tsunamis struck between two and five minutes post-earthquake and caused most of the deaths and damage. Tsunamis caused more than 90 percent of the deaths associated with this earthquake: 106 Alaskans and 16 California/Oregon residents were killed. Alaska's damages were most extensive in Kodiak Island, Seward, Whittier, and Valdez, with significant tsunami damage throughout areas adjacent to the Gulf of Alaska.*

*Kodiak: Witnesses to the Kodiak tsunami event observed ten waves that damaged or destroyed everything they reached, including the dock pier, roads, houses, and other facilities. They also destroyed the main electrical and water distribution systems. The tsunami caused $31.3 million in damages, destroyed 80 percent of the city's industrial base, and rendered 600 people homeless out of a population of 2,658. There were only six reported fatalities as most residents moved to high ground when they felt the earthquake* [Figure 6-62].

**Figure 6-62 1964 Tsunami Damage Along the Kodiak Waterfront**
*Source: USGS 1964*

***Seward:*** *The earthquake caused regional subsidence (~4 ft.) that exacerbated a local tsunami event. The local tsunami destroyed most of the facilities near the former shore, including a fuel tank farm that started the first of many fires. Additionally, the local tsunami spread floating, burning oil, which ultimately engulfed another large fuel tank farm further inland. The main dock collapsed with the waterfront and sank 30 fishing boats and 40 pleasure craft in the small boat harbor. The local tsunami also heavily damaged the railroad yards, moving a 120-ton locomotive 100 feet, and a 75-ton locomotive 300 feet* [Figure 6-63]. *About 25 minutes after the earthquake and local tsunami event, the tectonic tsunami event arrived in Seward. The waves carried flaming oil and debris into Seward and set fire to a large section of the town. Overall, Seward lost about 95 percent of its industrial base and 15 percent of its residential properties. There were 12 fatalities, 200 injuries, and approximately $14 million in damages.*

**Figure 6-63 1964 Tsunami Damage in Seward**
*A few months after the earthquake. Source: USGS 1964*

***Whittier****: A series of at least eight tsunami waves struck Whittier destroying two saw mills, the Union Oil Company, the Alaska Railroad depot, and several houses. The small boat harbor was also heavily damaged. The tsunamis were responsible for 13 deaths and approximately $10 million in damages in Whittier.*

***Chenega:*** *The Native village of Chenega was severely damaged by a tsunami. With 26 people killed, the community lost more than one-third of its population.*

***Valdez:*** *Much like Seward, a portion of the Valdez waterfront subsided into the bay during the earthquake, exacerbating a local tsunami. The earthquake and local tsunami heavily damaged or destroyed all structures near the former waterfront (Figure 6-64). Half of the downtown business district was totally destroyed, and fires burned uncontrolled for two weeks. Almost the entire town's fishing fleet (68 out of 70 boats) sank. The local tsunami swept away twenty-eight people gathered to watch a freighter unload. Shifting cargo in the freighter's hold caused additional fatalities.*

**Figure 6-64 Aerial Image of Valdez, Alaska**

*Showing the extent of inundation and destruction (dark area along the coastline) after the 1964 earthquake. Source: USGS 1964*

***1994 Skagway Tsunami and Seiche***

*On November 3, 1994, an underwater landslide collapsed a cruise ship wharf undergoing construction at the head of Taiya Inlet. The landslide generated a tsunami within the harbor, followed by a seiche, and resulted in one fatality and more than $25 million in damages. The cause of the landslide is not definitively known.*

Many Alaska communities are in close proximity to historic tsunamigenic events that have occurred along the Aleutian Trench. The NTWC lists the following earthquake generated tsunamis with observed or measured tsunami waves that have occurred since 1996 with measurable inundation heights (Table 6-4)

**Table 6-4 Alaska's Tsunami Events Since 2013**

| Date | Location | Earthquake Moment Magnitude (MW) | Wave Height | Source | |
|---|---|---|---|---|---|
| | | | Ft/In M/Cm | Latitude | Longitude |
| January 23, 2018 | Kodiak, Alaska | 7.9 | ~10 Cm | 56.046 | -149.073 |
| October 25, 2013 | Honshu, Japan | 7.1 | < 1 Cm | 37.156 | -144.661 |
| October 27, 2012 | Queen Charlotte Island, (Haida Gwaii), BC | 7.7 | ~6 Cm | 52.788° | -132.101 |
| January 13. 2007 | Kuril Islands | 8.1 | Undefined | 46.230 | -154.550 |
| June 10, 1996 | Andreanov, Alaska | 7.9 | ~ 3 Cm | 51.593 | -51.593 |

## 6.5.3. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location and Extent*

Alaska has a long earthquake and tsunami history, as documented by both the geologic and historic record. Tsunami threats vary by location along the coastline, by distance from the tsunami source, and according to the type of disturbance that generates the tsunami. Communities located on the open coast of Alaska Peninsula, Aleutian Islands and Southcentral Alaska all may experience local, regional, and distant tsunamis. Local landslide-generated tsunamis are more likely to occur near mouths of rivers draining into the ocean, glacial moraines, and other areas with high sedimentation rates. Even if there is no significant over-land inundation, tsunamis can generate dangerous ocean currents in narrow passages, straits, breakwaters, and near the tips of peninsulas.

Many communities believe their relatively protected location on the inward side of an island – away from Aleutian Trench, Queen Charlotte Fault zone or other open ocean created tsunami sources would protect them from severe impacts. However these perceived protected locations may be hit by significant waves propagating around the islands and through narrow channels. The 2011 Tohoku tsunami, originated in Japan, was registered both in Skagway and Juneau.

NOAA Center for Tsunami Research, PMEL describes their tsunami forecasting process through their real-time Deep-ocean Assessment and Reporting of Tsunami (DART) buoy system depicted as red triangles in Figure 6-65.

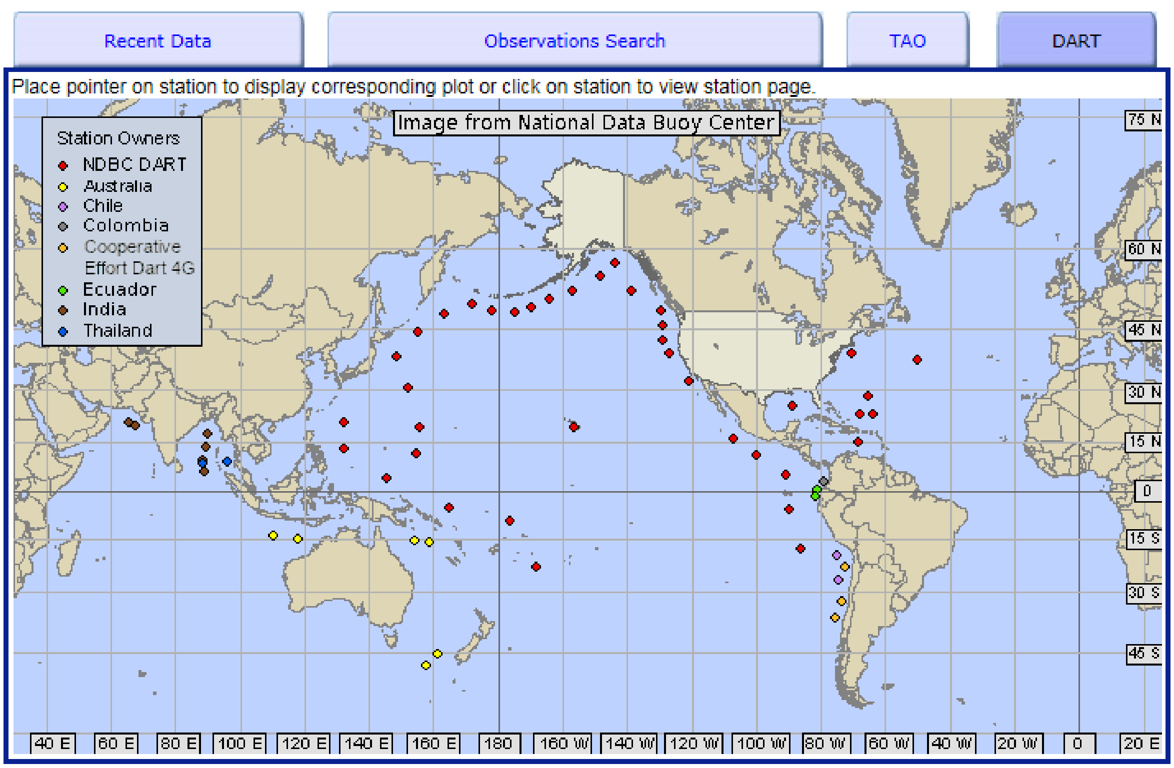



**Figure 6-65 NOAA DART Locations (July 2018)**
*Source PMEL, 2018: https://nctr.pmel.noaa.gov/Dart/*

The DART buoy system and other operational tools provide critical real-time threat data to enable emergency managers to anticipate potential impacts. The NOAA Tsunami Warning Centers use the "Short-term Inundation Forecasting for Tsunami" (SIFT) system to quickly estimate tsunami information as it travels through the open ocean. Figure 6-66 provides a representation of the SIFT forecasting process.

***SIFTView***

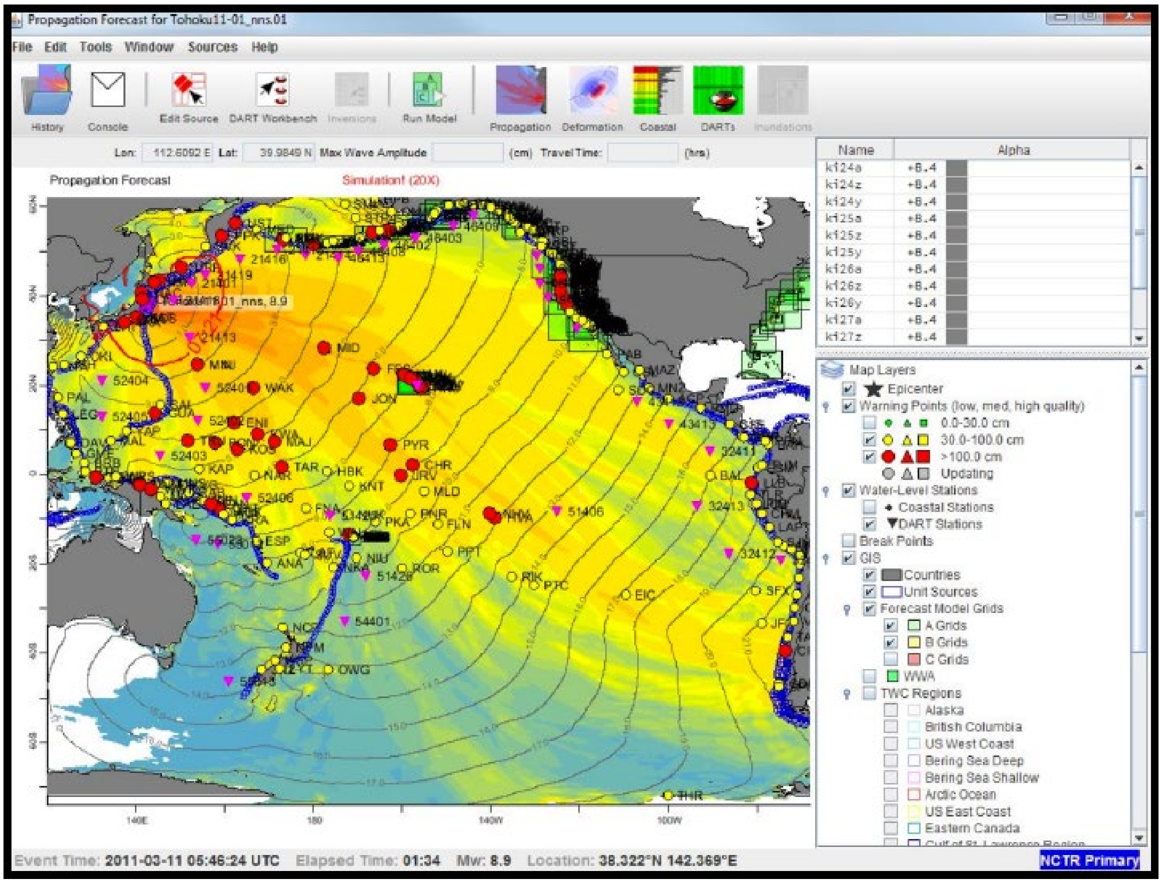



**Figure 6-66 SIFT Forecast Landfall Locations and Impacts**

*Primary **SIFTView** window, the propagation forecast map. Icons along the top provide access to SIFT utilities and tools. Source SIFT, 2018 https://nctr.pmel.noaa.gov/Pdf/brochures/sift_Brochure.pdf*

The UAF/AEC tsunami inundation map website lists (Table 6-5) the following inundation map in draft form ("draft," "draft-low resolution," or, "in-review"):

**Table 6-5 Tsunami Inundation Maps - Status**

| Community | Status | Community | Status | Community | Status |
|---|---|---|---|---|---|
| Adak | ** | Karluk | ** | Port Graham | ** |
| Akhiok | ** | Ketchikan | ** | Port Lions | ** |
| Anchor Point | ** | Larsen Bay | ** | Saint George | * |
| Atka | ** | Nanwalek | ** | Saint George Airport | * |
| Chiniak | ** | Nelson Lagoon | ** | Saint Paul | * |
| Craig | ** | Old Harbor | ** | Seldovia | + |

**Table 6-5 Tsunami Inundation Maps - Status**

| Community | Status | Community | Status | Community | Status |
|---|---|---|---|---|---|
| Dillingham | ** | Ouzinkie | ** | Shemya | ** |
| False Pass | ** | Perryville | ** | Skagway | + |
| Haines | + | Platinum | ** | | |
| Homer | + | Port Alexander | ** | | |

**Key:** * Draft, ** Draft, Low Resolution, + In Review
*Source: AIC - https://earthquake.alaska.edu/tsunamis/atom*

The UAF/AEC tsunami inundation map website lists the following inundation map depicting "flow," "max estimated inundation area," and/or with "Scenarios" (Table 6-6):

**Table 6-6 Tsunami Inundation Maps No Status Indicated**

| Community | Status | Community | Status | Community | Status |
|---|---|---|---|---|---|
| Akutan | * / ** | Juneau | ** | Tatitlek | * / ** |
| Chenega | ** | King Cove | ** | Unalaska | * / ** / + |
| Cold Bay | ** | Kodiak | ** | Valdez | * / ** / + |
| Cordova | ** | Nikolski | ** | Whittier | * / ** |
| Elfin Cove | ** | Sand Point | ** | Yakutat | ** |
| Gustavus | ** | Seward | * / ** / + | | |
| Hoonah | ** | Sitka | * / ** | | |

Key: * Flow Depth, **Max estimated Inundation Area, + Scenarios
*Source: AIC - https://earthquake.alaska.edu/tsunamis/atom*

### *Impact*

Alaska is subject to diverse tsunami impacts from a multitude of tsunamigenic sources. Potential impacts of tsunamis on Alaska communities are described in a series of modeling and mapping reports, which are available at the DGGS web-site (http://dggs.alaska.gov/pubs/tsunami). Potential impacts span the entire range of possibilities--from a barely detectable tsunami to completely destructive.

### *Recurrence Probability*

Because tsunamis that affect Alaska's coast can be generated by a number of phenomena, none of which themselves can be predicted, it is impossible to define a recurrence probability for tsunamis. However, the active geology of Alaska guarantees that there will be tsunamis in the future.

# 6.6. VOLCANO

## 6.6.1. HAZARD CHARACTERISTICS

Volcanoes are openings on the earth's surface where magma and gases escape from the subsurface. Lava flows and lava fragments (tephra) that are ejected from the openings, or vents, build the landforms we know of as volcanoes. A volcano vent connects to one or more linked underground storage areas of molten or partially molten rock (magma) through a series of cracks within and beneath the volcano. Magma originating many tens of miles beneath the ground forces its way upward by pressure from gas within it. Magma is lighter, less dense, and more buoyant than surrounding solid rock. It may ultimately break through weak areas to reach the surface; if so, an eruption begins. The connection to fresh magma allows a volcano to erupt over and over again in the same location.

The Alaska landscape has been profoundly shaped by volcanic processes. An average of one to two eruptions per year occurs in Alaska. During the last 2 million years, more than 130 volcanoes or volcanic fields have been active within the state (6-67). Of these volcanoes, about 90 have been active within the last 10,000 years (and might be expected to erupt again), and more than 50 have been active within historical time (since about 1760, for Alaska).


**Figure 6-67 Alaska's Historically Active Volcanos** *Source: DGGS/AVO 2018*

In 1912, the largest eruption of the 20th century occurred at Novarupta and Mount Katmai, located in what is now Alaska Peninsula's Katmai National Park and Preserve. These young volcanoes primarily stretch from the Wrangell Mountains to the far-western Aleutians (Figure 6-77). Volcanoes in Alaska and Russia have the potential to permanently displace entire communities and disrupt all travel modes (Figure 6-68).

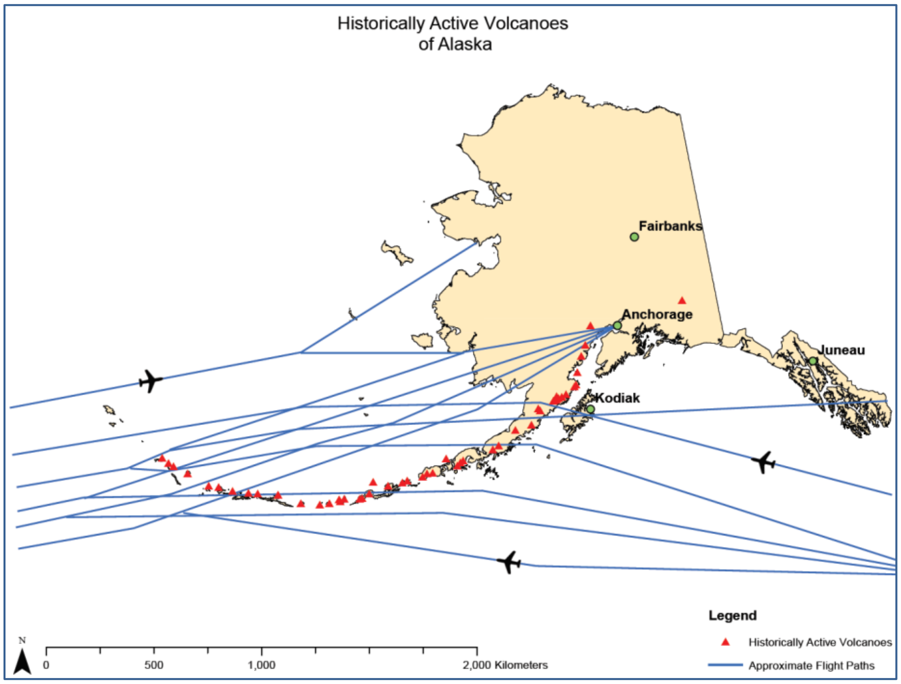



**Figure 6-68 Simplified Flight Paths of the North Pacific**

*Simplified illustration of approximate flights paths traveling over the historically active volcanoes of Alaska. Aircraft flying along these routes, some of the busiest in the world, carry more than 50,000 passengers and millions of dollars of cargo each day to and from Asia, North America, and Europe. Source: AVO/USGS* https://www.avo.alaska.edu/volcanoes/hazards.php

The significant trans-Pacific and intrastate air traffic traveling directly over or near Alaska's volcanoes, has necessitated developing strong communication and warning links between the Alaska Volcano Observatory (AVO), other government agencies with responsibility for aviation management, and the airline and air cargo industry.

As of April 2018, the Alaska Volcano Observatory (AVO) maintains monitoring networks on 32 of Alaska's more than 50 active volcanoes. Data from these networks includes seismic, infrasound, and ground deformation information that is recorded and examined for precursory signs of eruptive activity. AVO also examines Alaska volcano satellite images daily for signs of eruptive activity, ash clouds, or possible precursory ground heating. These methods aid in assessing volcanic activity.

### Volcano Types

Volcanoes display a wide variety of shapes, sizes, and behaviors. However, they are commonly classified into three main types: cinder cone, shield, and composite (stratovolcano or stratocone).

**Cinder cones** are the simplest volcano type. They are formed when lava is ejected from a single vent. As the lava is blown into the air, it breaks into small fragments and solidifies into cinders (small pieces) and bombs (chunks larger than 2.5 inches in diameter) before it hits the ground. These fall out of the air and accumulate around the vent to form a circular or oval cone. Most cinder cones have a bowl-shaped crater at the summit, and rarely rise more than a thousand feet above the ground surface. Cinder cones may form as flank vents on the sides of larger volcanoes, such as Aniakchak and Okmok volcanoes.

**Shield volcanoes** are formed of very fluid lava flows that accumulate to form broad, gently sloping volcanoes. The most famous shield volcanoes are the Hawaiian Islands. Wrangell, Yunaska, and Westdahl are examples of Alaska's shield volcanoes.

Most Alaska volcanoes are of composite type, for example, the Cook Inlet volcanoes: Iliamna, Redoubt, Spurr, and Augustine. **Composite volcanoes,** sometimes called stratovolcanoes, are typically steep-sided, large, symmetrical cones built by layers of lava, ash, and cinders. Composite volcanoes tend to erupt explosively because of the viscous magma within the volcano. Some volcanoes in Alaska exhibit evidence of having previously had explosive eruptions large enough to deplete underlying magma chambers, resulting in summit collapse and the formation of a caldera (i.e., a large, basin-shaped volcanic depression with a diameter many times larger than included volcanic vents). Caldera-forming eruptions are among the largest eruptions on earth. The 1912 eruption of Novarupta in Alaska is only one of several caldera-forming eruptions that have occurred since the 20$^{th}$ century.

### Volcano Hazards

Volcanoes produce a wide variety of hazards (Figure 6-69) that can kill people and destroy property. Large explosive eruptions can endanger people and property hundreds of miles away, and even affect global climate. Some volcanic hazards, such as landslides, can occur even when a volcano is not erupting.

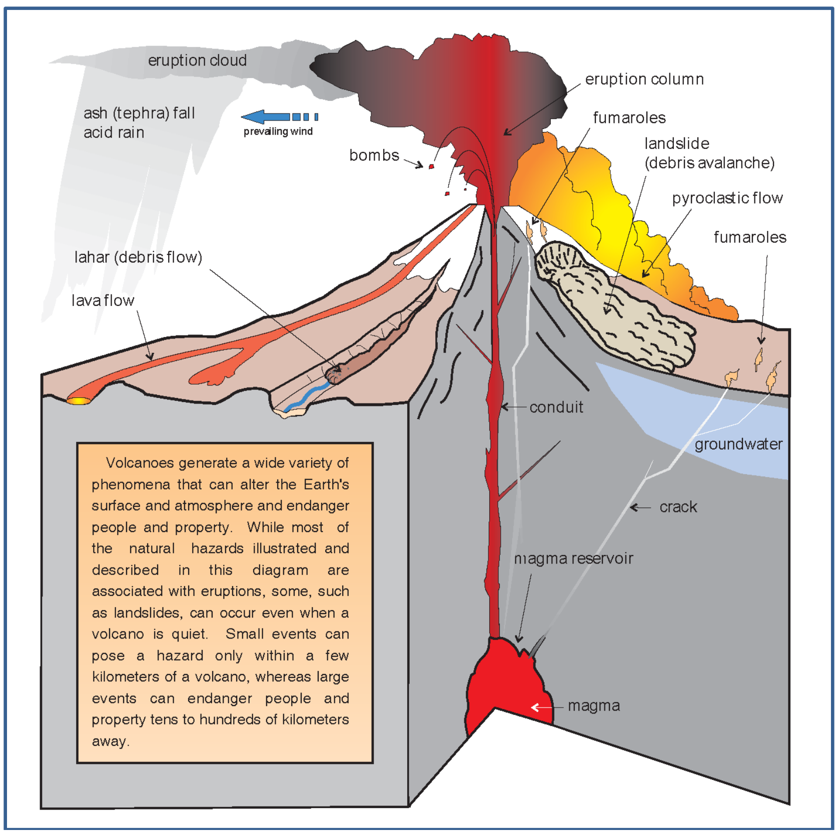



**Figure 6-69 Simplified Sketch of a Stratocone and Associated Eruption Hazards**
*Depicted phenomena do not necessarily occur simultaneously during a particular eruption.*
*Source: USGS 2018*

The major volcanic hazards are shown in Table 6-7.

**Table 6-7 Major Volcanic Hazards**

| | | |
|---|---|---|
| • Volcanic Ash Cloud | • Lahar | • Lava Flow |
| • Volcanic Ashfall | • Pyroclastic Density Current | • Ballistics |
| • Volcanic Gases | • Debris Avalanche | • Directed Blast |
| • Acidification | • Rockfall and Landslide | • Tsunami |

A ***Volcanic Ash Cloud*** is created when volcanic ash is explosively blasted high into the atmosphere during an eruption and then drifts away from the volcano with the wind. This is Alaska's principal future volcanic hazard associated with explosive eruptions. Ash-rich clouds produced during large eruptions can reach heights of 30,000 to 65,000 feet or more above the volcano, although most Alaska eruptions are smaller (a few thousand feet to 20,000 feet). Prevailing North Pacific winds usually carry ash clouds eastward from the volcano, but dispersal in other directions is possible, depending on wind patterns at the time of the eruption.

Alaska airspace is extremely busy with long-range, wide-body aircraft, as well as bush planes and smaller aircraft. The Ted Stevens Anchorage International Airport is the fifth-busiest cargo airport in the world. More than 50,000 people fly over or very near Alaska volcanoes as they travel the North Pacific (NOPAC) and Russian Far East air routes. Alaska's unique geographic location generates high air traffic volume—all direct air routes between the U.S. (even Los Angeles and New York) and Asian cities, such as Tokyo and Hong Kong, pass along the NOPAC routes. Most of the aircraft carrying freight between Europe and Asia come through Alaska for refueling, so a considerable percent of all air freight on earth passes near Alaska's many volcanoes (Figure 6-68).

Encounters between aircraft and volcanic ash are serious because the ash can cause severe damage to the engines as well as other equipment. Volcanic ash is abrasive, and melts at the high operating temperatures of modern jet engines. When ingested into a jet engine, volcanic ash erodes turbine blades, and the melted ash can adhere to critical parts, causing engine failure. Any forward-facing surface of an airplane engulfed in a volcanic ash cloud is likely to be eroded, including the cockpit, forward cabin windows, and landing-light covers. Cockpit windows may be abraded enough to prevent forward visibility. Ash entering sensitive electronics can interfere with navigation and other onboard systems. A flight crew may also lose the ability to transmit a distress call due to ash cloud electrical disturbances. Sulfur and other gases released in large eruptions also affect aircraft and their occupants. Acidic aerosols formed by the hydration of these volcanic gases produce a corrosive mist that causes passenger and flight crew respiratory problems, and accelerates vulnerable aircraft component deterioration. There were at least 79 aircraft-volcanic ash encounters worldwide that resulted in damage to the aircraft between 1953 and 2010. Nine of these encounters resulted in engine shutdown during flight.

Alaska's most serious ash-aviation incident took place on December 15, 1989, when a Boeing 747-400 aircraft temporarily lost power to all four engines after encountering an ash cloud from Redoubt volcano as the airplane descended for a landing in Anchorage. After steeply gliding through a descent of more than 14,000 feet, the pilot was able to restart the engines and land safely in Anchorage. While there were no injuries to passengers, the damage to engines,

avionics, and aircraft structure from this encounter was estimated at $80 million. Recent eruptions of Alaska volcanoes have resulted in numerous flight delays and cancellations for regional and international flights, including eruptions of Augustine in 2005, Kasatochi in 2008, Redoubt in 2009, multiple Pavlof eruptions, and most recently, Bogoslof volcano in 2016 and 2017.

A typical example in Alaska that illustrates aviation impact was the 2008 Okmok eruption on Umnak Island in the Aleutian Islands. On July 12, 2008, Okmok erupted explosively, sending ash to 50,000 feet (Figure 6-70). During successive eruptions over five and a half weeks, the residents of Nikolski were stranded due to flight cancellations. Unalaska/Dutch Harbor, (65 miles northeast) was dusted with ash on several occasions; outbound flights were grounded and inbound flights were diverted elsewhere.

**Figure 6-70 August 3, 2008 Okmok Volcano Eruption Plume**

*This photo was taken from Fort Glenn, Bering Pacific Ranch, on the eastern flank of the volcano.*
*Source: Jess Larsen AVO 2008 image URL: http://www.avo.alaska.edu/images/image.php?id=15392*

***Volcanic Ashfall*** is ash that falls to earth from an eruption cloud. The fragments in the ash cloud vary in size, and the heavier particles fall near the source while finer particles travel farther downwind. Transported ash will fall out of the cloud and accumulate on surfaces and structures, contaminate water sources, and infiltrate electronics and motors. The weight of significant accumulations may collapse structures and cause other damage. Chronic exposure to ash may be a significant public health hazard. Essential items, including dust masks, clean water, non-perishable food, and eye protection, are key in preparation, as significant ashfall may keep people housebound for extended time periods (Figures 6-71 and 6-72).

The largest eruption of the 20th century was the 1912 Novarupta-Katmai eruption, on the Alaska Peninsula. This eruption produced ashfall as far away as Dawson City (Yukon, Canada), Ketchikan (Southeast Alaska), and the Puget Sound in Washington. During the three days of the eruption, darkness and suffocating conditions caused by falling ash and sulfur dioxide gas

immobilized the population of Kodiak, Alaska. Sore eyes and respiratory distress were rampant, and water became undrinkable. Radio communications were totally disrupted, and with visibility near zero, ships could not dock. Roofs in Kodiak collapsed under the weight of more than a foot of ash, buildings were wrecked by ash avalanches that rushed down from nearby hillslopes, and other structures burned after being struck by lightning from the ash cloud. Similar conditions prevailed elsewhere in southern Alaska, and several villages were abandoned forever. Within 50 miles of the erupting vent, animal and plant life was decimated by ash and acid rain. Bears and other large animals were blinded by ash and starved when large numbers of the plants and small animals they lived on were wiped out. Millions of dead birds that had been blinded and coated by volcanic ash littered the ground. Aquatic organisms, such as mussels, insect larvae, and kelp, as well as the fish that fed upon them, perished in ash-choked shallow water. Alaska's salmon-fishing industry was devastated, especially from 1915 to 1919, because of the starvation and failure of many adult fish to spawn in ash-choked streams.


**Figure 6-71 Kodiak Building Partially Buried by Volcanic Ash**

*Photograph of a building in Kodiak partially buried by volcanic ash from the 1912 eruption of Novarupta/Katmai. Source: Amelia Elkinton Collection, accession number UAF-1974-175-399, Archives, Alaska and Polar Regions Collections, Rasmuson Library, UAF; http://vilda.alaska.edu/u?/cdmg11,1191*

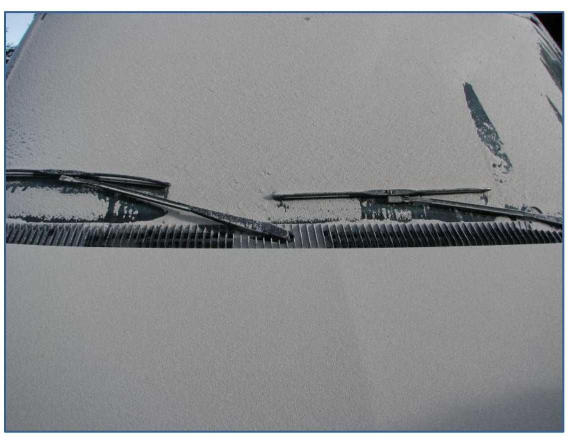


**Figure 6-72 Ashfall on a windshield in Homer, Alaska**

*Ashfall resulted from the April 4, 2009, eruption of Redoubt volcano.*
*Source: Dennis Anderson; AVO-UAF, image URL: http://www.avo.alaska.edu/images/image.php?id=17800*

During the most recent eruptions in Alaska, communities have received no more than trace amounts of ashfall (i.e., 1/32nd of an inch), although even small amounts of volcanic ash have resulted in transportation delays, school and business closures, and presented challenges to power and water systems. Recent eruptions of Cook Inlet volcanoes (Augustine, Spurr, Redoubt) have produced trace amounts of ash to Southcentral Alaska, especially the Kenai Peninsula, resulting in airport, school, and business closures, as well as ash cleanup costs and emergency supply stockpiling. The Kasatochi 2008 eruption deposited a small amount of ash on Adak, and eruptions of Pavlof often result in very minor ashfall on nearby communities. The Okmok 2008 and the Bogoslof 2016-2017 eruptions deposited trace amounts of ash in Unalaska and Dutch Harbor. Looking further back in time, the geologic record clearly shows that many Alaska communities are underlain by significant amounts of volcanic ash from prehistoric eruptions.

***Volcanic Gases*** are corrosive acidic mists that irritate eyes and respiratory systems. The gasses are dissolved in the magma but can be released during eruptions or through passive degassing activity. The gases consist largely of water vapor, carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), hydrogen sulfide ($H_2S$), and chlorine compounds, but may include other substances. Volcanic gases are released by both historically-active and older volcanoes.

Large eruptions can release large amounts of gas in a short period of time. This gas can be transported away from the eruption by wind on ash particles and as aerosols. Acid rain can be produced when high concentrations of these gases are leached out of the atmosphere. This acid rain can affect vegetation, livestock, humans, infrastructure, and machinery. Gases can also collect and be concentrated in topographic lows.

***Acidification*** occurs when a large amount of volcanic gas is dissolved in a water body, producing a highly acidic water volume. Vegetation and wildlife can be greatly affected by this contaminated water source. Acidified water may be transported great distances from the original source.

Between November 2004 and early May 2005, magmatic heat within Chiginagak volcano melted ice and snow on the summit, filling the crater with acidified water. In early May 2005, the water overtopped the crater wall at the base of the summit glacier and the acidic water and sulfurous debris flowed 17 miles downslope and into Mother Goose Lake, the headwaters of the King Salmon River. The flow killed all vegetation in its path and all aquatic life in the lake, preventing the annual salmon run (Figure 6-73). The few fishing lodges and guide services in the area lost revenue. Scientists from various government agencies studied the event and the Alaska Volcano Observatory deployed a data-logging seismometer for about one month but recorded no significant seismicity.

**Figure 6-73 Orange Colloidal Iron-Oxides**

*Colloidal iron-oxide found along the shore of acidified Mother Goose Lake, August 2005.*
*Source: Paul Tickner, AVO-UAF image URL: http://www.avo.alaska.edu/images/image.php?id=4262*

***Lahar*** is an Indonesian term describing a mixture of water and rock fragments flowing down the slopes of a volcano and/or river valleys. Sometimes called volcanic mudflow, a moving lahar looks like a mass of wet concrete consisting of rock debris ranging in size from clay to boulders more than 30 feet in diameter. Lahars vary in size and speed. Small lahars less than a few yards wide and several inches deep may flow a few feet per second. Large lahars hundreds of yards wide and tens of feet deep may flow several tens of feet per second; much too fast for people to outrun. They form in a variety of ways, but are routinely associated with volcanic eruptions (Figure 6-74). Lahars may also form from intense rainfall on loose volcanic rock deposits, breakout of a lake dammed by volcanic deposits, or water-saturated debris avalanches.

**Figure 6-74 Gray Mud, Boulders, and Debris from the April 4, 2009, Lahar**

*Lahar and flood in Drift River Valley, downslope of Redoubt volcano. Note prominent tree scars, and diffuse mud line that is up to 3 feet higher than the tree scars. Source: Chris Waythomas, AVO-UAF 2009. Image URL: http://www.avo.alaska.edu/images/image.php?id=18367*

Lahars are common in Alaska due to the abundance of volcanoes capped with snow and ice. When there is thermal activity at a volcano (either above or below the surface), there is potential for significant melt, producing large water volumes. This water can cause floods or can mix with sediment, ash, and other deposits to form lahars, debris flows, and mud flows.

***Pyroclastic Density Currents***, or "pyroclastic flows," are turbulent avalanches of hot gases and rock, typically traveling more than 50 mph at temperatures of approximately 400°F to 1300°F. They may flow directly from an erupting volcanic vent, form from a collapsing lava dome (a steep-sided mass of viscous and often blocky lava extruded from a vent), or result from the collapse of an eruption column (the ascending, vertical part of the mass of *erupting* debris and volcanic gas that rises directly above a volcanic vent). Pyroclastic density currents incinerate and smother everything in their path, and are among the most hazardous of volcanic phenomena. Pyroclastic flows and surges tend to follow valleys and other low-lying terrain, and can travel over topographic features such as lakes, ridges, and hills.

***Debris Avalanches*** occur when a mass of volcanic rock fragments and soil moving down a steep mountain slope or hillside behaves like a snow avalanche because of its high water content. They can happen without warning and travel quickly. The mass moves as a fluid and can attain speeds of 100 to 180 miles per hour. Their runout may extend many miles, and their high velocity and momentum allow them to cross valleys and run several hundred feet up slopes. Debris avalanches that occur near the coast can generate tsunamis if the debris advances into the water. Washington's Mount St. Helens eruption began as the largest debris avalanche in recorded history. Large debris avalanche deposits are seen in the geologic record at several Alaska volcanoes, including Tanaga, Shishaldin, Okmok, Yantarni, Augustine, Spurr, and Iliamna.

***Rockfall and Landslide*** are volcanic hazards because many volcanoes, and especially caldera walls, are steep-sided and constructed of accumulated products from previous eruptions. This material can be poorly consolidated, heavily weathered, or altered due to volcanic gases, creating unstable slopes that are collapse-susceptible. Earthquakes near or associated with volcanoes can lead to increased rockfall, as well as increased landslide frequency and size.

***Lava Flows***, moving outpourings of molten rock (i.e., lava), commonly erupt from volcanoes in Alaska; however, due to their chemistry, they are often slow moving and usually pose little hazard to humans. Explosions can occur when lava interacts with water, producing ash and other ballistics (e.g., lava or rock projectiles). Many Alaska volcanoes develop very thick lava flows called lava domes. Lava domes form directly at an eruptive vent by extruding slow, viscous lava. Their chemistry varies, although the lava typically has high silica content. A dome often appears as a pile of unstable rubble. Volcanic domes commonly occupy summit craters or the flanks of large composite volcanoes. The Novarupta dome, for example, measures 800 feet across and 200 feet high, and was formed at the end of the 1912 Katmai Volcano eruption (Figure 6-75). The Cook Inlet's 2009 Mount Redoubt eruption produced many lava domes, the largest one measuring 3,300 feet in length, 1,640 feet in maximum width, and at least 650 feet high. The total volume of this 2009 Redoubt lava dome would fill more than 500 Conoco-Philips buildings, which is the tallest structure in Anchorage at 300 feet.

**Figure 6-75 Novarupta Lava Dome from the 1912 Eruption**

*Novarupta is located in Valley of Ten Thousand Smokes, Katmai National Park and Preserve. Source: Jennifer Adleman; AVO 2012. Image URL:* [http://www.avo.alaska.edu/images/image.php?id=3120](http://www.avo.alaska.edu/images/image.php?id=3120)

***Ballistics***, lava or rock projectiles ranging in size from a few inches to tens of feet in diameter, can be produced by explosive volcanic eruptions. These objects usually land within about three miles of the vent. Ballistics can pose a substantial threat to humans and can cause considerable damage. Eruptions that involve magma and water interaction are especially capable of producing ballistics. As hot material comes into contact with water, violent steam explosions will shatter rocks and throw ballistics into the air.

***Directed*** or lateral, ***Blasts*** are eruptions radiating primarily outward from a volcano, as opposed to upward. The shock wave flattens forests and structures, while the super-heated blast debris and gasses disperse over the local area, incinerating and burying everything in their path. The deadly May 18, 1980, Mount St. Helens, Washington, eruption was a lateral blast. Calculations have shown that the blast's initial velocity of about 220 miles per hour quickly increased to about 670 miles per hour. The blast was heard hundreds of miles away in the Pacific Northwest, including parts of British Columbia, Montana, Idaho, and northern California, and caused widespread devastation as far as 19 miles from the volcano.

***Volcanic Tsunamis*** can be created by underwater eruptions, volcanic flank collapses that send large amounts of debris into a water body, or pyroclastic flows entering a water body. Communities surrounding Cook Inlet may be at an increased risk for volcanic tsunamis generated by activity from volcanoes near shore. Augustine volcano in Cook Inlet has generated at least one tsunami with deposits found near Homer.

## 6.6.2. HISTORY

This section describes a brief history of select eruptions in Alaska. For a more comprehensive look at the eruptive history of select volcanoes, the Alaska Volcano Observatory has published

detailed hazard reports for some of the most high-threat volcanoes including Hayes, Spurr, Redoubt, Iliamna, Augustine, Katmai group, Aniakchak, Emmons Lake Volcanic Center (includes Pavlof), Shishaldin, Fisher, Akutan, Makushin, Okmok, Kanaga, and Tanaga. Each report contains a description of the eruptive history of the volcano, the hazards they pose, and the likely effects of future eruptions to populations, facilities, and ecosystems. The reports can be freely downloaded from the Alaska Volcano Observatory website www.avo.alaska.edu, or by direct link at https://avo.alaska.edu/downloads/classresults.php?pregen=haz.

The largest volcanic eruption of the 20th century occurred at the Novarupta Volcano in June 1912. It generated an ash cloud extending over thousands of miles during the 3 day event (Figure 6-76). Within 4 hours of the eruption, the ash reached Kodiak and paralyzed the city (Figure 6-71). Many structures eventually collapsed and some buildings were destroyed by ash avalanches; ash tainted the drinking water and the air. Entire villages on the Alaska Peninsula evacuated, including Katmai and Savonoski. The volcanic ash and acid rain also killed animals and plants; many animals starved to death. The amount of ashfall from this eruption (Figure 6-76 and 6-77) was significantly greater than the recent eruptions of Redoubt, Spurr, and Augustine volcanoes. Fourteen earthquakes of M6 and M7 were associated with this event. An event of similar magnitude in the future is possible at a number of volcanoes along the Aleutian Arc.

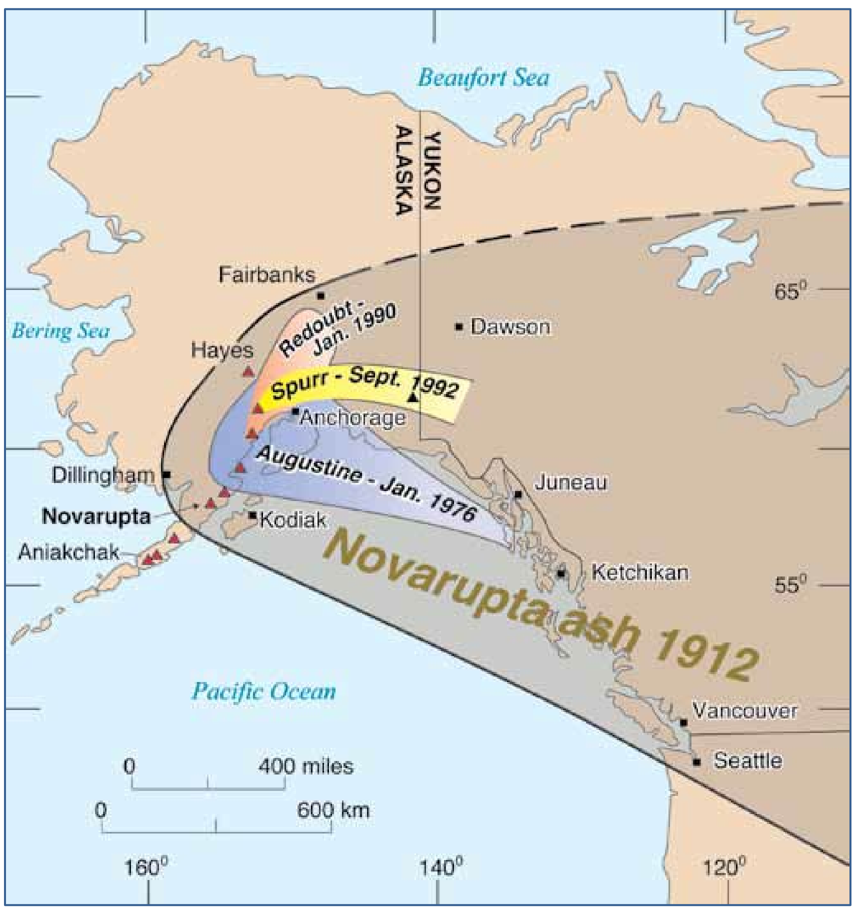



**Figure 6-76 1912 Novarupta Ash Distribution**

*Source, USGS, https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/vhp_img397.png*

**Figure 6-77 1912 Ashfall Remains as a ~1½ Foot Thick Unit Under Organic Material**

*As a result of the 1912 Novarupta eruption, volcanic ash fell on Kodiak Island, ~100 miles to the east. Decades later, this ashfall remains as a ~1-½ foot thick unit under just a few inches of organic material developed since 1912.*

*Source: Jennifer Adleman; AVO image URL: http://www.avo.alaska.edu/images/image.php?id=13227*

Archaeological and geologic evidence suggests that an eruption of Aniakchak volcano 3,500 years ago spread ash over much of Bristol Bay and generated a tsunami which washed up onto the tundra around Nushagak Bay. Within the past 10,000 years, Aniakchak volcano has significantly erupted on at least 40 occasions.

Examples of recent eruptions include Augustine Volcano in 1986 and again in 2005–2006. During both eruptions, repeated ash plumes rose to 30,000 feet above sea level or higher, disrupting air traffic and dusting Cook Inlet communities with ash. A lava dome formed in the summit crater towards the end of each of these eruptions. A concern during both eruptions was the possibility of a flank collapse and debris avalanche into Cook Inlet. Such an event could trigger a tsunami along lower Cook Inlet, as happened in 1883 when a debris avalanche flowed down the north flank of Augustine and into the ocean on the morning of October 6. Sea level rise of up to 20 feet was reported at English Bay across Cook Inlet.

Recent eruptions of Redoubt Volcano occurred in 1989–1990 and again in 2009. During both eruptions, voluminous lahars temporarily closed the Drift River Oil Terminal 27 miles downstream (Figure 6-78). This ash encounter in 1989 resulted in an estimated $80 million in damage to the aircraft. In Alaska, disruption of air transportation is a major issue with volcanoes due to the numerous flight routes across the North Pacific downwind of historically-active volcanoes (Figure 6-67).

**Figure 6-78 Runway, Helipad, and Service Buildings at the Drift River Oil Terminal**

*View west of the runway, helipad, and service buildings at the Drift River Oil Terminal, inundated by lahars from Redoubt Volcano's 2009 eruption. The lahar deposit is at least 20 inches thick at the buildings.*

*Source: Game McGimsey (AVO/UAF); AVO image URL: https://avo.alaska.edu/images/image.php?id=16988*

The 1989-1990 eruption of Mt. Redoubt seriously affected the population commerce, and oil production and transportation throughout the Cook Inlet region.

> *Redoubt Volcano is a strato-volcano located within a few hundred kilometers of more than half of the population of Alaska. This volcano has erupted explosively at least six times since historical observations began in 1778. The most recent eruption occurred in 1989-90 and similar eruptions can be expected in the future. The early part of the 1989-90 eruption was characterized by explosive emission of substantial volumes of volcanic ash to altitudes greater than 12 kilometers above sea level and widespread flooding of the Drift River valley. Later, the eruption became less violent, as developing lava domes collapsed, forming short-lived pyroclastic flows associated with low-level ash emission. Clouds of volcanic ash had significant effects on air travel as they drifted across Alaska, over Canada, and over parts of the conterminous United States causing damage to jet aircraft, as far away as Texas. Total estimated economic costs are $160 million, making the eruption of Redoubt the second most costly in U.S. history (USGS 1998).*

Mt. Spurr's 1992 eruption brought business to a halt and forced a 20 hour Anchorage International Airport closure. Communities 400 miles away reported light ash dustings.

> *Eruptions from Crater Peak on June 27, August 18, and September 16–17, 1992, produced ash clouds (fig. 11) that reached altitudes of 13 to 15 kilometers [8-9 miles] above sea level. These ash clouds drifted in a variety of directions and were tracked in satellite images for thousands of kilometers beyond the volcano (Schneider and others, 1995). One ash cloud that drifted southeastward over western Canada and over parts of the conterminous United States and eventually out across the Atlantic Ocean (fig. 12) significantly disrupted air travel over these regions but caused no direct damage to flying aircraft (USGS 2002)*

In 1992, another eruption series occurred, resulting in three separate eruption events. The first, in June, dusted Denali National Park and Manley Hot Springs with 2 millimeters of ash, a relatively minor event. In August, the mountain again erupted, covering Anchorage with ash, bringing

business to a halt and forcing officials to close Anchorage International Airport for 20 hours. St. Augustine's 1986 eruption caused similar air traffic disruption.

- Small ash clouds from the 2001 eruption of Mt. Cleveland were noted by USGS to have reached Fairbanks. These clouds dissipated somewhere along the line between Cleveland and Fairbanks. A full plume, visible on satellite imagery, was noted in a line from Cleveland to Nunivak Island.

The USGS Fact Sheet 030-97 "Volcanic Ash – Danger to Aircraft in the North Pacific" and the active volcanoes which could easily disrupt air travel during significant volcanic eruptions with ashfall events.

The DGGS Makushin Hazard Assessment, Report of Investigation 2000-4, Figure 8 (Figure 6-79), also depicts how an explosive Makushin Volcano eruption's plumes could impact airline flight routes.

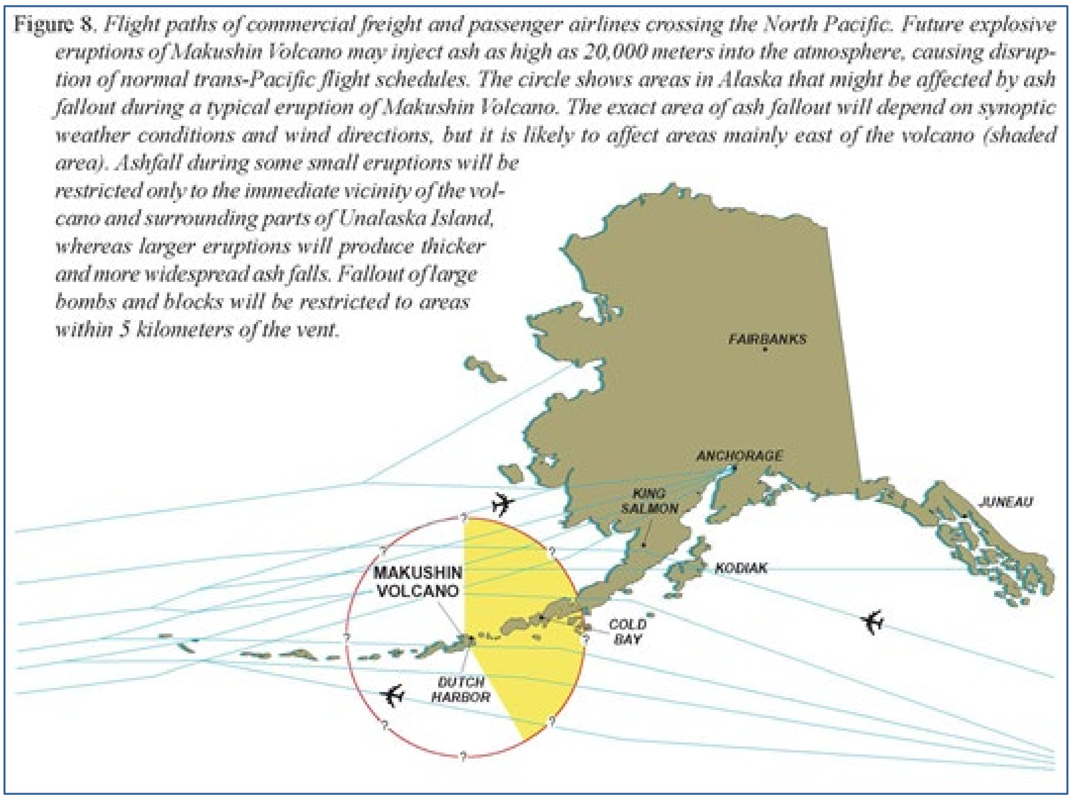



Figure 8. *Flight paths of commercial freight and passenger airlines crossing the North Pacific. Future explosive eruptions of Makushin Volcano may inject ash as high as 20,000 meters into the atmosphere, causing disruption of normal trans-Pacific flight schedules. The circle shows areas in Alaska that might be affected by ash fallout during a typical eruption of Makushin Volcano. The exact area of ash fallout will depend on synoptic weather conditions and wind directions, but it is likely to affect areas mainly east of the volcano (shaded area). Ashfall during some small eruptions will be restricted only to the immediate vicinity of the volcano and surrounding parts of Unalaska Island, whereas larger eruptions will produce thicker and more widespread ash falls. Fallout of large bombs and blocks will be restricted to areas within 5 kilometers of the vent.*

**Figure 6-79 Makushin Volcano Flight Proximity**
*Source, AVO: https://avo.alaska.edu/pdfs/MKhazrpt.pdf*

## 6.6.3. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location*

Alaska is at continual risk for volcanic eruptions from over 50 active volcanoes (Figure 6-68). Most of Alaska's volcanoes are far from settlements that could be affected near-field hazards such as pyroclastic flows and lava flows; however ash clouds and ashfall have historically caused significant impact to Alaska's human populations.

*When volcanoes erupt explosively, high-speed flows of hot ash (pyroclastic flows) and landslides can devastate areas 10 or more miles away, and huge mudflows of volcanic ash and debris (lahars) can inundate valleys more than 50 miles downstream... Explosive eruptions can also produce large earthquakes... the greatest hazard posed by eruptions of most Alaskan volcanoes is airborne dust and ash; even minor amounts of ash can cause the engines of jet aircraft to suddenly fail in flight (USGS 1998).*

### Extent

Geographic ashfall extent along with a record of ashfall layers found in stratigraphic sections illustrate at-risk areas for this hazard. During the last approximately 2 million years, active volcanoes have produced ash clouds that have covered nearly the entire state with at least one significant ash layer (Figure 6-80).

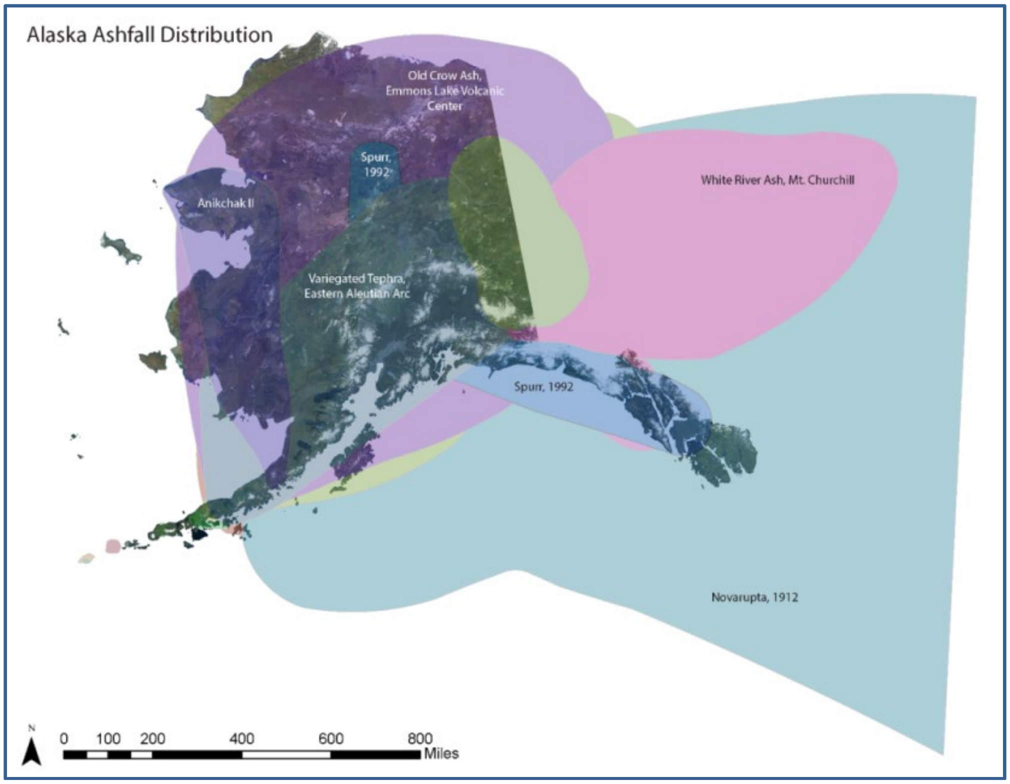



**Figure 6-80 Alaska Ashfall Distribution Map**

*Distribution shows simplified extents of documented volcanic ash (tephra) from more than 39 separate eruptive events, compiled from previously published sources. Selected large ash distributions are labeled. Separate ashfall events are denoted in different colors. Not all overlapping ashfalls are visible in this map. Source: Mulliken et al. 2018*

Geologic deposit investigations across the state have identified locations where more than 30 individual ashfall events have occurred (Figure 6-81). This record is a significant "at-risk indicator" for future ash events. For example, there are locations near Dutch Harbor that have received over 40 separate ashfall events over the last 8,000 years as indicated by separate layers of tephra ("tephra count") preserved in the soil. Small communities along the Alaska Peninsula and Aleutian Islands are at risk from volcanic eruptions for extended time periods. Regional periodic eruptions may severely impact seasonal and subsistence lifestyles.

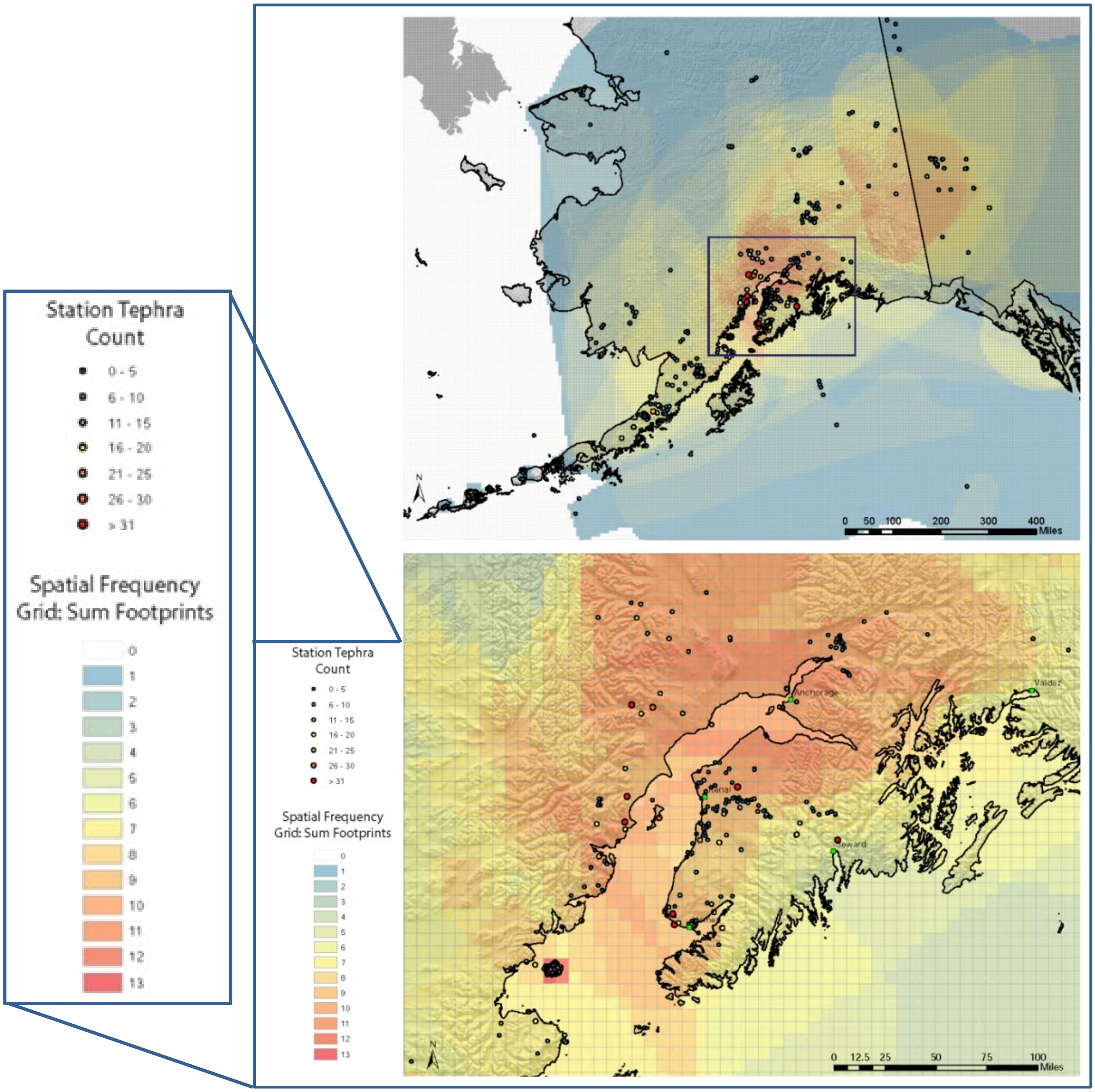



**Figure 6-81 Tephra Occurrence Layer Maps**

*Tephra occurrence information compiled from investigations of geologic deposits throughout Alaska. Inset map highlights Cook Inlet region. Colored dots represent the number of discrete tephra layers seen at each location. Colored grid indicates number of tephra footprints recorded for the area. Source: Mulliken et al. 2018 and DGGS staff, 2018 written communication.*

Alaska residents will likely experience ashfall during a massive volcanic eruption. A tsunami is possible if the eruption included a massive, high speed pyroclastic flow into the open ocean or adjacent large water body. A much more likely affect would be caused by drifting ash clouds that would result in prolonged traffic disruptions (air, land, or rail) preventing essential community

resupply (e.g. food and medicine delivery), and medical evacuation service capabilities to full service hospitals.

A massive eruption anywhere on earth, as depicted in Figure 6-82, could severely affect the global climate; radically changing everyone's long-term weather event risks for weeks, months, or years.

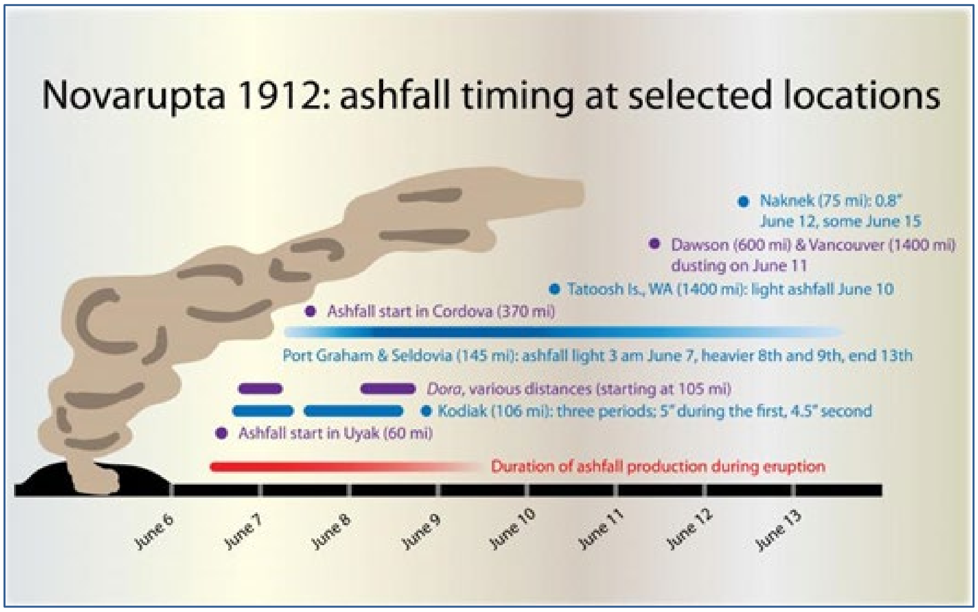



**Figure 6-82 Novarupta's Historic Ashfall Timeline**
*Source, AVO 2012: https://www.avo.alaska.edu/images/image.php?id=42381*

### Impact

Over the last few hundred years, an average of one to two eruptions occur each year in Alaska. Eruptions in the western Aleutian Islands impact local and trans-Pacific aircraft. Eruptions near or within Cook Inlet have the potential to impact a significant portion of the state's population and infrastructure. An ashfall event would undoubtedly be devastating to Alaska residents by straining its resources as well as transportation (air, ocean, land, and rail routes); especially if other hub communities are also significantly affected by a volcanic eruption. Residents would likely experience respiratory problems from airborne ash, personal injury, and potential residential displacement or lack of shelter with general property damage (electronics and unprotected machinery), structural damage from ash loading, state/regional transportation interruptions, loss of commerce, as well as water supply contamination.

These impacts can range from inconvenience, a few days with no transportation capability; to disastrous, heavy, debilitating ashfall throughout the state, forcing residents to be completely self-sufficient.

### Recurrence Probability

Geologists can make general long-term forecasts associated with individual volcano activities by carefully analyzing past activity, but these are on the order of trends and likelihood, rather than specific events or timelines. Short-range forecasts are often possible with greater accuracy.

Several signs of increasing activity can indicate that an eruption will follow within weeks or months. Magma moving upward into a volcano often causes a significant increase in small, localized earthquakes, and measurable carbon dioxide and compounds of sulfur and chlorine emissions increases. Shifts in magma depth and location can cause ground level elevation changes that can be detected through ground instrumentation or remote sensing.

# 6.7. WEATHER, SEVERE

## 6.7.1. HAZARD CHARACTERISTICS

This section defines Alaska's weather-related hazard threats, which influence Alaska's weather, and defines or explains each weather event's characteristics, location, extent (impact areas), actual or potential impacts or damage, and their general recurrence probability. Damaging weather impacts occur from seasonal, as well as sudden, climate change related conditions. Climate change affects all weather related events such as:

- Heavy rain
  - Freezing rain
  - Ice storms
- Extreme Cold
- Winter storms
- High Winds
- Storm Surge
- Ivu
- Excessive Snowfall
  - Drifting Snow
- Hail
- Thunderstorms and Lightening
- Tornadoes
- Water Spouts

### 6.7.1.1. CLIMATE CHANGE INFLUENCES

In contemporary usage, climate change commonly refers to the change in global or regional climate patterns that spans from the mid- to late 20th century to the present. Evidence collected by scientists and engineers from around the world tells an unambiguous story: the planet is warming. Climate change at high northern latitudes, such as Alaska, is causing rapid and severe environmental change.

Alaska's temperature rise rate has been twice the average of the rest of the U.S. in recent decades. During the period from 1949 to 2014, the statewide average annual air temperature increased by 3°F and average winter temperature increased by 6°F (ACRC 2018). This included considerable annual and regional variability, and was accompanied by a greater number of extremely warm days and fewer extremely cold days (CCSP 2008). The statewide average annual precipitation during this same period has increased by about 10 percent, with recent decades showing amounts largely above normal throughout Alaska, but with substantial annual and regional variability. S*ources: Shulski and Wendler 2007; ACRC, 2018*

Global climate is projected to continue changing over this century, and changes to Alaska's climate are expected to be unprecedented (Chapin et al. 2014). Average annual temperatures in Alaska are projected to rise by an additional 2°F to 4°F by 2050, and by 6°F to 12°F by the end of the century (depending on emission levels; Stewart et al. 2013). Projections of annual precipitation show an increase across Alaska as part of the broad pattern of increases projected for high northern latitudes.

The state's rapidly changing climate impacts are already pronounced, and will intensify as climate continues to change. The societal impacts of a changing climate are exacerbated as the frequency and magnitude of the physical processes that control climate-related natural hazards are amplified, threatening community resilience and increasing natural hazard vulnerability of infrastructure and property.

Alaska's glaciers are in steep decline and are among the fastest-melting glaciers in the world. Increases in the duration and intensity of melt on glaciers will lead to more runoff and flooding

in some catchments and declining dry-season flow in others as water storage is reduced. As glaciers continue to melt, an increase in glacial lake outburst floods is expected.

Arctic sea ice extent has decreased dramatically and is now declining at an accelerated rate. This is leading to ice-free conditions during intense coastal storms that enhance flooding and erosion, in particular accelerating erosion of ice-rich coastal terrain.

Snow cover extent and depth have been decreasing in most places in Alaska for nearly three decades. Warmer winter temperatures change the precipitation frequency of snow and rain, and are producing more frequent rain-on-snow events that increase avalanche hazards.

Permafrost has warmed by several degrees in northern Alaska and has already started thawing in many other parts of the state. Thawing permafrost will impact many communities and thousands of miles of road as landscape water balances shift and subsidence occurs.

As the distribution and frequency of snow, ice, and permafrost continue to change, slopes become more unstable, increasing the probability of large, damaging landslides and erosional events that threaten infrastructure and public safety.

**Climate change** is described as a phenomena of water vapor, carbon dioxide, and other gases in the earth's atmosphere acting like a blanket over the earth, absorbing some of the heat of the sunlight-warmed surfaces instead of allowing it to escape into space the more gasses, the thicker the blanket, the warmer the earth. Trees and other plants cannot absorb carbon dioxide through photosynthesis if foliage growth is inhibited. Therefore, carbon dioxide builds up and changes precipitation patterns, increases storms, wildfires, and flooding frequency and intensity; and substantially changes flora, fauna, fish, and wildlife habitats.

The governor's Alaska's Climate, Ecosystems and Human Health Work Group is tasked with determining how the changing ecosystems may impact human health and to identify, prioritize, and educate Alaskans about the connection between their health and changing environmental patterns.

**Extreme Cold** varies according to a region's normal climate; near freezing temperatures are considered "extreme" in areas unaccustomed to winter weather. Extreme cold usually involves temperatures between -20 to -50°F in Alaska. Excessive cold may accompany winter storms or can occur without storm activity during clear skies with high barometric pressure. Extreme cold accompanied by wind exacerbates exposure injuries such as frostbite and hypothermia.

Extreme cold interferes with infrastructure across Alaska for days or sometimes weeks at a time. Liquid fuels may congeal or freeze denying motorized transportation, heat, and electricity generation. In desperation, some people choose to burn propane stoves indoors, increasing their risk to carbon monoxide poisoning. Aircraft may be grounded, delaying the resupply to remote villages. Water and sewer pipes often freeze and rupture, flooding occurs later when they thaw.

**Winter Storms** include a variety of phenomena described above and as previously stated may include several components such as wind, snow, and ice storms. Ice storms include freezing rain, sleet, and hail can be the most devastating of winter weather phenomena; often causing automobile accidents, power outages, and personal injury. Freezing rain coats every surface it falls on with an icy glaze. Freezing rain most commonly starts in a narrow band on the cold side of a warm front, where surface temperatures are at or just below freezing temperatures. Ice

crystals high in the atmosphere grow by collecting water vapor molecules, sometimes supplied by evaporating cloud droplets. As the crystals fall, they encounter a layer of warm air where they particles melt and collapse into raindrops. As the raindrops approach the ground, they encounter a layer of cold air and cool to temperatures below freezing.

**Heavy or Excessive Snow** accumulation of more than 12 to 24 inches inside of 24 hours will immobilize a community and bring transportation to a halt. Airports and major roadways will close, disrupting supply flow and emergency response service access. Excessive accumulation will collapse roofs, knock down trees and power lines, damage parked light aircraft, and capsize small boats. Heavy snow dramatically increases avalanche and flooding risks. Snow removal, damage repairs, and business loss will financially impact communities. Heavy snow is associated with vehicle accidents, overexertion, hypothermia, and lost travelers. Heavy snow is most common in coastal areas and is rarely experienced in interior Alaska.

**High Winds** in excess of 60 miles per hour (mph) occur frequently over the coastal areas along the Bering Sea and the Gulf of Alaska. They can also combine with loose snow to produce blizzards. Alaska's high wind can equal hurricane force but fall under a different classification because the winds are not cyclonic, nor do they possess other hurricane characteristics. High winds occur when there are winter low-pressure systems in the North Pacific Ocean and the Gulf of Alaska, and in the interior due to strong pressure differences.

Down slope wind storms created by temperature and pressure differences on mountainous terrain can produce winds in excess of 120 mph. Areas like the Coast Mountains, Brooks Range, and the Alaska Range experience down slope winds.

Localized downdrafts, downbursts, and microbursts, are also common wind hazards in Alaska. Downbursts and microbursts are often generated by thunderstorms. Downbursts are areas of rapidly falling rain-cooled air. Upon reaching the ground, the downburst spreads out in all directions in excess of 125 mph. Microbursts are smaller scale, more concentrated downbursts reaching speeds up to 150 mph. Both types of wind, commonly lasting 5 to 7 minutes, are hazardous to aviation. These winds reach hurricane force and have the potential to seriously damage port facilities, impact the fishing industry, and cause damage to community infrastructure (especially above ground utility lines) while disrupting vital marine transportation.

**Ice Storms (Freezing Rain)** describe occasions when excessive ice accumulations are expected during a freezing rain event. They are a particularly hazardous winter weather phenomena and often cause numerous automobile accidents, power outages, and personal injury. Ice storms form from freezing rain it passes through a thin layer of cold air just above the ground, it cools to below freezing. The drops remain in a liquid state until they impact a surface and freezes on contact.

**Hail.** Thunderstorms produce hail in ball or irregular shapes greater than 0.75 inch in diameter. The size and severity of the storm determine the size of the hailstones. Unlike the hail in mid-western states, Alaskan hail is small (pea-sized) and fairly rare. The extreme atmospheric conditions necessary to generate damaging sized hail (greater than 0.75 inch diameter) are highly unusual in Alaska.

**Thunderstorms** hazards are lightning, heavy rain, snow, updrafts, downdrafts, severe aircraft turbulence and icing, damaging hail, high winds, and flash flooding. A thunderstorm is

considered severe if winds reach or exceed 58 mph, it produces a tornado, or generates surface hail at least 1 inch in diameter. Thunderstorms affect relatively small areas the average thunderstorm is about 15 miles in diameter and lasts less than 30 minutes in any given location.

Lightning exists in all thunderstorms. It is formed from built-up charged ions within the thundercloud. Lightning is hazardous to humans and frequently start wildfires.

Most thunderstorms in Alaska are usually the single-cell or pulse variety developing from a combination of atmospheric instability and moisture; triggered by surface heating from the sun. The storms generally last only 20-30 minutes and do not usually produce severe weather. Pulse thunderstorms occasionally produce high winds, hail, or weak tornadoes. Multi or super cell thunderstorms and squall line tornadoes are rare events in Alaska.

One of the most common hazard impacts from thunderstorm activity in Alaska is wildland fire in Alaska interior's northern boreal forests. The Bureau of Land Management (BLM) lightning activity sensors positioned across the interior locate an average of 26,000 cloud-to-ground lightning strikes per year. Very active thunderstorm days may feature 8,000 to 12,000 lightning strikes, mainly occurring during the late afternoon hours from the end of June to the beginning of July. Lightning strike wildfires are much less prevalent in the coastal region than in the interior, because the frequency of storms is smaller and the climate is much wetter.

In a typical year, Alaska has fewer than 25 days with thunderstorms and they do not occur uniformly over the state. A majority of the storms occur over a region between the Yukon and Tanana rivers during the warmest summer months. The most active area for lightning strikes is the White Mountains, north of Fairbanks. Other areas experiencing frequent thunderstorms are the Yukon-Tanana uplands and flats, the Nowitna, Tetlin, and Kantishna River Flats, the Ray Mountains, and the Kuskokwim Mountains.

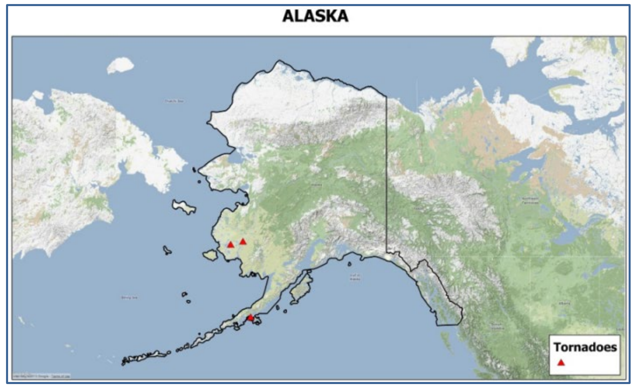
Thunderstorms are also observed along the southern coastal areas, with a higher frequency along the eastern Gulf of Alaska coast between Cordova and Craig. Interestingly, these storms occur during the winter months as well as during summer. Lightning caused injuries and deaths are unusual in Alaska; however, in 1986, one person was killed and three others injured near Tok, when they took shelter under a tree that was struck by lightning.

**Tornadoes** are rare in Alaska. They most frequently occur in the Yukon-Kuskokwim Delta. Of the five tornado damage potential categories (Fujita Scale 1-5), Alaska tornadoes rarely exceed the lowest level, but have the potential to cause damage or casualties when they touchdown in developed areas. Waterspouts, the spinning upward movement of water through wind action, are more common in Alaska and occur in all southern maritime areas of the state. Damage occasionally results from the vortices' action on property.

Low pressure cyclones develop in the Bering Sea and Gulf of Alaska, where warm moist air from the South Pacific meets cold air from the Arctic. Coastal storms are born in the Aleutians and delivered to the Alaska coast. They are most common from the fall through the spring and are known to cause coastal flooding and erosion (Figure 6-42, page 6-53).

In Tornado Climatology, June 26, 2013, Ms. Kathryn Prociv describes Alaska tornado impacts:

> *Out of all 50 states, Alaska is the state that has the lowest number of recorded tornadoes. There have only been four recorded tornado events since 1950, the last of which*




*occurred on August 25th, 2005. All tornadoes have been rated at the F/EF0 level. Referring to the map, the majority of the tornadoes have occurred in the southwestern part of the state, where the terrain is flatter and the climate is moderated and more maritime in nature due to proximity to the Gulf of Alaska…*

*Basically, Alaska is not a tornado state — it currently experiences one tornado roughly once every 15 years."*
*Source: U.S. Tornadoes 2013:* *https://www.ustornadoes.com/2013/06/26/u-s-tornadoes-that-occur-outside-the-u-s-the-continental-u-s-that-is/*

Residents in Sand Point on the Alaska Peninsula witnessed a short-lived tornado in 2005. In December, 2007, cold air funnels caused damage north of Juneau when they went over water and became a series of waterspouts.

**Waterspouts** are similar to tornados that occur over water. Communities along the Bering Sea, Bristol Bay, Cook Inlet, and Koyuk areas, as well as other Alaska locations witness water spouts and are concerned they could disrupt shipping and eventually approach land, threatening their fairly fragile infrastructure.

*What is a water spout? A water spout is a whirling column of air and water mist. Water spouts fall into two categories: fair weather waterspouts and tornadic waterspouts.*

*Tornadic waterspouts are tornadoes that form over water, or move from land to water. They have the same characteristics as a land tornado. They are associated with severe thunderstorms, and are often accompanied by high winds and seas, large hail, and frequent dangerous lightning.*

*Fair weather waterspouts usually form along the dark flat base of a line of developing cumulus clouds. This type of waterspout is generally not associated with thunderstorms. While tornadic waterspouts develop downward in a thunderstorm, a fair weather waterspout develops on the surface of the water and works its way upward. By the time the funnel is visible, a fair weather waterspout is near maturity. Fair weather waterspouts form in light wind conditions so they normally move very little."*

*Source NOAA, 2018:* *https://oceanservice.noaa.gov/facts/waterspout.html?_sm_au_=iVV7VMPsW24tR516*

The NWS shared waterspout events along Turnagain Arm near Anchorage, Alaska on July 20, 2014:

*Check out these pictures of a Waterspout observed this morning over Turnagain Arm! These pictures were taken from this morning by Anchorage residents along the hillside.*

*Waterspouts like this, while rare, are not an unheard of sight to see over Alaskan waters. They have been observed in the past over the Bering Sea and Southwest coast, as well as in the Panhandle.*

*While the pictures may look similar to that of a Tornado or funnel cloud typically seen in areas of the Lower 48, these Waterspout's are created differently. Visit this page made by our friends at the National Ocean Service to learn how fair weather Waterspouts such as this are created, and how they are different from a Tornado.*

*Source: Photos taken from the Anchorage Hillside toward Turnagain Arm, by Derek Reynolds, https://www.facebook.com/NWSAlaska/posts/708132242573505*

*Source: Turnagain Arm Funnel Cloud July 20, 2014 by Jon-Michael Graham, [https://www.facebook.com/Channel2Weather/photos/a.10152149282076104/10152149282391104/?type=3&theater](https://www.facebook.com/Channel2Weather/photos/a.10152149282076104/10152149282391104/?type=3&theater)*

Ruben Lipinski, an Anchor Point, Alaska resident described his sighting as reported by Jenny Neyman, Redoubt Reporter:

> *Robin Lipinski is used to the unusual when looking out over Cook Inlet. Endlessly variable vistas are part of why he lives where he does, about three miles north of the Anchor River, in Anchor Point, overlooking the inlet.*
>
> *'You never know what you're gonna see out there, either ship traffic or weather," Lipinski said…*
>
> *A 30-foot-diamater waterspout, whirling to life midinlet and sweeping toward shore, gorging itself on water sucked from the surface, spewing spray 40 to 50 feet in the air. If it had been on land, Lipinski figures it was strong enough to rip tin off a roof.*
>
> *'It was a big white funnel that was hanging off the bottom of the cloud, then you could see it moving toward the east. The water was really just boiling," Lipinski said. "If there were any little minnows on the surface of the water they went for a ride...*
>
> *One side of the inlet was sunny, the other side of the inlet where the funnel was coming from was one of those big cumulonimbus clouds — one of those big thunderhead-looking things. It was actually pretty warm, and I think that's why it formed. I think it was hot meeting cold," Lipinski said. "It's this time of year, I guess, when the weather's changing. It's winter one day, summer the next.'…"*

The article went on to say that,

> *Dave Stricklan, a hydro-meteorological technician at the National Oceanic and Atmospheric Administration forecast office in Anchorage, said waterspouts are unusual, but not unheard of, in Alaska.*
>
> *'It's kind of rare. We don't see a whole lot of them," he said. "It's not anything big, like the tornadoes you get down in the Lower 48. They are pretty small, and waterspouts are more reported out along the (Aleutian) chain, a few near the Bethel area, stuff like that. I would think there's probably more out there that're not reported because of the lack of population.'"*
> *Source: The Redoubt Reporter2011*

Figure 6-83 displays Alaska's annual rainfall map based on Parameter-elevation Regressions on Independent Slopes Model (PRISM) that combines climate data from NOAA and Natural

Resources Conservation Service (NRCS) climate stations with a digital elevation model to generate annual, monthly, and event-based climatic element estimates such as seasonal as well as anomaly precipitation and temperature.

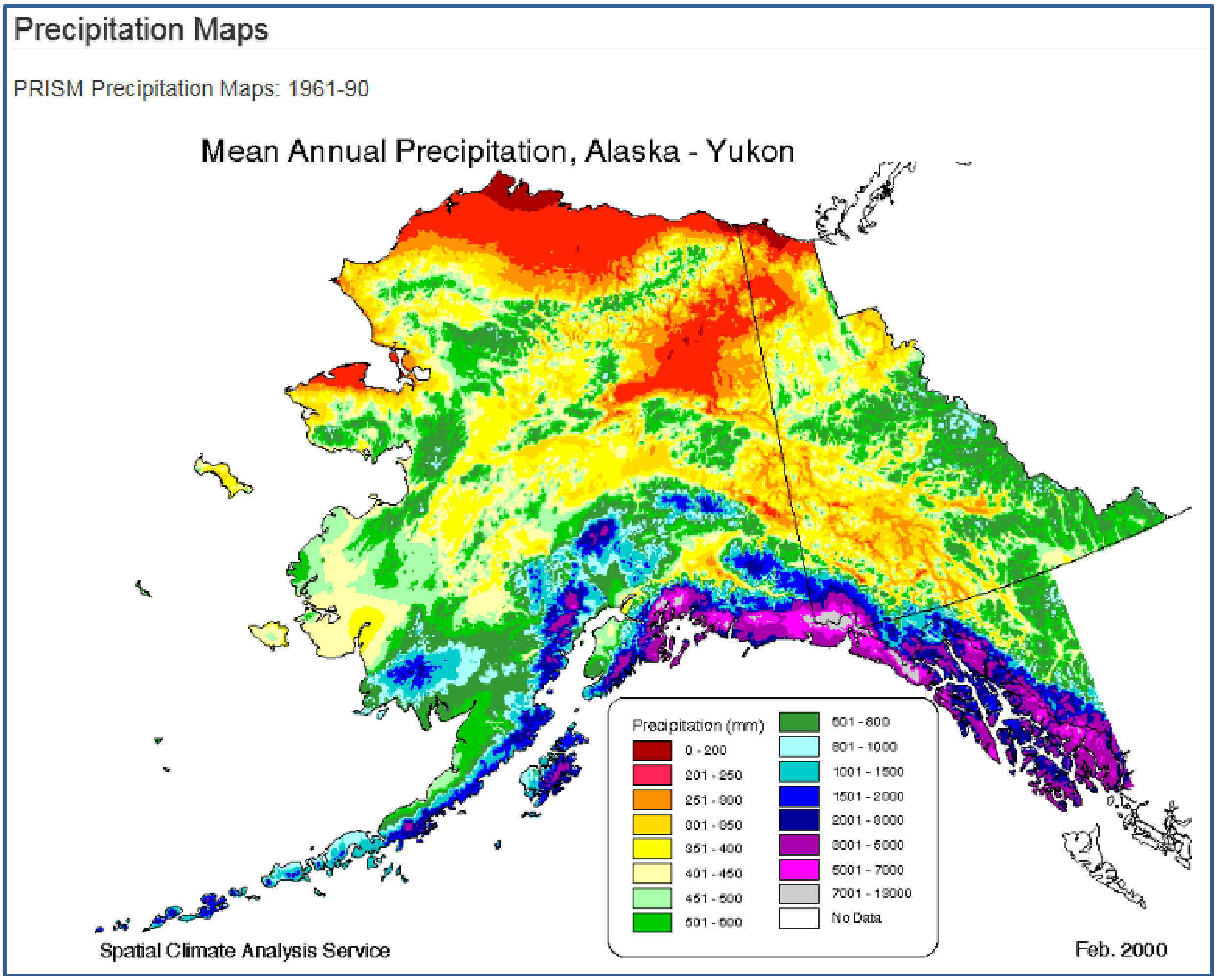



**Figure 6-83 Statewide Historical Rainfall Map**

*Source: Prism, 2018*

## 6.7.2. WEATHER HAZARD HISTORY

Alaska is continually impacted by severe weather events such as hurricane force / straight line wind, excessive rain, sea storms, winter storms, and extreme cold. These severe weather events typically have disastrous results in various locations throughout the state.

The NOAA, Alaska Region's 2018 "Alaska Public Forecast Zone Boundaries" map (Figure 6-84), displays inclusive weather zone boundaries and numbering. Both features will assist communities with locating current, forecast, or historic weather and climate change related events or conditions for diverse locations throughout the state.

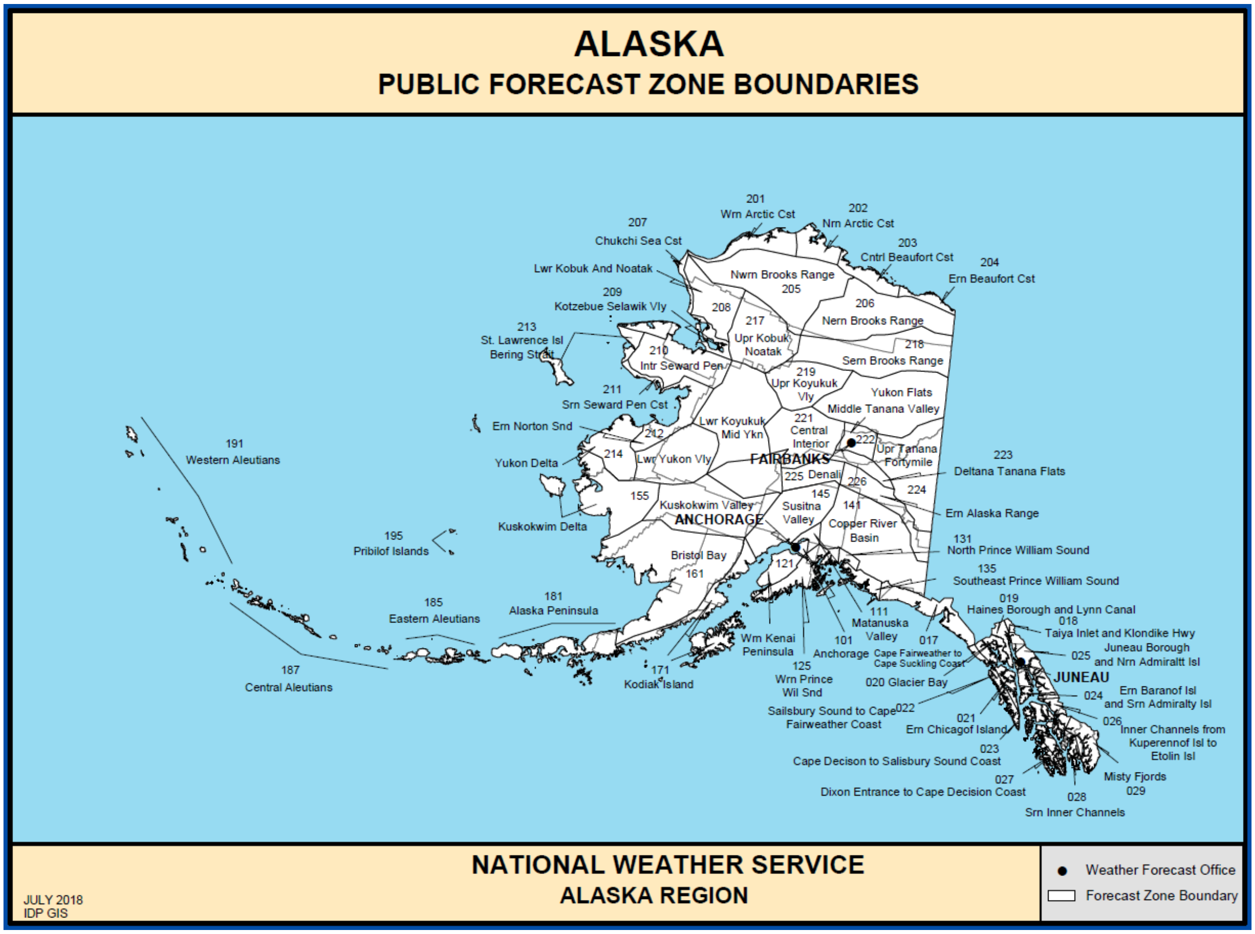



**Figure 6-84 AK Public Forecast Zone Boundaries**

*Source: NOAA, Alaska Region, 2018:* https://www.weather.gov/media/pimar/PubZone/ak_zone.pdf

**Climate Change.** The UAF Arctic Climate Impact Assessment (ACIA) describes recent weather changes and how they impact Alaska:

> *18.3.3.1. Changes in climate*
>
> *Alaska experienced an increase in mean annual temperature of about 2 to 3 ºC between 1954 and 2003…Winter temperatures over the same period increased by up to 3 to 4 ºC in Alaska and the western Canadian Arctic, but Chukotka experienced winter cooling of between 1 and 2 ºC…*
>
> *The entire region, but particularly Alaska and the western Canadian Arctic, has undergone a marked change over the last three decades, including a sharp reduction in snow-cover extent and duration, shorter river- and lake ice seasons, melting of mountain glaciers, sea-ice retreat and thinning, permafrost retreat, and increased active layer depth. These changes have caused major ecological and socio-economic impacts, which are likely to continue or worsen under projected future climate change. Thawing permafrost and northward movement of the permafrost boundary are likely to increase slope instabilities, which will lead to costly road replacement and increased maintenance costs for pipelines and other infrastructure. The projected shift in climate is likely to convert some forested areas into bogs when ice-rich permafrost thaws. Other areas of*

*Alaska, such as the North Slope, are expected to continue drying. Reduced sea-ice extent and thickness, rising sea level, and increases in the length of the open-water season in the region will increase the frequency and intensity of storm surges and wave development, which in turn will increase coastal erosion and flooding…*

*18.3.3.4. Impacts on people's lives*

*Traditional lifestyles are already being threatened by multiple climate-related factors, including reduced or displaced populations of marine mammals, seabirds, and other wildlife, and reductions in the extent and thickness of sea ice, making hunting more difficult and dangerous. Indigenous communities depend on fish, marine mammals, and other wildlife, through hunting, trapping, fishing, and caribou/reindeer herding. These activities play social and cultural roles that may be far greater than their contribution to monetary incomes. Also, these foods from the land and sea make significant contributions to the daily diet and nutritional status of many indigenous populations and represent important opportunities for physical activity among populations that are increasingly sedentary… Source: ACIA 2015*

The University of Alaska Geophysical Institute's Alaska Climate Research Center (ACRC) provided the following 2017 Alaska Statewide mid-winter and mid-summer summaries; there were no 2018 data at the time of this SHMP. The planning team determined that spring and fall weather, although different, can be viewed as transition periods between the winter and summer extremes.
http://akclimate.org/statewide-archive?field_year_list_value=2017&field_month_value=All&sort_by=field_year_value&sort_order=ASC

***Note:*** *These data are 2017 centric and used as historical representations only. Future global climate change conditions will affect future weather patterns and events.*

***Note:*** *Actual community temperatures and depths may vary due to their relative proximity to their respective locations and identified weather zones as depicted in Figure 6-96.*

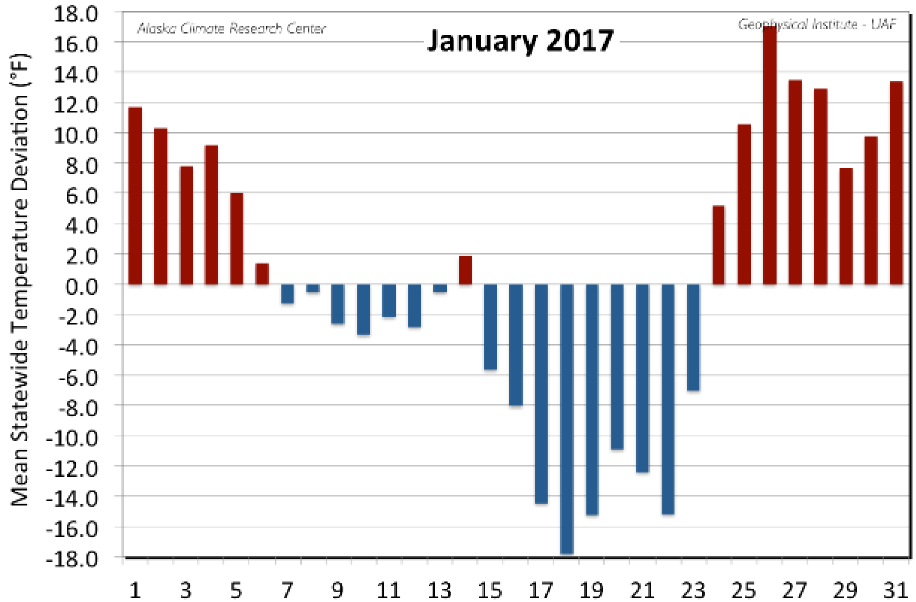
***Alaska Statewide Climate Summary***
***January 2017***

***Temperature***

*After fifteen months in a row with mean statewide temperatures above normal, January 2017 hit the mean monthly normal for January. The monthly mean temperature of all First Order Stations was 14.4°F, matching the normal of 14.4°F. This is 7.9°F below the January 2016 mean of 22.3°F. Calculating the mean daily temperatures of the First Order Stations, 15 days of the month were above the 30-year normal, with 16 days below normal. Above normal temperatures started the month, and above normal temperatures the ended of the month, with the transition to colder and mixed temperatures occurring between around 7th and 23rd (see Figure). The peak positive deviation for the month occurred on the 26th at 17.0°F. The greatest negative deviation occurred on the 18th with -17.8°F. Monthly mean temperatures (see table) were above normal for eight of the 19 First Order Stations. As was the case in October, November and December, Barrow held the spot with the greatest positive deviation in January with a significant 13.1°F above its normal of -0.3°F. Kotzebue had the next greatest positive deviation with 4.5°F. The station with the greatest negative deviation was Talkeetna with -6.7°F. Two other*

*stations had greater than -3.0°F deviations: Anchorage and King Salmon both with -3.5°F.*

*The highest daily maximum temperature of the First Order Stations for January was 50°F reported at Annette on the 17th. Annette also held the spot for the highest mean temperature for the month at 38.8°F. The lowest temperature of -56°F was observed at Bettles on the 19th and Bettles also reported the lowest January mean monthly temperature with a value of -12.1°F.*




*Daily mean temperature deviation from the normal temperature for the mean of the First Order Stations for January 2017.*

*There were only a limited number of new daily temperature record events in January, and all were new highs. Barrow set three new daily temperature records during the first three days of the month.*

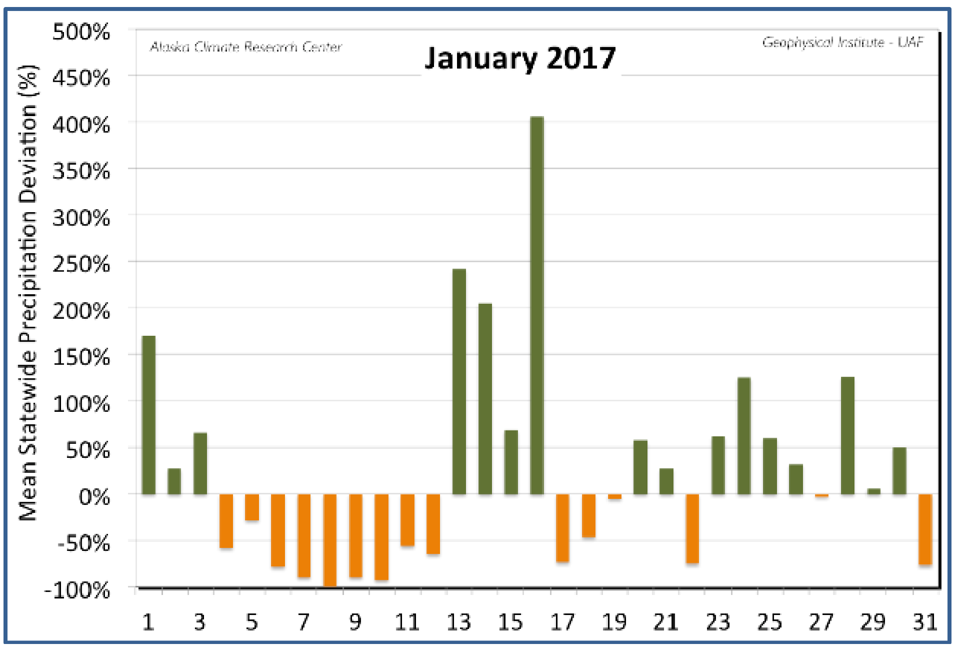
| Date | Temperature Records | | | | |
|---|---|---|---|---|---|
| | **Station** | **Element** | **New Record** | **Old Record** | **Year of old Record** |
| 01/01/17 | Barrow | High Temperature | 36 | 30 | 1928 |
| 01/01/17 | Kotzebue | High Temperature | 38 | 36 | 1968 |
| 01/02/17 | Barrow | High Temperature | 34 | 30 | 1968 |
| 01/03/17 | Barrow | High Temperature | 30 | 29 | 2004 |
| 01/26/17 | Juneau | High Temperature | 46 | 45 | 2016 |

***Precipitation***

*Continuing the trend from December, January's precipitation was significantly above normal, with the overall precipitation calculated as 27% above the average; this calculation was based on the mean of the deviations in percentage of the First Order Stations. Eleven of the First Order Stations and 16 days of the month reported above normal values. This is quite a bit wetter than January 2016, which reported a negative precipitation deviation of 23% below normal. The greatest daily precipitation amount occurred on the 16th. The leading station with a greater than*

*normal monthly precipitation amount was Barrow with 0.47", or 262% above normal. Anchorage was the station with the next greatest deviation with 134% above normal. The relatively driest station was King Salmon with just 15% of normal.*

| Station | Precipitation | | | | |
|---|---|---|---|---|---|
| | Observed (in) | Normal (in) | Delta (in) | Delta (%) | (%) |
| Anchorage | 1.71 | 0.73 | 0.98 | 134% | 234% |
| Annette | 8.24 | 10.73 | -2.49 | -23% | 77% |
| Barrow | 0.47 | 0.13 | 0.34 | 262% | 362% |
| Bethel | 1.21 | 0.78 | 0.43 | 55% | 155% |
| Bettles | 0.92 | 0.81 | 0.11 | 14% | 114% |
| Cold Bay | 5.13 | 3.16 | 1.97 | 62% | 162% |
| Delta Junction | 0.50 | 0.31 | 0.19 | 61% | 161% |
| Fairbanks | 0.96 | 0.58 | 0.38 | 66% | 166% |
| Gulkana | 0.83 | 0.46 | 0.37 | 80% | 180% |
| Homer | 2.67 | 2.63 | 0.04 | 2% | 102% |
| Juneau | 6.27 | 5.35 | 0.92 | 17% | 117% |
| King Salmon | 0.15 | 1.02 | -0.87 | -85% | 15% |
| Kodiak | 2.95 | 8.29 | -5.34 | -64% | 36% |
| Kotzebue | 0.55 | 0.62 | -0.07 | -11% | 89% |
| McGrath | 0.54 | 1.09 | -0.55 | -50% | 50% |
| Nome | 0.72 | 0.94 | -0.22 | -23% | 77% |
| St. Paul Island | 1.51 | 1.58 | -0.07 | -4% | 96% |
| Talkeetna | 1.68 | 1.36 | 0.32 | 24% | 124% |
| Yakutat | 13.39 | 13.66 | -0.27 | -2% | 98% |




*Daily mean precipitation deviation from the normal for the First Order Stations for January 2017.*

*January's highest monthly precipitation total reported for a First Order Station was 13.39" at Yakutat, and Yakutat also reported the highest daily total of 2.53" on the 17th. There were a limited number of precipitation records as noted in the table below.*

| Date | Precipitation Records | | | | |
|---|---|---|---|---|---|
| | Station | Element | New Record | Old Record | Year of old Record |
| 01/01/17 | Barrow | Precipitation | 0.32 | 0.16 | 1924 |
| 01/16/17 | Delta Junction | Precipitation | 0.20 | 0.19 | 1952 |
| 01/16/17 | Juneau | Precipitation | 1.49 | 1.01 | 2005 |
| 01/16/17 | Skagway | Precipitation | 1.10 | 0.57 | 1928 |
| 01/30/17 | Cold Bay | Precipitation | 0.74 | 0.57 | 1988 |

### Snowfall

*January was the second month this winter with above average snowfall across the State, but like December, just barely. Based on the mean of the deviations from all 15 stations, which measure snowfall, the overall deviation from the normals was 2% above the expected amount. This is considerably greater than the snowfall deviation from January 2016, which had a 60% deficit. Six of the 15 First Order Stations reported above normal snowfalls. Anchorage had the greatest positive deviation at 181% above its expected amount with a total of 31.7". Anchorage also reported the highest one-day snowfall at 10.3" on the 21st, a new daily record, breaking the 1961 record of 3.8". This is the second highest one-day snowfall for Anchorage in January after the 11.2" from January 1st, 2007. The greatest snow depth was 27" and was reported at Anchorage on the 21st. There were a limited number of snowfall records as noted in the table below. Snowpack continued to be low, with around half of normal.*

| Station | Snowfall | | | | |
|---|---|---|---|---|---|
| | Observed (in) | Normal (in) | Delta (in) | Delta (%) | (%) |
| Anchorage | 31.7 | 11.3 | 20.4 | 181% | 281% |
| Annette | 1.0 | 7.6 | -6.6 | -87% | 13% |
| Barrow | 4.7 | 2.6 | 2.1 | 81% | 181% |
| Bethel | 9.8 | 9.6 | 0.2 | 2% | 102% |
| Bettles | 13.1 | 13.9 | -0.8 | -6% | 94% |
| Cold Bay | 12.5 | 14.1 | -1.6 | -11% | 89% |
| Fairbanks | 17.0 | 10.3 | 6.7 | 65% | 165% |
| Juneau | 3.7 | 27.7 | -24.0 | -87% | 13% |
| King Salmon | 3.0 | 10.2 | -7.2 | -71% | 29% |
| Kodiak | 7.4 | 13.0 | -5.6 | -43% | 57% |
| Kotzebue | 11.3 | 9.1 | 2.2 | 24% | 124% |
| McGrath | 14.7 | 15.7 | -1.0 | -6% | 94% |
| Nome | 10.4 | 12.7 | -2.3 | -18% | 82% |
| St. Paul Island | 14.2 | 12.6 | 1.6 | 13% | 113% |
| Yakutat | 27.6 | 31.9 | -4.3 | -13% | 87% |

| Date | Snowfall Records | | | | |
|---|---|---|---|---|---|
| | Station | Element | New Record | Old Record | Year of old Record |
| 01/01/17 | Barrow | Snowfall | 3.1 | 1.6 | 1924 |
| 01/13/17 | Anchorage | Snowfall | 4.0 | 2.5 | 1990 |
| 01/16/17 | Anchorage | Snowfall | 5.3 | 3.7 | 2008 |
| 01/19/17 | McGrath | Snowfall | 4.8 | 4.7 | 1949 |
| 01/20/17 | Anchorage | Snowfall | 2.2 | 1.9 | 2011 |
| 01/21/17 | Anchorage | Snowfall | 10.3 | 3.8 | 1981 |

***Newsworthy Events***

*The New Year started off with Yakutat registering a low of 16°F, 20°F colder than Barrow at 36°F for the same day. Avalanche reduction hazard efforts were conducted along the Dalton Highway in the Brooks Range, while the Steese Highway was closed from mile 80 to 114. The Steese Highway was closed in the same area on the 3rd, while a travel advisory was issued for the Dalton Highway on the 5th due to high winds and being impassable along the northern end of the road. The Elliot Highway experienced hazardous driving conditions. Notable wind speeds from the snow storm at the end of the year were: 52 mph at Northway, 62 mph at Sheenjek River in the Southeaster Brooks Range, 66 mph at Inigok Airfield in Northwestern Brooks Range, 70 mph at Jago River in Northeastern Brooks Range, 61 mph at Fort Greely, 75 mph at Camden Bay and 77 mph at Cape Lisburne. In Fairbanks, the road crews were still mopping up on the 6th of January.*

*The Klondike Highway was closed on the 6th, while Taku winds hit the Juneau area on the 9th with minor damage reported. Winds were reported up to 94 mph at downtown Juneau, 72 mph at Eldred Rock and 61 mph at Point Bishop near Juneau. High winds along the northern Panhandle on the 8th included: 67 mph at Fiver Fingers, 66 mph at Eldred Rock, 55 mph at Skagway and 52 mph at Yakutat. Hazardous driving conditions were reported along the Dalton Highway again on the 11th, and then for the Elliott Highway on the 13th. More snow in the Southcentral area on the 13th included: over 18" at Valdez, over 9" at Eagle River, and 6" to 7" reported at locations from Palmer to Anchorage.*

*High winds in the Southeast on the same day ranged up to 67 mph at Lincoln Island, 54 mph at Hydaburg, 52 mph at Juneau and 51 mph at Ketchikan. Hazardous driving conditions were reported along the Haines Highway on the 14th due to heavy rain and black ice on the road. Heavy rains reported along the Panhandle included: 3.89" at Shelter Cove, 3.26" at Ketchikan, 2.78" near Haines and 2.72" at Yakutat. The storm continued along the Panhandle the following day with winds up to 70 mph at Sitka, 61 mph at Hydaburg, 59 mph at Annette, 54 mph at Skagway and 43 mph at Yakutat. The rainfall totals for the storms from 11th to 16th were: 11.70" at Pelican, 7.18" at Yakutat, 6.61" at Ketchikan and 5.54" at Sitka. The Klondike Highway was was closed from the 16th to 18th due to heavy rain and black ice.*

*Snowfall totals for the Southcentral areas on the 16th were 8" at Portage and Hatcher Pass and 8" at Thompson Pass, while parts of Anchorage received 4" to 5". The next day, high winds and drifting snow made for difficult travel along parts of the Parks and Richardson Highways.*

*Extreme cold began to descend across much of the State on the 17th with a temperature range of 101°F from -51°F at McGrath and Tanana to +50°F at Annette. Anchorage Airport hit -15°F on the 18th, and this was the first time in five years this cold of a temperature had been reported. Barrow reported -30°F, and this ended the longest streak of 387 days, on record, of temperatures staying above this mark. Previous record had been 369 days ending on January 20th, 2006. Temperatures dropped lower on the 18th with -51°F reported at Fairbanks Airport, the first time for that temperature in six years, and it has not been colder than -51°F since the -52°F on New Year's Eve 1999. In the Fairbanks area, -59°F was reported near the Salcha River, -52°F at Eielson and -51°F at Ft Wainwright. Tanana also reported -59°F and Bettles reported -56°F. The next day Tanana and Bettles reported a low of -53°F. In the Southcentral area temperatures were:*

*-38°F at Talkeetna, -33°F at Wasilla, -20°F at Palmer and -29°F at Kenai. Elliot Highway reported hazardous driving conditions on the 20th. The next day the sun rose at Barrow for the first time in over 2 months.*

*On the 21st, heavy snowfall impacted the Southcentral areas resulting in avalanche warnings being issued for the south and western Kenai Mountains, and hazardous driving conditions reported along the Seward Highway due to snow and high winds up to 50 mph. Moose Pass reported snowfall totals of over 2 feet. The heavy snowfall prompted the city of Seward to declare a local emergency and request aid from the State as more than 2 ½ feet of snow had fallen in the city. The snowstorm gave Anchorage a winter total of 44.3", more than the previous two winters combined, and resulted in a number of vehicle accidents and the collapse of the dome roof of a sports facility. Two days later avalanche reduction efforts were instituted from miles 19 to 45 along the Seward Highway, and this was repeated for miles 80 to 100 on the 26th. Freezing rain in Anchorage on the 26th generated a number of vehicle accidents and the closure of all after school activities. More avalanche warnings were issued on the 26th for the Kenai Mountains and Turnagain Pass.*

*As warmer temperatures pushed across the State, Eielson AFB reported a high of +36°F on the 26th, 89°F warmer than the -53°F from the previous week. Denali Park reported 43°F on the 26th, with winds up to 60 mph through the passes of the Alaska Range. The warming created ice roads along the Elliott Highway and drivers were warned to avoid the road.*

*More high winds along the Panhandle on the 27th resulted in observations of 84 mph at Cape Decision, 77 mph at Hydaburg, 67 mph at Ketchikan, 62 mph at Sitka and Juneau, and 60 mph at Yakutat. The next day winds topped out at 71 mph at Cape Fairweather, 64 mph at Lincoln Island, 58 mph at Annette, 55 mph at Juneau, and 52 mph at Ketchikan and Yakutat. More snow in the Southcentral area on the 38th totaled up to 8" at Wasilla, 7" at Eagle River and up to 6" around Anchorage. Total January snowfall at sea level at Alyeska was over 56". Toward the end of the month, avalanche reduction efforts were conducted along the Dalton Highway in the Brooks Range.*

# *Alaska Statewide Climate Summary*

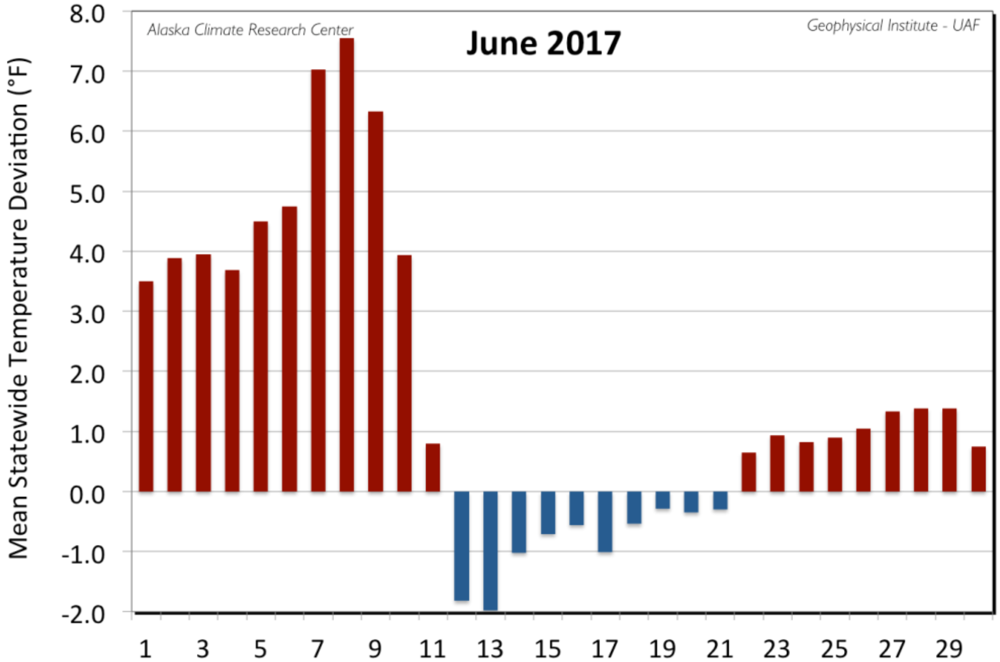
## *June 2017*

### *Temperature*

*June 2017 marks 18 months out of the last 20 months with mean statewide temperatures at or above normal. The mean monthly temperature for June 2017 was above normal with the mean temperature of all First Order Stations at 53.5°F, 1.8°F above the normal of 51.7°F. This is 0.6°F below the June 2016 mean of 54.1°F. Calculating the mean daily temperatures of the First Order Stations, the first eleven days of the month were above the 30-year normal, followed by ten days of below normal temperatures, then the month ended with nine more days above normal. The greatest positive deviation occurred on the 8th with 7.5°F above normal, and the greatest negative deviation occurred on the 13th at -2.0°F. (see Figure). Monthly mean temperatures were above normal for 16 of the 19 of the First Order Stations (see table). Kotzebue held the spot with the greatest positive deviation in June with 5.4°F above its normal of 45.7°F. The other stations with deviations greater than or equal to 3°F were Nome (4.9°F), St. Paul Island (3.2°F) and Bethel (3.0°F). Note that all these stations are located in western Alaska. Juneau was the station reporting the greatest below normal mean temperature with 53.3°F, 1.3°F below its June normal of 54.6°F.*

| Station | Temperature | | |
|---|---|---|---|
| | Observed (°F) | Normal (°F) | Delta (°F) |
| Anchorage | 55.3 | 55.2 | 0.1 |
| Annette | 55.3 | 55.1 | 0.2 |
| Barrow | 34.7 | 35.6 | -0.9 |
| Bethel | 55.5 | 52.5 | 3.0 |
| Bettles | 59.9 | 58.5 | 1.4 |
| Cold Bay | 48.0 | 46.3 | 1.7 |
| Delta Junction | 59.8 | 57.6 | 2.2 |
| Fairbanks | 62.8 | 60.4 | 2.4 |
| Gulkana | 56.2 | 54.4 | 1.8 |
| Homer | 54.4 | 50.6 | 3.8 |
| Juneau | 53.3 | 54.6 | -1.3 |
| King Salmon | 53.7 | 51.5 | 2.2 |
| Kodiak | 50.8 | 49.7 | 1.1 |
| Kotzebue | 51.1 | 45.7 | 5.4 |
| McGrath | 59.4 | 57.4 | 2.0 |
| Nome | 52.7 | 47.8 | 4.9 |
| St. Paul Island | 45.6 | 42.4 | 3.2 |
| Talkeetna | 56.8 | 57.0 | -0.2 |
| Yakutat | 52.0 | 50.8 | 1.2 |

*The highest daily maximum temperature of the First Order Stations for June was 90°F reported at Fairbanks on the 9th, a new daily record, breaking the 1957 record of 87°F. This was the second earliest 90°F daily high on record, after the 90°F high on May 28, 1947, as well as the first 90°F in Fairbanks since June 2013. Fairbanks also held the spot for the highest mean temperature for the month at 62.8°F. The lowest temperature of 22°F was observed at Barrow on the 5th, and Barrow also reported the lowest June mean monthly temperature with a value of 34.7°F.*




*Daily mean temperature deviation from the normal temperature for the mean of the First Order Stations for June 2017.*

*There were a very limited number of new temperature record events this June as delineated in the following table.*

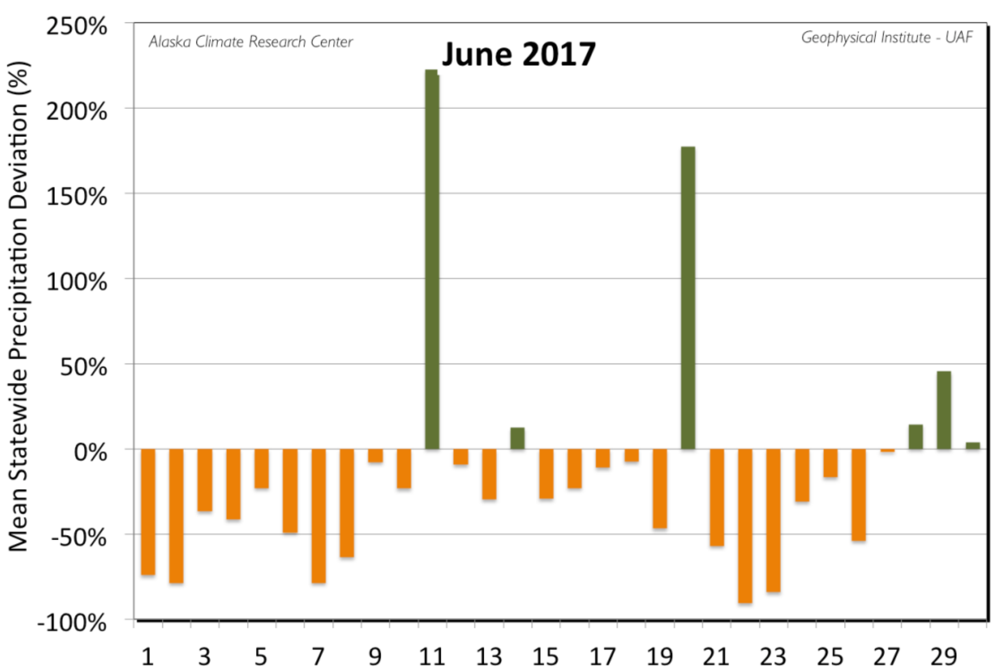
| ***Date*** | ***Temperature Records*** | | | | |
|---|---|---|---|---|---|
| | ***Station*** | ***Element*** | ***New Record*** | ***Old Record*** | ***Year of old Record*** |
| *06/02/17* | *Bethel* | *High Temperature* | *76* | *75* | *1993* |
| *06/06/17* | *St. Paul* | *High Temperature* | *57* | *55* | *2016* |
| *06/09/17* | *Delta Junction* | *High Temperature* | *88* | *83* | *1957* |
| *06/09/17* | *Fairbanks* | *High Temperature* | *90* | *87* | *1957* |
| *06/09/17* | *Haines Airport* | *High Temperature* | *83* | *82* | *1946* |
| *06/19/17* | *King Salmon* | *Low Temperature* | *34* | *35* | *1997* |

### *Precipitation*

*June's precipitation was notably below normal, with the overall precipitation calculated as 17% below the average; this calculation was based on the mean of the deviations in percentage of the First Order Stations. Thirteen of the First Order Stations and 24 days of the month reported below normal values. This is drier than June 2016, which reported a precipitation surplus of 21%. The greatest daily precipitation amount occurred on the 11th. The station reporting the greatest precipitation deviation was King Salmon at 45% above normal with 2.40", 0.75" above its normal of 1.65". The relatively driest station was Gulkana at just 24% of normal.*

| ***Station*** | ***Precipitation*** | | | | |
|---|---|---|---|---|---|
| | ***Observed (in)*** | ***Normal (in)*** | ***Delta (in)*** | ***Delta (%)*** | ***(%)*** |
| *Anchorage* | ***0.87*** | ***0.97*** | ***-0.10*** | ***-10%*** | ***90%*** |
| *Annette* | ***6.33*** | ***4.88*** | ***1.45*** | ***30%*** | ***130%*** |
| *Barrow* | ***0.26*** | ***0.32*** | ***-0.06*** | ***-19%*** | ***81%*** |

| Station | Precipitation | | | | |
|---|---|---|---|---|---|
| | Observed (in) | Normal (in) | Delta (in) | Delta (%) | (%) |
| Bethel | 1.39 | 1.72 | -0.33 | -19% | 81% |
| Bettles | 0.43 | 1.40 | -0.97 | -69% | 31% |
| Cold Bay | 1.94 | 2.72 | -0.78 | -29% | 71% |
| Delta Junction | 2.06 | 2.31 | -0.25 | -11% | 89% |
| Fairbanks | 1.73 | 1.37 | 0.36 | 26% | 126% |
| Gulkana | 0.34 | 1.40 | -1.06 | -76% | 24% |
| Homer | 0.46 | 0.82 | -0.36 | -44% | 56% |
| Juneau | 3.86 | 3.24 | 0.62 | 19% | 119% |
| King Salmon | 2.40 | 1.65 | 0.75 | 45% | 145% |
| Kodiak | 7.98 | 5.91 | 2.07 | 35% | 135% |
| Kotzebue | 0.20 | 0.58 | -0.38 | -66% | 34% |
| McGrath | 1.23 | 1.52 | -0.29 | -19% | 81% |
| Nome | 1.18 | 0.98 | 0.20 | 20% | 120% |
| St. Paul Island | 0.93 | 1.35 | -0.42 | -31% | 69% |
| Talkeetna | 0.52 | 1.92 | -1.40 | -73% | 27% |
| Yakutat | 3.81 | 6.39 | -2.58 | -40% | 60% |




*Daily mean precipitation deviation from the normal for the First Order Stations for June 2017.*

*June's highest monthly precipitation total reported for a First Order Station was 7.98" at Kodiak. Kodiak also reported the highest daily total of 2.22" on the 29th, a new daily record, breaking the old record of 1.84" from 1965.*

*A limited number of daily precipitation records were set this June. Fairbanks on the 11th broke a record set only the previous year with 1.09", topping the 2016 record of 0.95". King Salmon received the same amount, 1.03" on the 14th, more than doubling the 1978 record of 0.49". The rainfall total of 1.24" in Sitka on the 16th broke the previous record of 1.21" also set in 1978.*

***Newsworthy Events***

*On June 1st, the North Robertson fire was reported 30 miles northwest of Tok, at mile 1349 of the Alaska Highway. By the next day over 200 firefighters were onsite, and air tankers were dropping water and retardant as the fire approached nearby structures. The fire was 40% contained on the 5th, and 85% by the 11th. It burned a total of 800 acres. Burn suspensions were initiated for central and eastern Interior Alaska on the 2nd.*

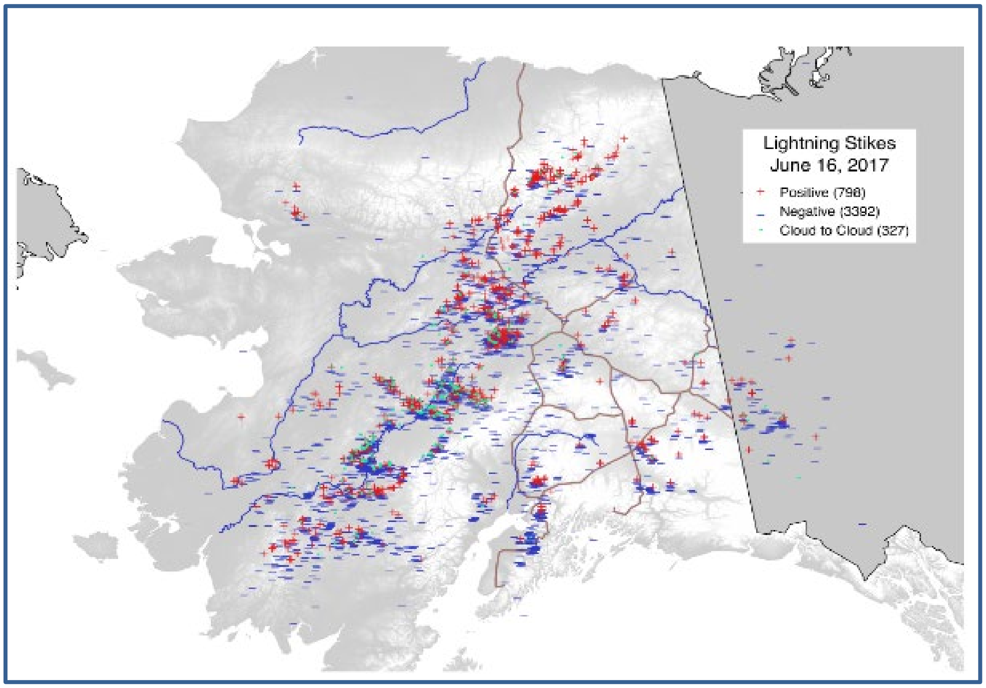
*The Bell Creek fire, started by lightning on the 4th, approached the village of Crooked Creek along the Kuskokwim River. Fire crews and takers were dispatched to fight the fire. The fire reached 2,600 acres. The Deadpan's Slough fire also started on the 4th within two miles of the village of Anvik, and was also fought to protect structures.*

*On the 5th, heavy rainfall was reported across southern portion of the Panhandle with Ketchikan reporting 2.60", 1.64" at Zarembo and 1.27" at Annette. For much of the next week, red flag warnings were issued for the middle and eastern Interior due to continued high temperatures and winds. Heavy lightning strikes in Western Alaska on the 6th started 19 new fires in the Galena zone.*

*Smoke from the South Fork Salcha, north of the Pogo Mine, reached Fairbanks on the 9th. This fire was not actively fought even though it was within two miles of the road to the Pogo Mine. It ended the month at over 8,000 acres. A small wildfire temporarily closed the Richardson Highway near Fairbanks at mile 308 on the 9th. The fire was fought vigorously with firefighters and multiple aircraft, and listed as out on the 11th at a total of 15 acres. The fire being close to Birth Lake aided in the fighting efforts.*

*Skagway had a high temperature of 88°F on the 8th, highest temperature in almost eight years. The warm weather increased snowmelt in the mountains, and the Taiya and Chilkat Rivers were running at bankfull levels over the next two days. Needed rainfall moved over the Interior on the 10th and 11th. Some forty-eight hours totals are: 1.73" at Moose Creek Dam near Fairbanks, 1.57" at Little Chena River, 1.41" at Two Rivers, 1.07" at Salcha and 1.04" near Nenana. The high temperatures in the Interior broke on the 13th, with warnings of possible morning frost in low-lying areas on the 13th through the 15th. On the 14th, a low of 28°F was reported at Goldstream Cre[e]k, 26°F at Angel Creek and 23°F at Upper Salcha River.*

*The East Fork fire was started by lightning late on the 15th about five miles north of Sterling on the Kenai Peninsula. More than 80 personal and a tanker staffed the fire by the next day, while smoke from the fire blew into Anchorage. The fire burned about 1,000 acres before being brought under control over the next few days.*




*Lightning strikes plotted across Alaska on June 16th, 2017. A total of 4517 were recorded. Data courtesy of the Alaska Interagency Coordination Center.*

*Heavy rains impacted the northern Southeast area on the 17th with 3.06" reported at Snettisham, 1.50" at Eaglecrest and 1.22" at Auke Bay. Two to three inches of snow was reported in the Chilkat Pass on the British Columbia side of the border also on the 17th. More than 1,400 electrical customers were without power for a time near Fairbanks on the 17th due to high winds from thunderstorms.*

*A thunderstorm dropped more than an inch of hail on the town of Eagle on the 23rd, while 0.66" of rain was also reported. A red flag warning was also issued for the eastern Interior on the 23rd and 24th, as well as flash flood warnings for Tanacross area with up to 2.20" of rain reported southeast of Fairbanks. A red flag warning was again issued for the eastern Interior on the 29th, while smoke from the South Fork fire blew into the Fairbanks area again.*

*By the end of June there had been 165 human caused fires that burned about 6,000 acres and 90 lightning caused fires that had burned about 183,600 acres. The largest fire at 16,800 acres was the Pitka Fork a limited suppression area in the Southwest." (Source: UAF/GI 2017)*

DHS&EM's DCI records the following severe weather disaster events. Due to Alaska's geographic size, each event would have impacted locations differently than reported within the respective event summaries.

***83. Omega Block Disaster, January 28, 1989 & FEMA declared (DR-00826) on May 10, 1989.*** *The Governor declared a statewide disaster to provide emergency relief to communities suffering adverse effects of a record breaking cold spell, with temperatures as low as -85 degrees. The State conducted a wide variety of emergency actions, which included: emergency repairs to maintain & prevent damage to water, sewer & electrical*

*systems, emergency resupply of essential fuels & food, & DOT/PF support in maintaining access to isolated communities.*

***Note:*** *The Disaster Cost Index lists numerous additional disasters events that began from severe weather events; too many to list here.*

The Western Region Climate Center (WRCC) provides a brief description of various features, conditions or relationships that affect Alaska's climate. *(**Note**: maps referenced at this data source are not available for public access: http://prism.nacse.org/normals/special_projects.php)*

***Topographic Features***

*Alaska is the westernmost extension of the North American Continent. Its east-west span covers a distance of 2,000 miles, and from north to south a distance of 1,100 miles. The state's coastline, 33,000 miles in length, is 50 percent longer than that of the conterminous United States. In addition to the Aleutian Islands, hundreds of other islands, mostly undeveloped, are found along the northern coast of the Gulf of Alaska, the Alaska Peninsula, and the Bering Sea Coast. Alaska contains 375 million acres of land and many thousands of lakes…*

*Permafrost is a major factor in the geography of Alaska. It is defined as a layer of soil at variable depths beneath the surface of the earth in which the temperature has been below freezing continuously from a few several thousands of years. It exists where summer heating fails to penetrate to the base of the layer of frozen ground. Permafrost covers most of the northern third of the state. Discontinuous or isolated patches also exist over the central portions in an overall area covering nearly a third of the state. No permafrost exists in the south-central and southern coastal portions including southeastern Alaska, the Alaska Peninsula, and the Aleutian chain.*

***Climatic Zones***

*The geographical features … have a significant effect on Alaska's climate, which falls into five major zones... The climate zones are: (1) a maritime Zone which includes southeastern Alaska, the south coast, and southwestern islands; (2) a maritime continental zone which includes the western portions of Bristol Bay and west-central zones. In this zone the summer temperatures are moderated by the open waters of the Bering Sea, but winter temperatures are more continental in nature due to the presence of sea ice during the coldest months of the year; (3) a transition zone between the maritime and continental zones in the southern portion of the Copper River zone, the Cook Inlet zone, and the northern extremes of the south coast zone; (4) a continental zone make up of the remainders of the Copper River and west-central divisions, and the interior basin; and (5) an artic zone, shown on the map as the arctic drainage division.*

***Precipitation***

*In the maritime zone a coastal mountain range coupled with plentiful moisture produces annual precipitation amounts up to 200 inches in the southeastern panhandle, and up to 150 inches along the northern coast of the Gulf of Alaska. Amounts decrease to near 60 inches on the southern side of the Alaska Range in the Alaska Peninsula and Aleutian Island sections. Precipitation amounts decrease rapidly to the north, with an average of 12 inches in the continental zone and less than 6 inches in the arctic region.*

*Snowfall makes up a large portion of the total annual precipitation. For example, Yakutat averages 216 inches of snow annually and has a total annual precipitation (rain plus water equivalent of snow) of about 130 inches. Along the arctic slope, Barrow receives an average of 29 inches of snow annually and a total annual precipitation of slightly*

*more than 4 inches. Total snow depths on the ground are controlled by the temperature of an area. Fortunately, most of the areas of heavy snow have relatively mild temperatures which prevent total depths from becoming excessive. Present-day snow removal equipment is able to keep highways and airports operational.*

*Precipitation extremes are of interest. With reference to total amounts (both rain and snow) and based on existing records, the greatest annual precipitation occurred at MacLeod Harbor on Montague Island in the Gulf of Alaska with 332.29 inches in 1976. This station also holds the record for monthly totals with 70.99 inches in November 1976.*

*The record maximum for 24 hours occurred on December 29, 1955, in the city of Cordova (North Gulf of Alaska coast) with a measured amount of 14.13 inches. Snowfall extremes are all credited to a station at Thompson Pass, which is on the highway north of Valdez. The record measurements are: season (1952-53) 974.5 inches; month (February 1953) 298 inches; and 24-hour (December 1955) 62 inches.*

***Temperature***

*Mean annual temperatures in Alaska range from the low 40's under the maritime influence in the south to a chilly 10 degrees along the Arctic Slope north of the Brooks Mountain Range. The greatest seasonal temperature contrast between seasons is found in the central and eastern portion of the continental interior. In this area summer heating produces average maximum temperatures in the upper 70's with extreme readings in the 90's. The highest recorded temperature for the state is 100 degrees at Fort Yukon in June 1915. In winter the lack of sunshine permits radiation to lower temperatures to the minus 50's and occasionally colder for two or three weeks at a time. Average winter minimums in this area are 20 to 30 degrees below zero. The coldest temperature ever recorded in Alaska was minus 80 degrees at Prospect Creek on January 23, 1971.*

*Elsewhere in the state, temperature contrasts are much more moderate. In the maritime zone the summer to winter range of average temperatures in from near 60 to the 20's. In the transition zone, temperatures range from the low 60's to near zero; in the maritime-continental zones the range is from the low 60's to 10 below zero. The arctic slopes has a range extending form the upper 40's to 20 below zero.*

*Winter temperatures play a principal role in the flow of most of Alaska's rivers. Usually beginning in late October and extending into May (and sometimes early June for the northernmost steams), thick layers of ice form, permitting passage with all types of heavy equipment. In many areas construction work and oil exploration is done in winter because both the ground and the streams are frozen hard enough from the use of the heaviest of equipment. Several rivers cease to flow completely during the coldest months.*

***Wind***

*A normal storm track along the Aleutian Island chain, the Alaska Peninsula, and all of the coastal area of the Gulf of Alaska exposes these parts of the state to a large majority of the storms crossing the North Pacific, resulting in a variety of wind problems. Direct exposure results in the frequent occurrence of winds in excess of 50 mph during all but the summer months. Shemya, on the western end of the Aleutian Islands, has experienced winds on an estimated 139 mph (estimated because the wind recorder pen could only record up to 128 mph). Wind velocities approaching 100 mph are not common but do occur, usually associated with mountainous terrain and narrow passes. For years, strong winds have taken their toll of both merchant and fishing vessels.*

*An occasional storm will either develop in or move into the Bering Sea then move north or northeastward, creating strong winds along the western coastal area. Because of the*

*low flat ground in many places along the coast, these winds will cause flooding during the time the winds are blowing onshore. Winter storms moving eastward across the southern Arctic Ocean cause winds of 50 mph or higher along the arctic coast. Except for local strong wind conditions, winds are generally light in the interior sections.*

*Strong winds, or in fact any wind occurring in the areas of extreme winter cold, create a definite hazard to personnel exposed for even brief periods of time. For example, (using a wind chill chart developed by the U.S. Army) a temperature of a -13°F and an accompanying wind of 15 mph equals conditions that would be experienced with a temperature of -49°F and no wind. If the temperature is a -49°F and the winds 10 mph, the resulting equivalent temperature is -81°F.*

***Climate and the Economy***

***Timber***
*Wooded areas in the state total approximately 100 million acres of both commercial and non-commercial timber. Southeastern Alaska is and always has been the principal production area. Lumber and pulp mills are important contributors to the economy of that portion of the state. In south-central Alaska high, barren mountains and numerous glaciers limit the forests to about 10 to 20 percent of the total area. Some commercial logging has occurred in the Tyonek area on the northwest shore of Cook Inlet and in the Matanuska-Susitna Valley. Some forested land exists in the central interior and southwestern portions along major rivers like the Yukon and the Kuskokwim but, to date, has not been developed commercially. No commercial timber is found north of the Brooks Range or along the western coastal region. Western interior forested areas are limited to small isolated patches without permafrost.*

***Farming***
*It is estimated that statewide there are 18 to 20 million acres of land potentially suitable for cropland, but less than 20 thousand acres are actually under or have been under cultivation. The largest acreages are devoted to grass crops for hay, silage, and pasture. Rangelands are widespread in the Alaska mainland. Wild caribou herds foraging on portions of these lands have numbered in the hundreds of thousands and are an important source of protein in many Alaska villages. Cattle and sheep are raised in areas of the Kenai Peninsula, the Alaska Peninsula, and the Aleutian Islands, and small herds of reindeer are raised on the tundra lands of the Seaward Peninsula. Vegetable crops, especially potatoes, are also important, and limited mild production in the Matanuska Valley north of Anchorage and the Tanana Valley near Fairbanks provide fresh dairy products to local residents. Within the agricultural areas the growing season averages 80 to 110 days each year. This is a short growing season, but the daily potential of 16 to 19 hours of sunshine each day produces some of the finest and largest vegetables grown anywhere.*

***Mineral***
*Oil is by far the most important mineral product at this time. Current commercial production is at Prudhoe Bay, the Kenai Peninsula, and offshore Cook Inlet. Production from the Prudhoe Bay field is now at 750,000 barrels per day and is projected to reach 1.2 million barrels per day by the end of 1978. The trans-Alaska pipeline, completed in 1977, transports this crude petroleum from the Prudhoe Bay field on the North Slope of Alaska to a refinery at North Pole and to Valdez, a deepwater port in the northern Gulf of Alaska. The petroleum is then moved by oceangoing tankers to refineries in Alaska and the contiguous 48 states. Exploration for additional petroleum is in progress in several*

*land areas and on the outer continental shelf from the Gulf of Alaska to the Beaufort Sea coast. Commercial gas wells are producing in the Barrow area and the Kenai Peninsula, and a large pipeline is expected to be built in the next 5 to 10 years to transport Prudhoe Bay gas to the lower 48 states.*

*Coal is mined in the Healy area, and several other large deposits have been located but are not commercially mined. Gold mining has resumed in the vicinity of Nome, bornite is mined in the vicinity of Kobuk, and platinum of the Bering Sea coast. All other types of mining are of a minor nature but are expected to develop as problems of transportation and production costs are solved.*

***Fishing***
*The fishing industry, which includes the taking of crab and shrimp, is another leading industry in Alaska. Commercial fishing occurs along the entire Alaska coast but is heaviest in the southeastern Bering Sea, along the Aleutian Islands, and around the coast of the Gulf of Alaska. Salmon have been the main product, but shellfish, particularly ding and tanner crab and shrimp, are becoming more important. A new fishery for bottom fish is emerging with the implementation of the U.S. zone of extended jurisdiction within 200 miles of the coast. Halibut have also long been an important part of the harvest. In recent years, at least one Alaskan port has been listed among the top 10 U.S. ports in terms of both pounds of fisheries products landed and total economic value of the landings.*

***Tourism***
*Out-of-state visitors have been increasing in number each year. Because of the airplane, tourism extends into nearly every part of the state. This is particularly true if game hunting is included. Hunting for bear, caribou, moose, and sheep draws hundreds of people to the state each year and contributes many thousands of dollars to the economy" Source: WRCC, 2018 https://wrcc.dri.edu/Climate/narrative_ak.php.*

The WRCC also provides specific Alaska community or area centric climate summaries for (Figure 6-85). They can be accessed at: https://wrcc.dri.edu/summary/climsmak.html.

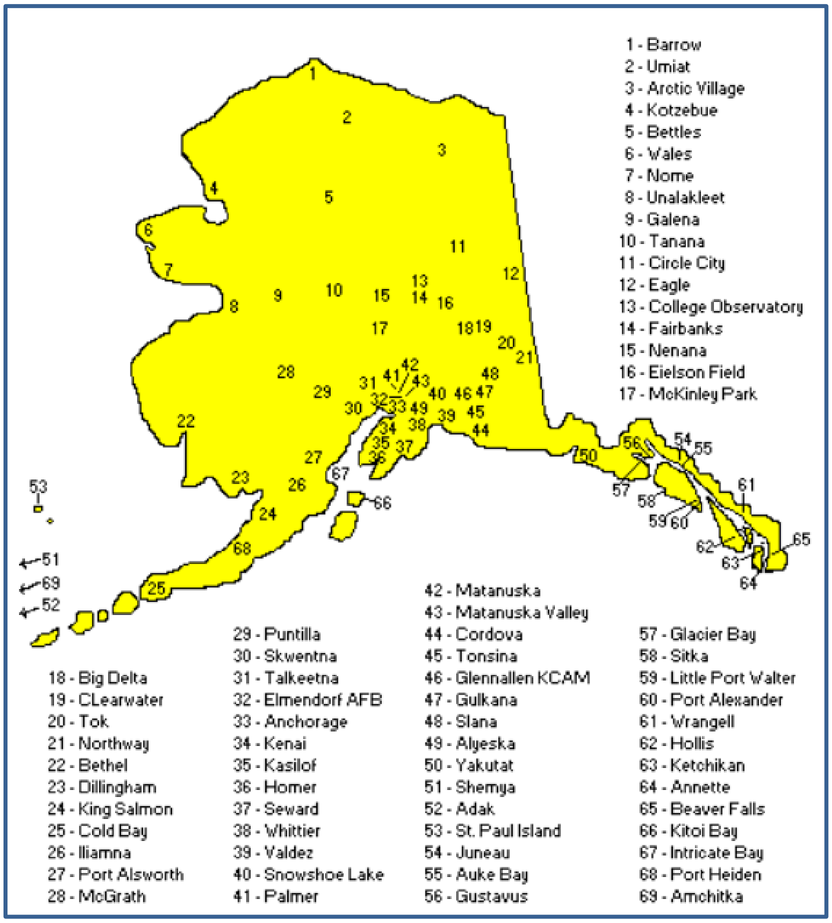



**Figure 6-85 WRCC Climate Summaries for Alaska Communities**
*Source: WRCC 2018*

The Alaska Geospatial Data Clearinghouse (AGDC) and the Spatial Climate Analysis Service (ACAS) describe the state's locational severe weather event differences (Figure 6-86).

*Maximum seasonal differences (mean January-mean July) in surface temperature occur in central Alaska and adjacent areas of Canada, while minimum seasonal differences occur in southeast Alaska, in a narrow coastal region around much of the state, and throughout the Aleutian Islands... For precipitation, positive seasonal differences occur in southeast Alaska... The coasts of south-central Alaska and the Aleutian Islands (especially the outer islands) also have some positive seasonal differences, but these are generally smaller than those in southeast Alaska. Maximum negative differences occur in some northern portions of south-central Alaska, in interior Alaska, and in adjacent areas of Canada. This annual variation is determined by the seasonal cooling and warming of the interior while coastal variability is moderated by the oceans. Again, the black overlay in Figure 6 was applied after the differencing between modeled data sets was performed…*

*Annual (12 month) mean monthly surface temperatures (°C) were computed for the AGDC and the SCAS data sets (Fig. 8a, b). Maxima occur in the coastal regions of southeastern and south-central Alaska, the Alaska Peninsula and along the Aleutian Islands. Minima occur in the mountains (Alaska Range, Chugach Mountains, and*

*Wrangell-St. Elias Mountains) of south-central Alaska, northern Alaska (Brooks Range and North Slope), and adjacent areas of Canada. Mean monthly statewide temperatures at each time step (Fig. 8c) show an annual cycle with a high in July and a low in January. Monthly mean temperature differences (AGDC – SCAS) are relatively small compared to the dynamic range of Alaskan surface temperatures (Fig. 8d).*

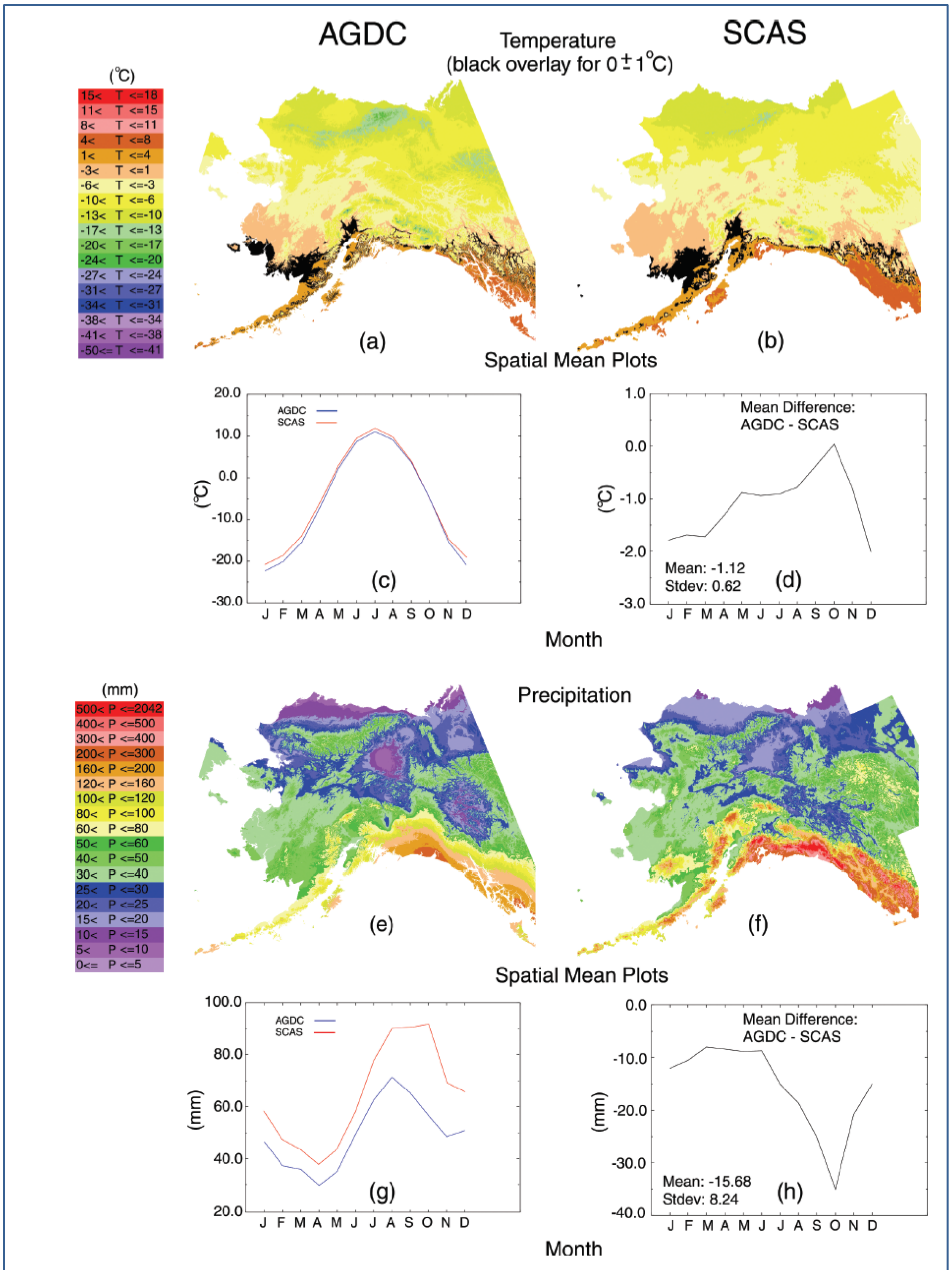



FIG. 8. Annual (12 month) means and spatially averaged monthly means of the variables for the AGDC and SCAS data sets.

**Figure 6-86 Alaska Seasonal Temperature and Precipitation by Location**

*Source: AGDC and ACAS 2004:* [*https://www.researchgate.net/publication/228668828_Comparing_Maps_of_Mean_Monthly_Surface_Temperature_and_Precipitation_for_Alaska_and_Adjacent_Areas_of_Canada_Produced_by_Two_Different_Methods?_sg=n1lHQ1Hb2S0-hLanl5_cRbcR7geqGKZ6Sqyu63LVoXYZ0lN_r5Og_5XqiMMRDrsHkG2HRnU29w*]

## 6.7.3. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location*

The state experiences periodic severe weather impacts. The most common are heavy rain, sleet, and icing; along with high winds, extreme cold or heat, drought, and winter storms.

### *Extent*

All of Alaska is vulnerable to the severe weather effects. Each location experiences diverse affects to severe storm conditions, snow depths, wind speeds, and extreme temperature ranges.

### *Impact*

The intensity, location, and topography influence severe weather event impacts. Hurricane force winds, rain, snow, and storm surge can be expected to impact the entire area.

Extreme weather events such as , rain, snow, wind or a combinations of these conditions is transportation become immobilization (e.g., all transportation: air, boat, road; even snow machine, and ATV traffic stops). Impacts can range from unfortunate to catastrophic. Essential supply deliveries, emergency response, medical transport, and critical subsistence activities cannot resume until the weather clears and populations can move about safely.

Heavy snow accumulations can cause roof collapse and knock down trees and power lines. Heavy snow can also damage light aircraft and sink small boats. A quick thaw after a heavy snow can cause substantial flooding. Snow removal, damage repairs, and business disruptions can have severe economic impacts to individuals, villages, and cities.

Weather injuries and deaths usually occur from vehicle and/or snow machine accidents as well as overexertion and hypothermia caused by overexposure to severe weather events.

Aircraft may be grounded due to extreme cold and ice fog conditions, cutting off access and delaying community supply deliveries. Long cold spells can cause rivers to freeze, disrupt shipping, and increase the likelihood of ice jams and associated flooding or overflow threats.

Extreme weather interferes with community infrastructure and its proper functions. It can cause fuel to congeal in storage tanks and supply lines and stop electric power generation, which in-turn causes heaters and furnaces to stop and water and sewer pipes to freeze or rupture. If extreme cold conditions are combined with low or no snow cover, the ground's frost depth can increase, disturbing buried pipes. The greatest danger from extreme cold is the effect on people. Prolonged exposure to the cold and high winds can cause frostbite or hypothermia and become life-threatening; infants and elderly people are most susceptible. Carbon monoxide poisoning is also a possible effect as people will use supplemental heating devices not intended for indoor use during extreme weather events.

While the scope, severity, and pace of future climate change impacts are difficult to predict, it is clear that potential changes could affect our agencies' ability to fulfill their respective missions. The challenges posed by climate change, such as more intense storms, frequent heavy precipitation, heat waves, drought, extreme flooding, and higher sea levels could significantly alter the types and magnitudes of hazards faced by communities and the emergency management

professionals serving them. Some specific areas where climate change could influence response, recovery, and mitigation are:

- Coastal regions, which are becoming increasingly populated and developed. More frequent severe storms may increase the necessity of increased emergency services and associated response and recovery capacity.
- Critical infrastructure resiliency is necessary to ensure operational continuity service delivery is essential and may experience task priority challenges.

### *Recurrence Probability*

Alaska will continue to experience diverse and seasonal severe weather events. The state has a 1 in 1 year (1/1=100 percent) chance for severe weather to occur within any given year.

## 6.8. WILDLAND FIRE AND COMMUNITY FIRE CONFLAGRATION

While a part of the natural ecosystem, fires in Alaska are a dangerous hazard when they involve local communities. During the five year period spanning 2013 through 2018, over 82 fire-related fatalities were recorded in Alaska. Since 2013, the State has declared over 3,077 fire related emergencies or disasters.

For the purposes of profiling the hazard in Alaska, fires in this section are characterized by their primary fuel source into two categories:

- Wildland fire, which consumes natural vegetation.
- Community fire conflagration, which propagates among structures and infrastructure.

Fire is a natural wildland management force in the Alaskan Interior. It is a key environmental factor in cold-dominated ecosystems. Without fire, organic matter accumulates, the permafrost table rises, and ecosystem productivity declines. Fire rejuvenates an ecosystem by removing decaying matter and returning their nutrients to the soil, preserving vegetative diversity and wildlife habitat unique to Alaska. In the absence of wildland fires, many plant and animal species would no longer thrive.

While fire is critical for maintaining the viability of Alaska's ecosystems, it must be tempered with the need to protect human life and property. This is particularly true of fires burning in "wildland urban interface" areas, where structures and other human development meet or intermingle with undeveloped wildland. Wildland urban interface (WUI) has gained importance throughout Alaska with increased development adjacent to wild lands.

Firefighter and public safety is the primary concern of each local and wildland response agency. In Alaska, thousands of acres burn every year in 300 to 800 fires primarily between the months of March and October. According to the Alaska Interagency Coordination Center (AICC), Alaska lost 7,815,367.8 acres from 2013 through 2017. This figure consisted of the 2,408 wildland fires that started throughout that same time period. This is an average of 3,246 acres per wildland fire.

### 6.8.1. MANAGEMENT IN ALASKA

Wildland fire management in Alaska is a joint effort among federal, state, local, and tribal governments, native organizations, local fire departments, communities, and landowners. The land management agencies, also known as jurisdictional agencies, have the overall land and resource management responsibilities as provided by federal, state or local law.

The "Alaska Master Cooperative Wildland Fire Management and Stafford Act Response Agreement," Exhibit C, found in the "2018 Alaska Statewide Annual Operating Plan," provides essential agency coordination information. Table 2 within the plan lists statewide fire dispatch centers demonstrating their commitment to effective firefighting resource allocation and coordination (Figure 6-87) throughout the state.

Table 2: Alaska Dispatch Centers

| Dispatch Center | Location | Managing Agency |
|---|---|---|
| Alaska Interagency Coordination Center | Fort Wainwright | BLM/AFS |
| State Logistics Center | Fairbanks | DNR |
| Anchorage Interagency Dispatch Center* | Anchorage | BLM |
| Upper Yukon / Tanana / Military Zone Dispatch Center | Fort Wainwright | BLM/AFS |
| Galena Zone Dispatch | Galena | BLM/AFS |
| Delta Area Dispatch | Delta Junction | DNR |
| Fairbanks Area Dispatch | Fairbanks | DNR |
| Kenai Interagency Dispatch Center | Soldotna | DNR |
| Mat-Su Area Dispatch | Palmer | DNR |
| Southwest (McGrath) Dispatch | McGrath | DNR |
| Tok Area Dispatch | Tok | DNR |
| Valdez-Copper River Area Dispatch | Glennallen | DNR |
| Chugach National Forest Dispatch | Anchorage | USFS |
| Tongass National Forest Dispatch | Ketchikan | USFS |

**Figure 6-87 Alaska Fire Dispatch Centers**
*Source: 2018 Alaska Statewide Annual Operating Plan, Exhibit C*

### Fire Management Options in Alaska

Prior to the planning efforts in the 1980s, decisions regarding wildland fire management were based upon available resources. In 1988, interagency planners established four fire management options (Critical, Full, Modified and Limited) and defined response priorities for each wildland fire option. Standard responses ranged from aggressive suppression to surveillance. In 1998, the 1988 management option definitions were incorporated into the Alaska Interagency Wildland Fire Management Plan update; the plan guides wildland fire response within Alaska.

Alaska wildland fire suppression agencies have developed and implemented the 2018 Alaska Interagency Wildland Fire Management Plan (http://fire.ak.blm.gov/administration/awfcg.php). The plan establishes response options and priorities. The range of responses provides an opportunity for agencies to achieve both protection and natural resource management goals and objectives, as well as essential fuels and vegetation management resources.

BLM in coordination with the AICC, provides the BLM Alaska Fire Management Plan Interactive Web Maps to support their fire mitigation initiatives. The following maps and associated tools depict Alaska Fire Management Plan components available to guide mitigation planning efforts and initiatives.

Figure 6-88 displays Alaska's wildland fire management options: Critical, Full, Modified, Limited and Unplanned.

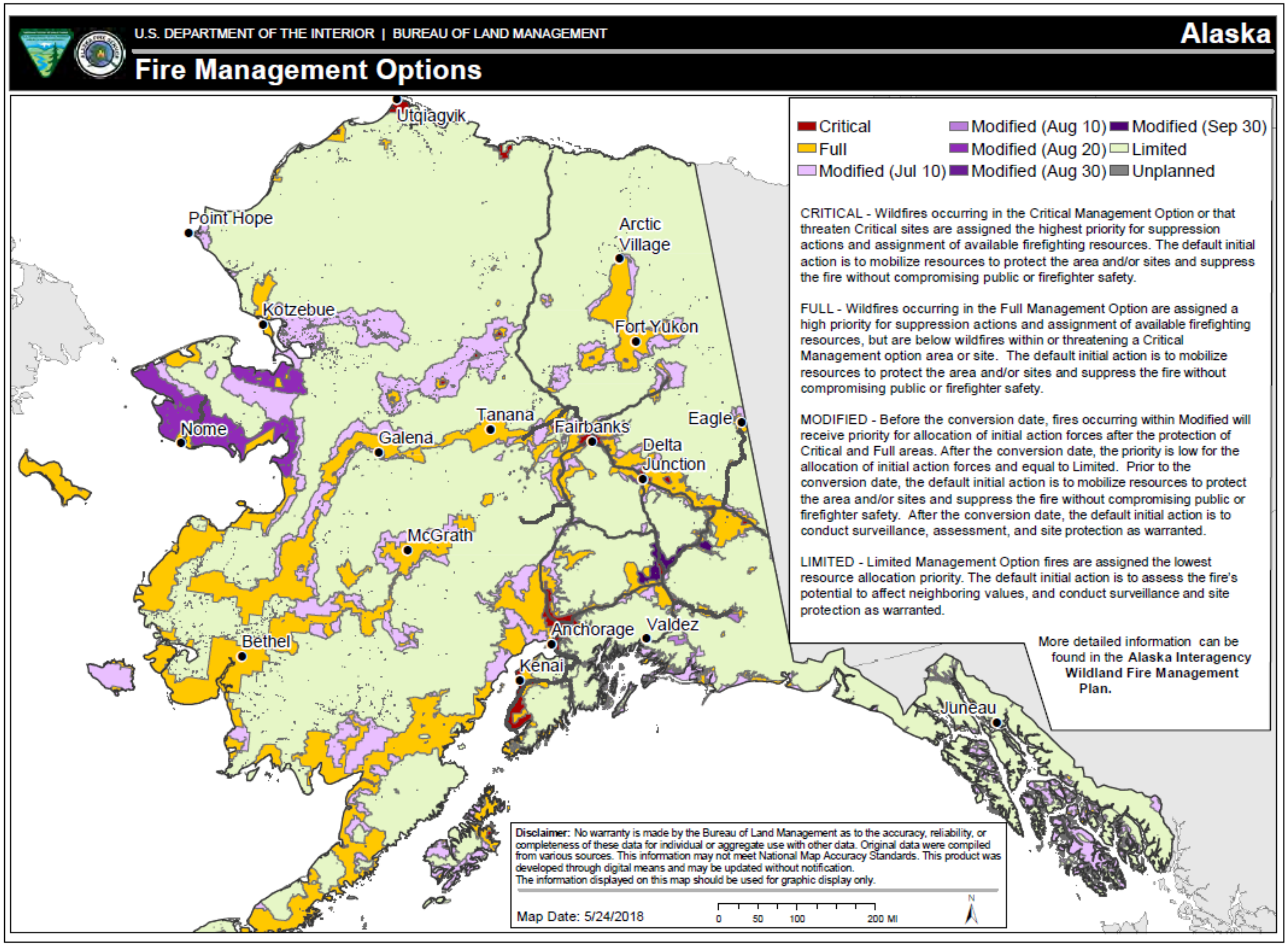



**Figure 6-88 Alaska Fire Management Options**
*Source: AICC, 2018*

Figure 6-89 depicts Alaska's 2018 fire management options and responsible jurisdictions.

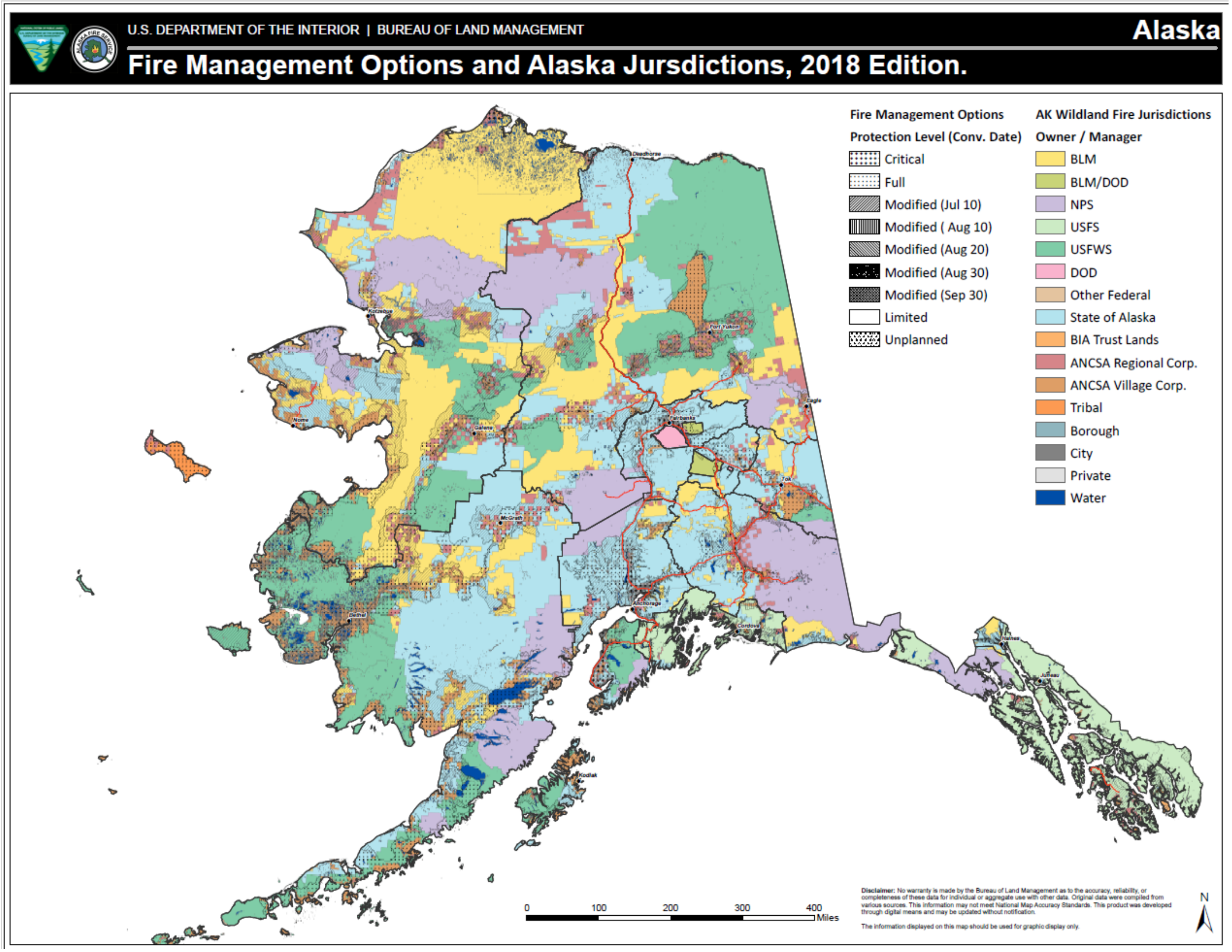



**Figure 6-89 Alaska Fire Management Options with Jurisdictional Responsibilities**
*Source: AICC, 2018*

Alaska is divided into three protection areas supported by diverse agencies as specified in the *Alaska Statewide Master Agreement:* (http://fire.ak.blm.gov/administration/asma.php). (Figure 6-90)

- US Department of Agriculture, Forest Service, and National Forest System
- Alaska Department of Natural Resources, Division of Forestry
- U.S. Department of Interior, Bureau of Land Management, and Alaska Fire Service

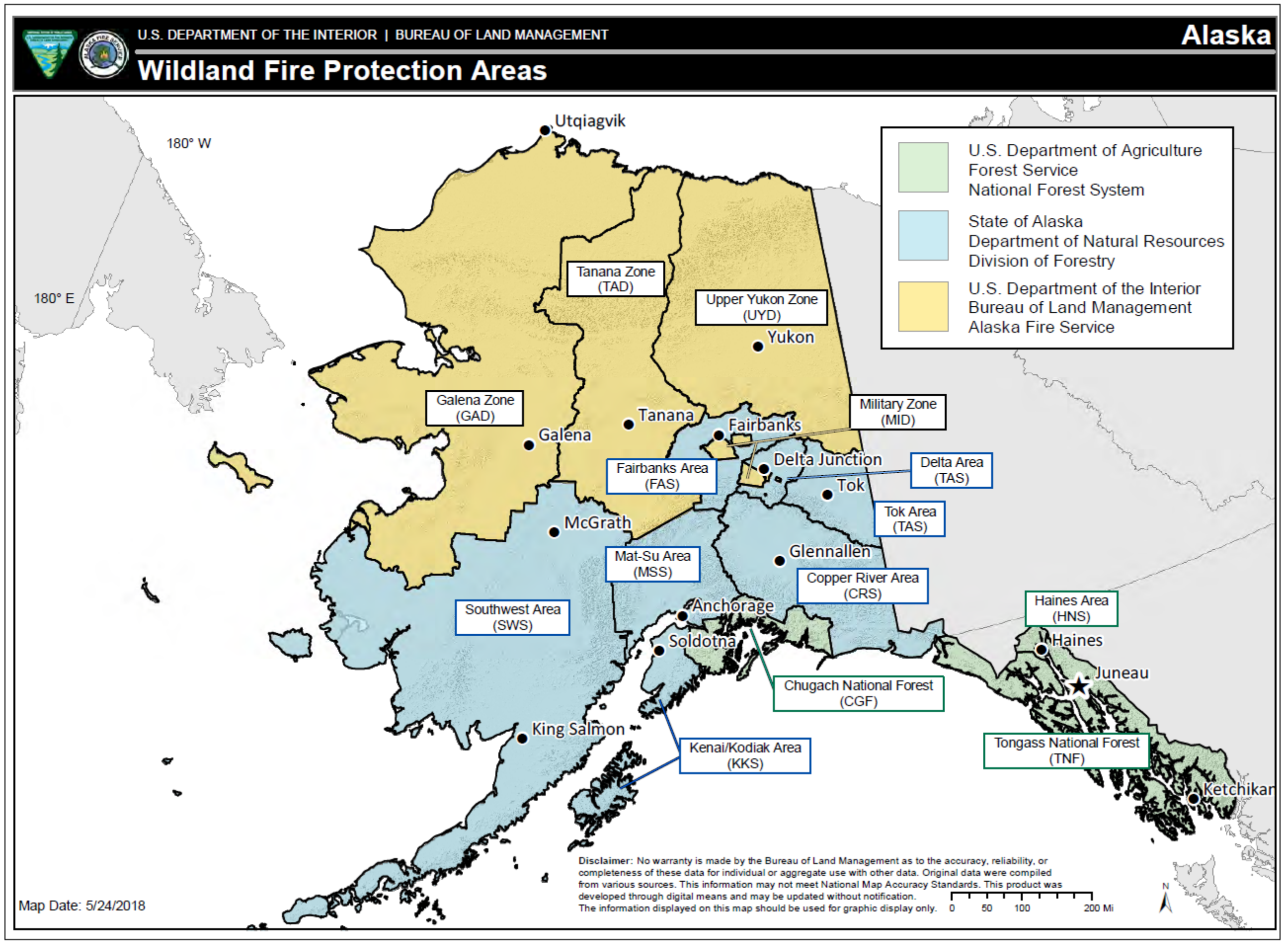



**Figure 6-90 Alaska Fire Protection Areas**

*Source: AICC, 2018*

## 6.8.2. WILDLAND FIRE HAZARD CHARACTERISTICS

A wildland spreads through vegetation consumption. It often begins unnoticed, spreads quickly, and is usually signaled by dense smoke that may be visible from miles around. Wildland fires can be caused by human activities (e.g., such as unattended burns or campfires) or by natural events such as lightning. Wildland fires often occur in forests or other areas with ample vegetation. In addition to wildland fires, wildfires can be classified as tundra fires, urban fires, interface or intermix fires, and prescribed burns.

The following three factors contribute significantly to wildland fire behavior and can be used to identify wildland fire hazard areas.

**Topography** describes slope increases, which influences the rate of wildland fire spread increases. South-facing slopes are also subject to more solar radiation, making them drier and thereby intensifying wildland fire behavior. However, ridge tops may mark the end of wildland fire spread since fire spreads more slowly or may even be unable to spread downhill.

**Fuel** is the type and condition of vegetation plays a significant role in the occurrence and spread of wildland fires. Certain types of plants are more susceptible to burning or will burn with greater intensity. Dense or overgrown vegetation increases the amount of combustible material available to fuel the fire (referred to as the "fuel load"). The ratio of living to dead plant matter is also important. Climate change is deemed to increase wildfire risk significantly during periods of prolonged drought as the moisture content of both living and dead plant matter decreases. The fuel load continuity, both horizontally and vertically, is also an important factor.

**Weather** is the most variable factor affecting wildland fire behavior is weather. Temperature, humidity, wind, and lightning can affect chances for ignition and spread of fire. Extreme weather, (e.g., high temperatures and low humidity) can lead to extreme wildland fire activity. Climate change increases the susceptibility of vegetation to fire due to longer dry seasons. By contrast, cooling and higher humidity often signal reduced wildland fire occurrence and easier containment.

The frequency and severity of wildland fires is also dependent on other hazards, such as lightning, drought, and infestations (e.g., the damage caused by spruce-bark beetle infestations). If not promptly controlled, wildland fires can grow into an emergency or disaster. Even small fires can threaten lives and resources and destroy improved properties; they can also impact transportation corridors and/or infrastructure. In addition to affecting people, wildland fires may severely affect livestock and pets. Such events may require emergency water/food, evacuation, and shelter.

The indirect effects of wildland fires can be catastrophic. In addition to stripping the land of vegetation and destroying forest resources, large, intense fires can harm the soil, waterways, and the land itself. Soil exposed to intense heat may lose its capability to absorb moisture and support life. Exposed soils erode quickly and enhance river and stream siltation, thereby enhancing flood potential, harming aquatic life, and degrading water quality. Lands stripped of vegetation are also subject to increased debris flow hazards.

**Climate Factors:** According to the Global Climate Change Impacts in the U.S., published in 2009 by the U.S. Global Change Research Program, "Under changing climate conditions, the average area burned per year in Alaska is projected to double by the middle of this century. By

the end of this century, area burned by fire is projected to triple under a moderate greenhouse gas emissions scenario and to quadruple under a higher emissions scenario." Climate Central's most recent assessment of large wildfires in Alaska appears to support that projection (Figure 6-91).

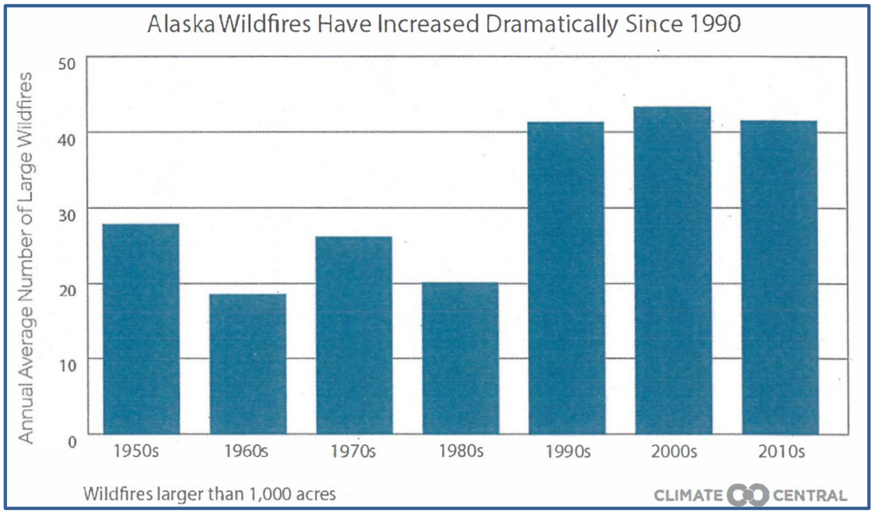



**Figure 6-91 Alaska Wildfires Have Increased Dramatically Since 1990**
*Source: "Age of Alaskan Wildfires", Climate Central, 2015*

Since 1990, Alaska has experienced nearly twice the number of wildfires per decade compared to periods 1950 through 1980. Additionally, the sparsely populated Arctic region experienced only three wildfires over 1,000 acres from 1950 to 1970. Since 2000, there have been over 33 large wildfires.

The average duration of the wildfire season in the Arctic region runs May through July. Other regions south of the Arctic, such as southcentral may run late April through mid-September, depending upon weather-related factors. Average annual precipitation in Alaska has increased since 1950, but not quite as much as the average annual temperature (Figures 6-92 and 6-93).

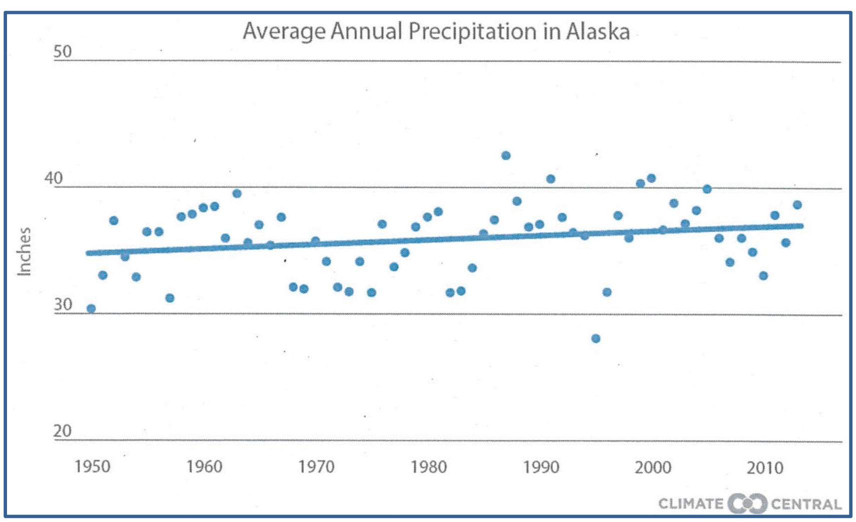



**Figure 6-92 Average Summer Precipitation in Arctic Alaska**
*Source: "Age of Alaskan Wildfires", Climate Central, 2015*

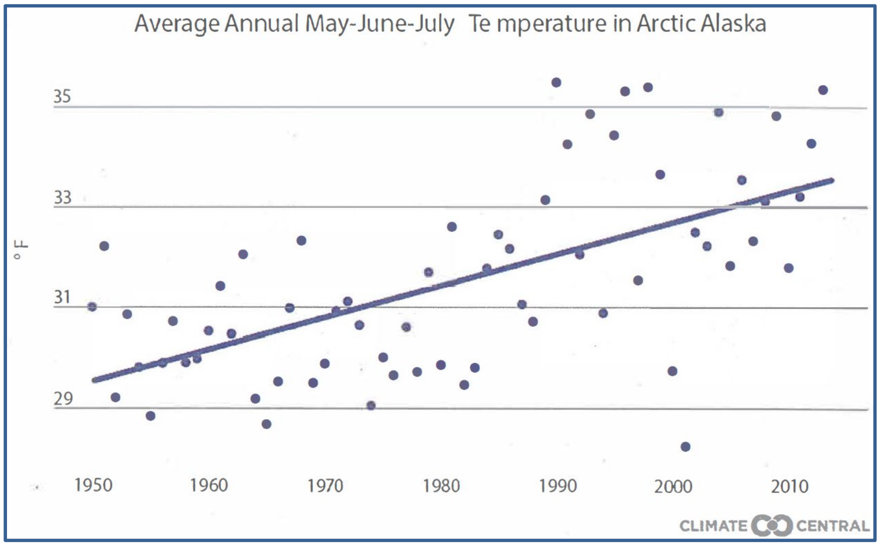



**Figure 6-93 Average Summer Temperatures in Arctic Alaska**
*(Source: "Age of Alaskan Wildfires", Climate Central, 2015)*

## 6.8.3. WILDLAND FIRE HAZARD HISTORY

The Alaska Division of Forestry and the Alaska Fire Service (State Agency Collectively) identified the following human-caused "High Profile Fires." These included the McHugh Creek, Sockeye, Funny River, Hasting, Caribou, and Parks Highway fires (Table 6-8).

**Table 6-8 High Profile State Agency Managed Wildfires**

| Fire Name | Fire Number | Year | Area Burned (Acres) | Location | Forestry Office | Estimated Cost | Residences Destroyed | Outbuildings Destroyed | Buildings Damaged |
|---|---|---|---|---|---|---|---|---|---|
| **McHugh Creek** | 601541 | 2016 | 780 | MOA | Matanuska Susitna Area (MSA) | 6,261,621 | -- | -- | -- |
| **Sockeye** | 501282 | 2015 | 7,220 | Willow | MSA | 7,347,213 | 55 | -- | 44 |
| **Funny River** | 403140 | 2014 | 195,858 | KPB | Kenai Kodiak Area (KKA) | 14,319,380 | -- | -- | -- |
| **Hasting** | 111271 | 2011 | 54,000 | FNSB | Fairbanks Area (FAS) | 18,476,249 | 1 | 1 | -- |
| **Caribou** | 703278 | 2007 | 56,000 | KPB | KKA | 7,124,524 | 88 | 109 | -- |
| **Parks Highway** | 611163 | 2006 | 130,000 | Nenana | FSA | 9,654,725 | 2 | 14 | -- |

DHS&EM tracks State and federal disaster declarations within their Disaster Cost Index (DCI). The DCI listed the following fire events that lists affected communities and agencies as applicable within each event (spanning 2013 through present).

***AK-15-247 2015 Alatna Washeteria Fire declared by Governor Walker on April 25, 2015:*** *On the morning of 15 April, 2015, the Multi-Purpose Building in Alatna caught fire in the boiler room. The building houses the water treatment facility, Washeteria, and clinic. The fire was extinguished, but not before it caused substantial damage to the water treatment facility and heating components, rendering both inoperable. The Washeteria and*

*clinic sustained substantial smoke damage. Extensive damage to the electrical wiring in the Multi-Purpose Building has been reported and the entire building is without power. Damage to the water treatment facility has cut off the supply of potable water to the village. The cause of the fire is unknown at this time. Currently, village residents are able to drive across the Koyukuk River to Allakaket, five miles away on the other bank, and access potable water and the clinic; however, this option will not be viable for long as break-up is imminent.*

***AK-15-249 2015 Sockeye Wildfire declared by Governor Walker on June 15, 2015:*** *Beginning on June 14, 2015 and continuing, a large urban interface wildfire exacerbated by record high temperatures caused widespread damage to the community of Willow and surrounding areas of the Matanuska Susitna Borough. The response to the wildfire is hampered by red flag warnings for record warm temperatures, strong winds, low humidity, and dry thunderstorms this month that affects the entire central portion of the state, including the Matanuska Susitna Borough. The wildfire has damaged or destroyed at least 50 private homes and/or secondary structures and damaged several more, and resulted in 175 residents seeking refuge in temporary shelters, although these numbers are expected to rise. The following conditions exist as a result of this disaster: a robust emergency response and management operation requiring substantial additional labor, equipment, and support costs to combat the fire; activation of the emergency operations center; damage or destruction of at least 50 homes and other structures; evacuation and sheltering of 175 residents and hundreds of pets/work animals to date; severe damage to personal and real property; disruption of power, natural gas, communications, and other utility infrastructure requiring temporary and permanent repairs. A federal Fire Management Grant (FMAG) has been authorized to assist in the cost of suppression.*

***AK-15-250 2015 Kenai Wildfire declared by Governor Walker on June 19, 2015:*** *Beginning on June 15, 2015 a series of wildfires have occurred in the Kenai Peninsula Borough as a result of prolonged hot, dry weather and human error. The most significant of these is the Card Street Wildfire which began on June 15 and damaged 11 buildings in Sterling, including 3 primary residences. The fire moved away from residences into the Kenai Wildlife Refuge... The Alaska Division of Forestry, local firefighters, and national wildland firefighter teams are currently working to gain control of the Card Street fire and numerous other fires within the Borough. A federal Fire Management Grant (FMAG) has been authorized to assist in the cost of suppression. The SEOC has been fully activated to support firefighting efforts. In addition, the AK National Guard and DOD are providing fire suppression support with troop and resource deployments as well as supporting SEOC operations.*

***AK-15-251 2015 Summer Alaska Wildfires*** *Beginning on June 14, 2015 and continuing, wildland fires have impacted multiple communities throughout the state requiring emergency response, evacuations, and sheltering. Due to ongoing fire growth and new fire starts, the number of communities that will be impacted or threatened and the extent of community fire damage is unknown. Current and forecasted weather including warm temperatures, strong winds, low humidity, and dry thunderstorms indicate a continued wildland fire threat to the state. The following conditions exist as a result of this disaster: a robust emergency response and management operation requiring substantial additional labor, equipment, and support costs to combat the fire; activation of the emergency operations center; evacuation and sheltering of over 200 residents from five different communities.*

***<u>AK-16-259 2016 Kotlik Fire Disaster declared by Governor Walker on October 4, 2016:</u>*** *On August 18, 2016, a structural fire destroyed the old school facility and several nearby buildings in the Lower Yukon River community of Kotlik. Since construction of a new school in Kotlik in 2003, the old school was boarded up and utilities shut off to preserve it for future use. The fire also destroyed: a small city building used by the Native Village of Hamilton as their tribal office; a 100-foot section of boardwalk; and the teacher housing, a generator building, and two storage buildings owned by the Lower Yukon School District (LYSD).*

*The City of Kotlik Local Government submitted a local Disaster Declaration with Request for State Assistance, dated September 9, 2016 which was received by the DHS&EM on September 12, 2016. In their declaration, the City of Kotlik specifically requested disaster relief for debris removal/clean up, technical assistance and funding to reconstruct the City gymnasium, public disaster assistance for emergency protective measures, temporary and permanent repairs to school water and sewer pipe lines and electrical systems. (DHSEM)*

The State Division of Forestry provided the following details for the Kodiak Twin Creek Fire that started on August 27, 2015 (Figure 6-94):

*The Twin Creeks Fire, also known locally as the Chiniak Fire, started near the Kodiak Island community of Chiniak on Thursday evening, August 27. overnight and the next day strong winds quickly spread this fire through 5,000 acres of grass, timber and logging slash on Leisnoi, Incorporated lands. The Chiniak Library, at last one homne, and a cabin was destroyed by the fire.*

**Figure 6-94 Twin Creek Fire**
*Source: DOF, Kodiak, AK 2015*

The Twin Creek Fire involved a large portion of the island, threatening the entire Chiniak Community as depicted in Figure 6-95.

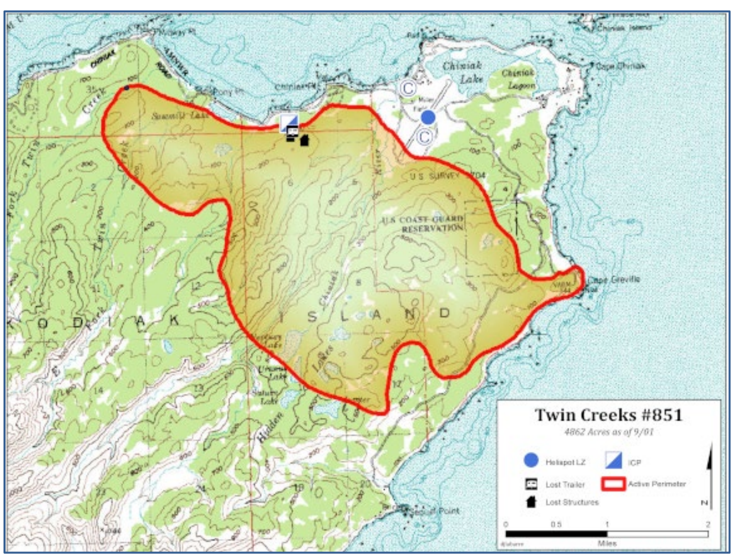



**Figure 6-95 Twin Creek Fire Perimeter Map**
*Source: DOF 2015*

The Alaska Interagency Coordination Center (AICC) identified wildland fires that occurred throughout Alaska since 1939 are displayed in Figure 6-96. The dataset is comprehensive the exact number and not pertinent to the SHMP update.

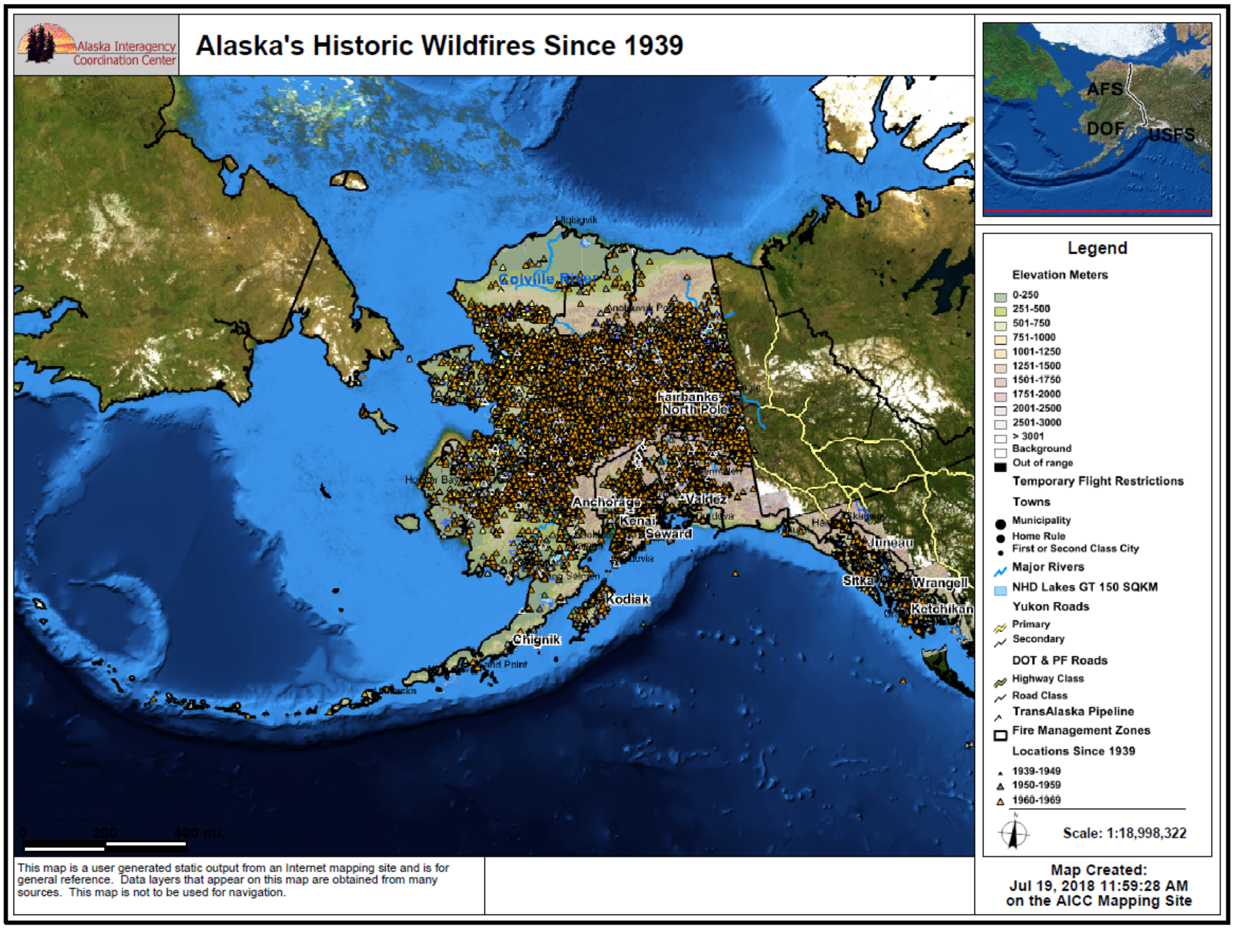



**Figure 6-96 Alaska's Historic Wildfire Locations**
*Source: AICC, 2018*

The Alaska Interagency Coordination Center (AICC) identified 3,077 wildland fires with 82 associated deaths (most deaths occurred in structure fires, with a few from wildfires) that have occurred throughout Alaska since the legacy 2013 SHMP was implemented. Table 6-9 lists the number of fires that occurred annually, acres burned, and the approximate total costs.

**Table 6-9 Alaska's Annual Wildfire Count Since 2013**

| Fire Year | Total | Acres Burned | Total Cost ($) |
|---|---|---|---|
| 2018 (Jan-July) | 354 | 433,925 | |
| 2017 | 362 | 653,148 | $20,969,348.78 |
| 2016 | 579 | 496,603 | $29,245,707.86 |
| 2015 | 771 | 5,146,541 | $134,652,246.69 |
| 2014 | 392 | 233,530 | $31,359,448.89 |
| 2013 | 619 | 1,320,978 | $77,124,691.41 |
| **Total** | **3,077** | **8,284,724** | **$293,351,443.64** |

*Source: AICC 2018*

Table 6-10 lists the costs from the Feds vs State perspective.

**Table 6-10 Actual Federal / State Cost Sharing from Table 6-12**

| Federal Costs | State Costs |
|---|---|
| $158,137,761 | $135,213,682 |

*Source: DOF 2018*

The Alaska Department of Forestry (DOF) and the Alaska Forest Service (AFS) identified 3,077 wildland fires that occurred throughout Alaska spanning 2013 through 2017. DOF, AFS, and the USFS protect land for a variety of owners. Table 6-11 data identifies number of fires by landowner and their approximate costs, but it does not provide acres burned, or their respective causes.

**Table 6-11 Wildfires not Identified by AICC Due to Land Ownership**

| Owner | Number (#) Fires | Approximate Fire # Percentage (%) | Fire Cost/ Agency ($) | Fire Percentage/ Agency (%) |
|---|---|---|---|---|
| ANCSA | 381 | 12% | $84,786,034 | 29% |
| BIA | 18 | 1% | $7,179,039 | 2% |
| BLM | 229 | 7% | $16,333,027 | 6% |
| BOROUGH | 81 | 3% | $4,412,717 | 2% |
| CITY | 56 | 2% | $116,030 | 0% |
| DOD | 200 | 6% | $40,300,334 | 14% |
| NPS | 99 | 3% | $3,105,843 | 1% |
| PRIVATE | 895 | 29% | $17,708,827 | 6% |
| STATE | 788 | 26% | $87,292,119 | 30% |
| USFS | 60 | 2% | $1,897,513 | 1% |
| USFWS | 270 | 9% | $30,219,960 | 10% |
| **Totals** | **3077** | **100%** | **$293,351,444** | **100%** |

## 6.8.4. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location*

Wildland fires may occur anywhere in Alaska when weather, fuel availability, topography, and ignition sources combine to form the most favorable wildland fire conditions. All of Alaska is considered to be vulnerable to wildland fire which includes various vegetation such as grasses and tundra. Since 2013, 3,077 wildland fire events (Table 6-11) have occurred within Alaska.

Figure 6-97 displays Alaska wildland fire locations since the legacy 2013 SHMP was implemented.

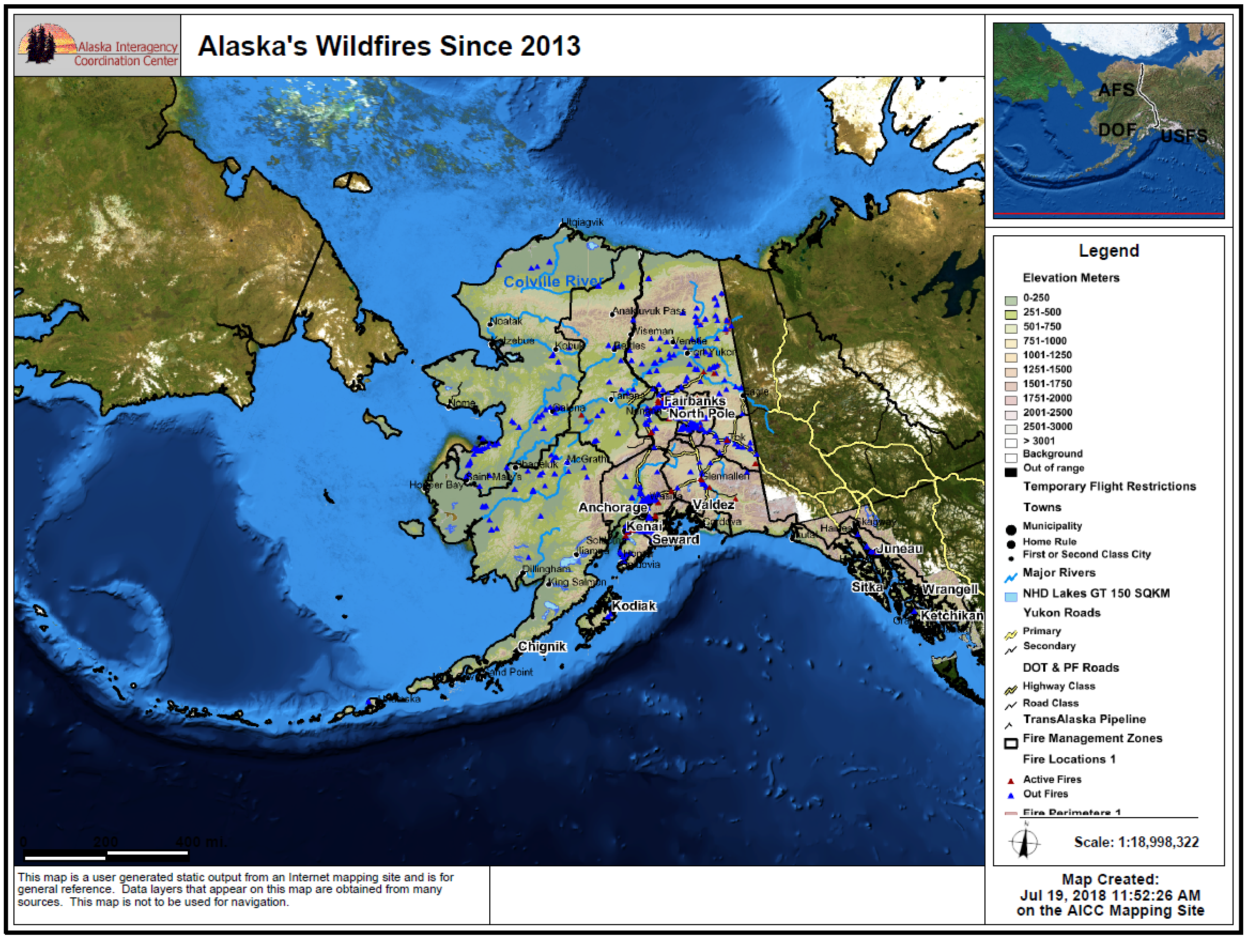
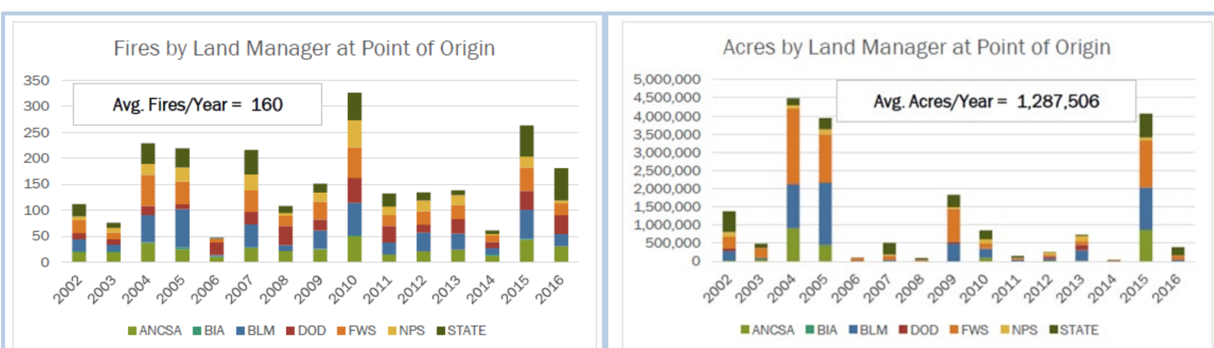
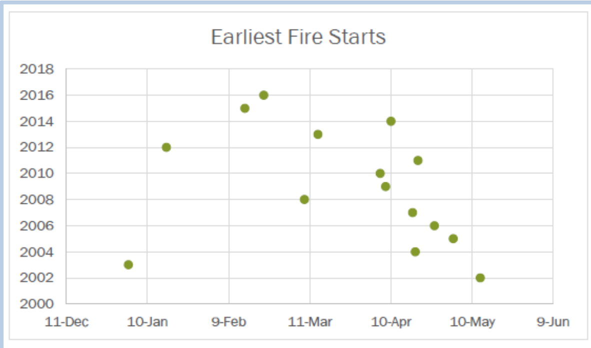


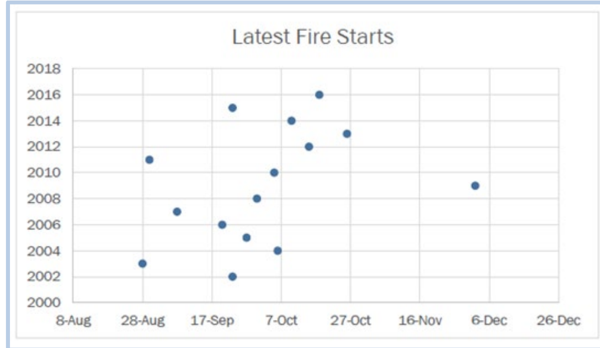

**Figure 6-97 Alaska's Historic Wildfire Locations Since 2013**
*Source: AICC 2018*

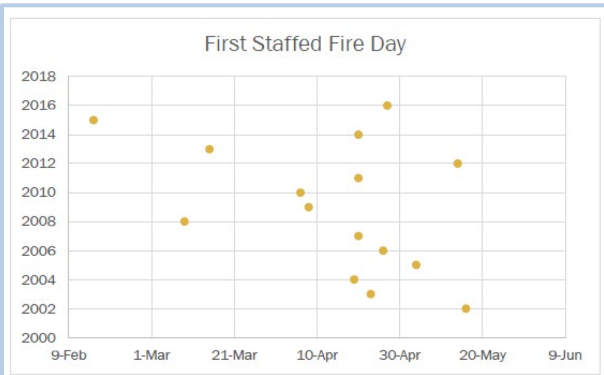
Figures 6-98 (includes the following 12 charts) displays the AFS's seasonal wildland fire threat statistics.

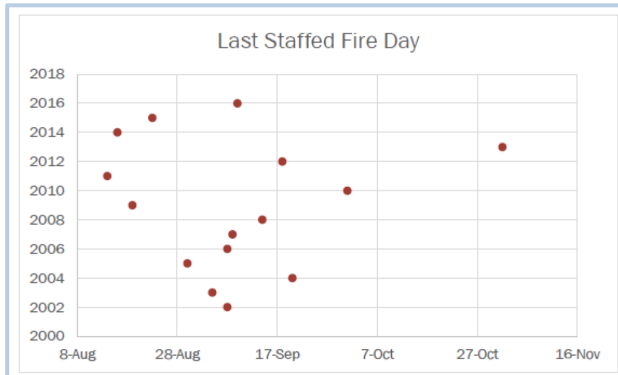


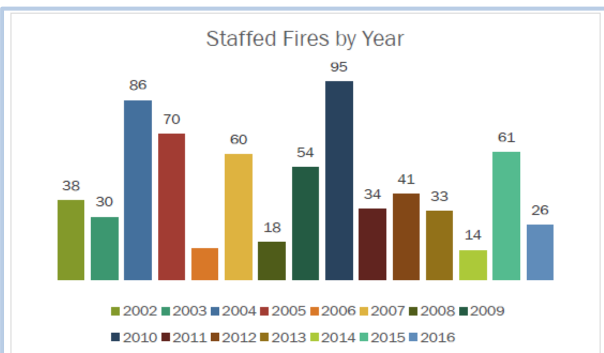

Acres Protected by Land Manager
ANCSA 23,577,576 12% BIA 514,727 0% BLM 58,409,573 31% DOD 1,606,865 1% NPS 26,163,254 14%
OTHER FED 827 0% PRIVATE 55,485 0% STATE 34,617,104 18% USFWS 46,139,307 24%

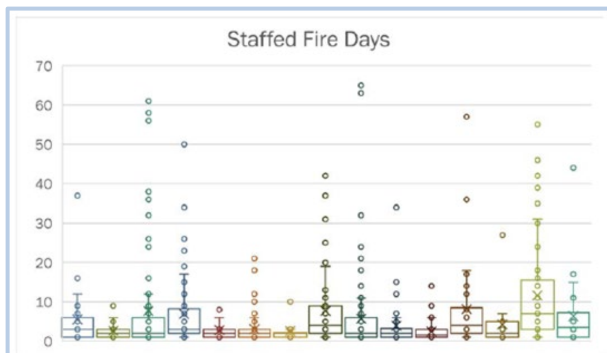

Earliest Fire Starts
2018
2016
2014
2012
2010
2008
2006
2004
2002
2000
11-Dec
10-Jan
9-Feb
11-Mar
10-Apr
10-May
9-Jun

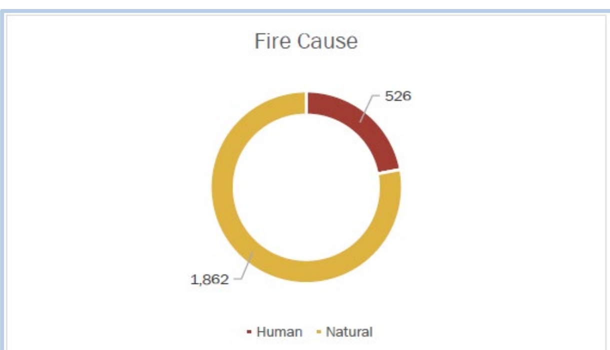

Latest Fire Starts
2018
2016
2014
2012
2010
2008
2006
2004
2002
2000
8-Aug
28-Aug
17-Sep
7-Oct
27-Oct
16-Nov
6-Dec
26-Dec

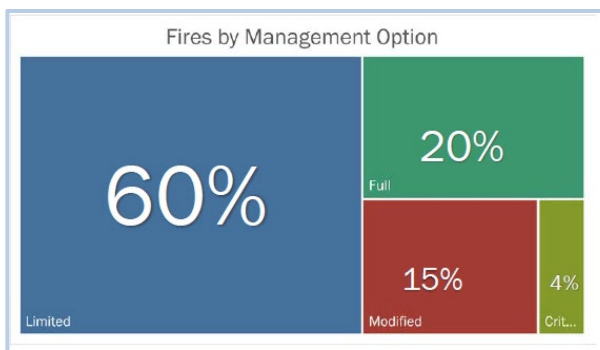

First Staffed Fire Day
2018
2016
2014
2012
2010
2008
2006
2004
2002
2000
9-Feb
1-Mar
21-Mar
10-Apr
30-Apr
20-May
9-Jun

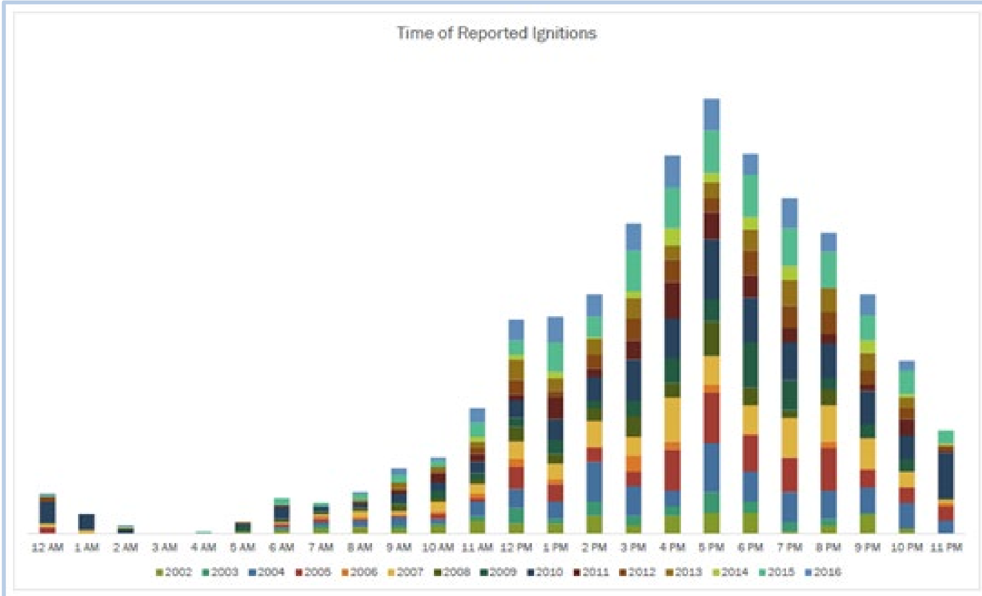

Last Staffed Fire Day
2018
2016
2014
2012
2010
2008
2006
2004
2002
2000
8-Aug
28-Aug
17-Sep
7-Oct
27-Oct
16-Nov

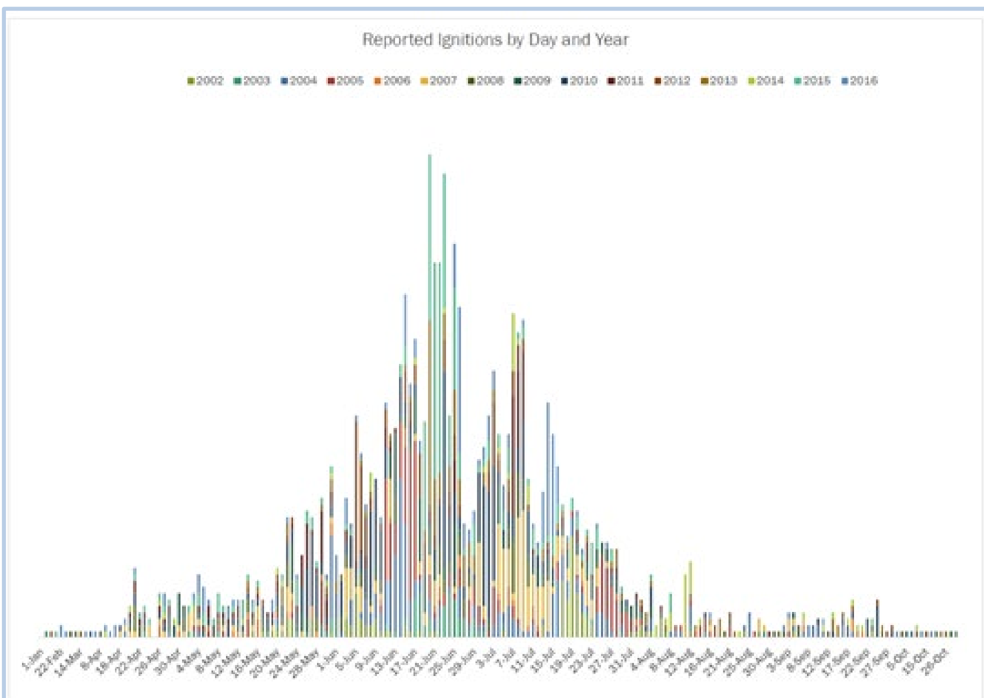

Staffed Fires by Year
38
30
86
70
60
18
54
95
34
41
33
14
61
26
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016


Staffed Fire Days
70
60
50
40
30
20
10
0


Fire Cause
526
1,862
Human
Natural


Fires by Management Option
60%
Limited
20%
Full
15%
Modified
4%
Crit...

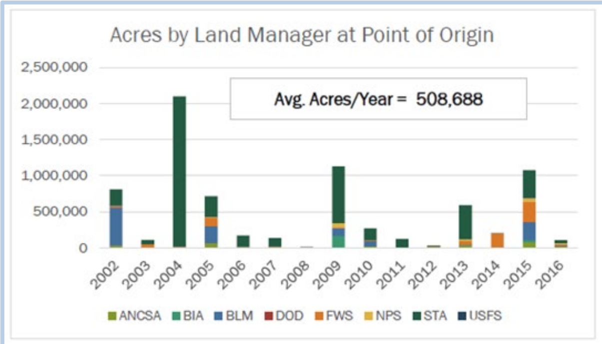


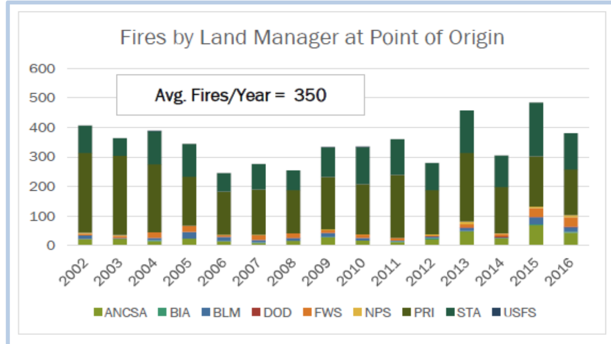



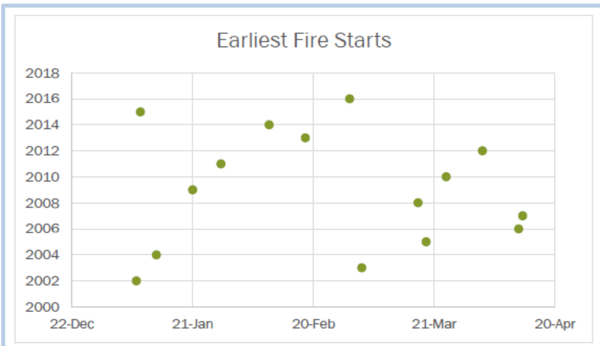

**Figures 6-98 2002-2016 AFS Fires Statistics**

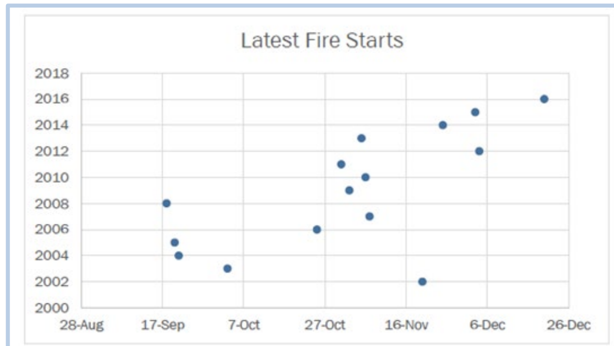
*Source: AFS 2018*

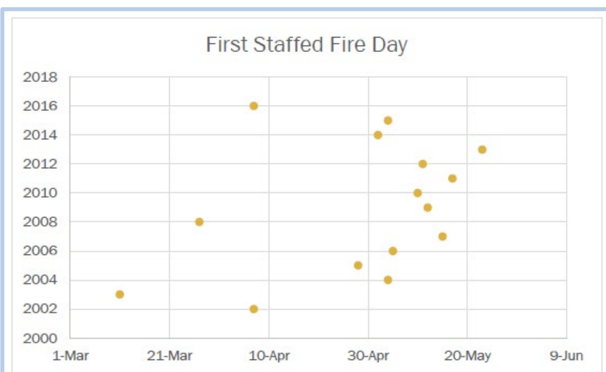
Figures 6-99 (includes the following 12 charts) displays the DOF's seasonal wildland fire threat statistics.

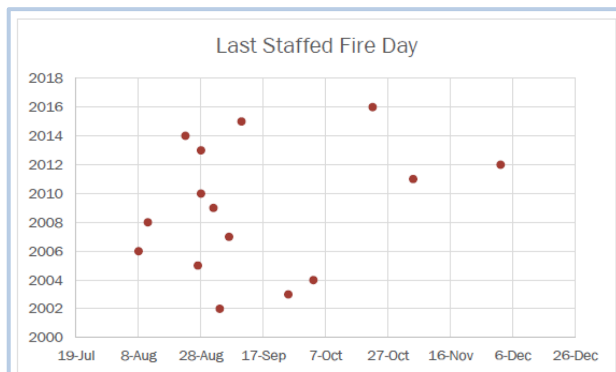


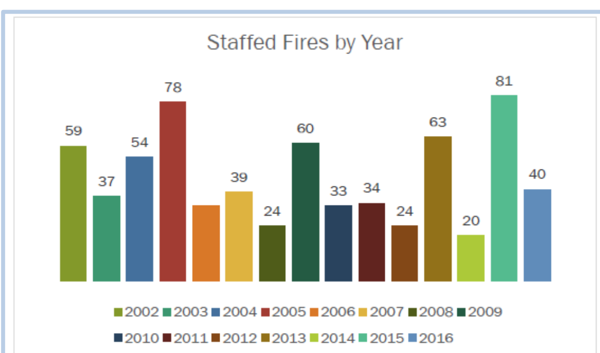



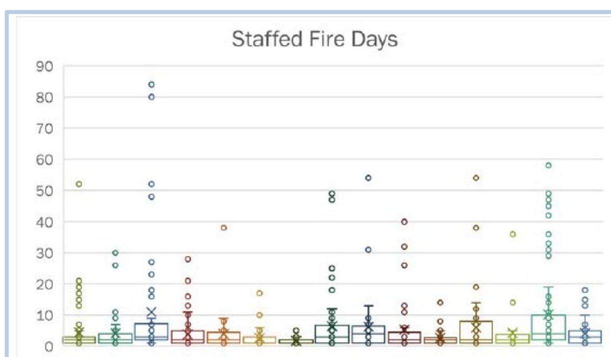



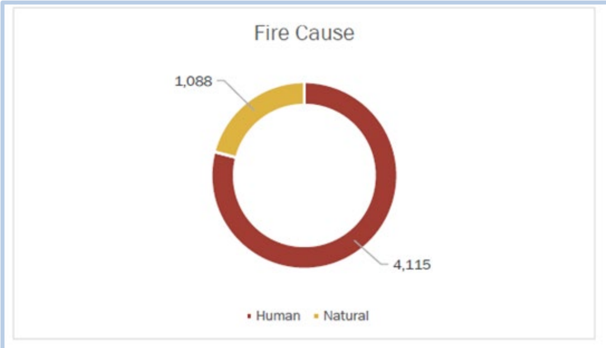



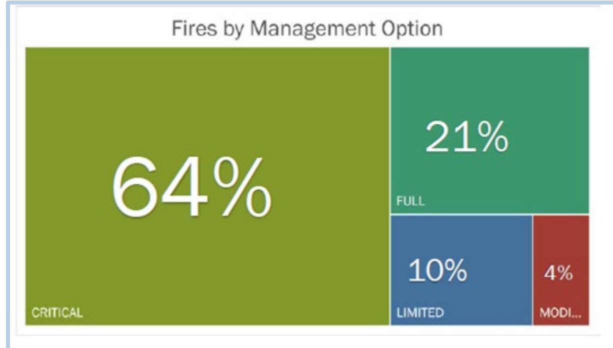



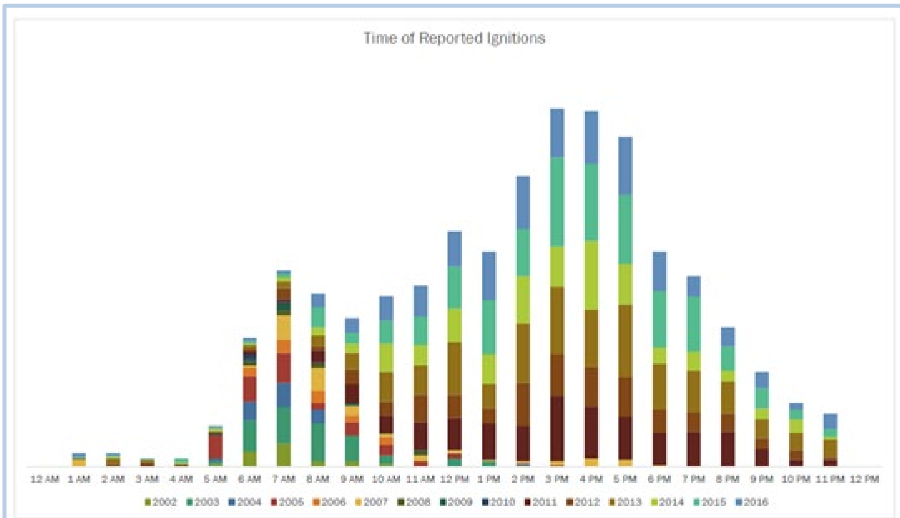



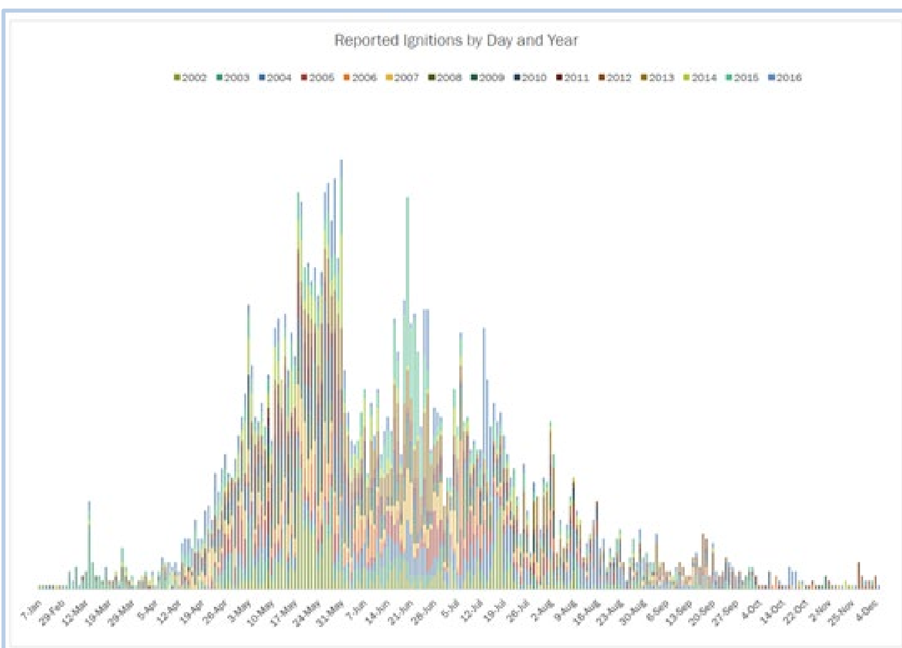






**Figures 6-99 2002-2016 DOF Fires Statistics**

*Source: DOF 2018*

## 6.8.5. CONFLAGRATION FIRE

Urban conflagration is a large destructive fire that is widespread throughout an urban area or community involving one or more developed areas in the community. In contrast to the commonly destructive individual property fire, conflagration involves a larger portion of the community's built environment. In small communities, conflagrations frequently overwhelm resources and damage infrastructure. In rural Alaskan communities, the loss of a critical building, such as a school, may warrant a local disaster declaration.

## 6.8.6. CONFLAGRATION HAZARD CHARACTERISTICS

Conflagration fires are very difficult to control. Complicating factors are wind, temperature, slope, proximity of structures, and community firefighting capability, as well as building construction and contents. Additional factors facing response efforts are hazardous substance releases, structural collapse, water service interruptions, unorganized evacuations, and loss of emergency shelters. Historical national conflagration examples include the Chicago City Fire of 1871 and the San Francisco City fire following the 1906 earthquake.

***Structural Fire vs. Wildland Fire***

Many wildland firefighters are neither equipped nor trained for structure fires. Structural fire suppression within defined service areas is the responsibility of volunteer, city, or borough fire departments. When wildland firefighters encounter structure, vehicle, dump or other non-vegetative fires during the performance of their wildland fire suppression duties, firefighting efforts are often limited to wildland areas.

## 6.8.7. CONFLAGRATION HAZARD HISTORY

DHS&EM tracks State and federal disaster declarations within their Disaster Cost Index (DCI). The DCI listed the numerous remote locational wildland fire events, many of which burned residential properties and could be called urban interface fire events (Section 6.8.3).

Substantial community infrastructure can be damaged or destroyed from a single fire event. These fires can cripple remote communities when they lose basic utilities (e.g., power, water, stores, clinics) and structure uses by any hazard event. Structure fires are more likely to threaten human life. AFS and DOF state that 82 lives were lost in structure and wildland fires from 2013 to 2017.

Alaska community fires listed in the Disaster Cost Index (Table 6-12) include:

**Table 6-12 Historical Community Fires**

| Location | Date | Impacts |
|---|---|---|
| Kotlik Structure Fire | 08/16/2016 | A structural fire destroyed the old school facility and several nearby buildings |
| Kenai Wildfire | 06/05/2015 | Card Street Wildfire which began on June 15 and damaged 11 buildings in Sterling, including 3 primary residences. |
| Sockeye Fire | 06/15/2015 | A large urban interface wildfire exacerbated by record high temperatures caused widespread damage to the community of Willow and surrounding areas of the Matanuska Susitna Borough. |

**Table 6-12 Historical Community Fires**

| Location | Date | Impacts |
|---|---|---|
| Alatna Multi-Purpose Building Fire | 04/15/2015 | The Multi-Purpose Building in Alatna caught fire in the boiler room. The building houses the water treatment facility, Washeteria, and clinic. |
| Stuart Creek Fire | 06/14/2013 | The fire started during an Army artillery training exercise, burned more than 87,000 acres required evacuating of 1,200 residents and ,many sled dog teams from the area. It was one of the largest wildfires in the U.S. in 2013. This fire cost $21 million to fight the fire. |
| Dot Lake Fire | 08/28/2011 | The village utility building provided water and heat for several home homes in the community through an underground utilidor and is utilized as a watering point for other residents in the area. |
| Birch Creek Fire | 05/26/2011 | The tribal office building fire spread and destroyed the community's power plant, tribal office, potable watering point, and telephone building. |
| Hooper Bay Fire | 08/03/2006 | The fire continued through the next day and resulted in the destruction of the community's elementary school, high school, school support facilities, community store, and 14 homes – nearly 10% of the entire community. |
| Sleetmute | 12/20/2001 | A fire destroyed the community building in Sleetmute. The building housed the clinic, Council Office, Village Public Safety Officer (VPSO) office, washeteria, and the TV equipment for the Alaska Rural Communication Service (ARCS) satellite station. |

Figure 6-100 provides an aerial view of the July 2013 Stuart Creek Fire, Pleasant Valley, AK.

**Figure 6-100 July 2013 Stuart Creek Wildland Urban Interface Fire**
*Source: Photo Courtesy InciWeb; Pleasant Valley Area 2013*

Sleetmute experienced a community fire in 2001 (Figure 6-101) that destroyed its tribal office, Village Public Safety Office, washeteria, and TV equipment for the ARCS satellite station.

**Figure 6-101 2001 Sleetmute Conflagration Fire**
*Source: DHS&EM, 2001*

## 6.8.8. LOCATION, EXTENT, IMPACT, AND RECURRENCE PROBABILITY

### *Location*

Under certain conditions wildland fires may occur anywhere in Alaska when weather, fuel availability, topography, and ignition sources combine to form the most favorable wildland fire conditions. Most of Alaska's urban centers could potentially experience a wildland/urban interface fire because of the state's extensive spruce bark beetle infestation, and excessive dry fuels surrounding residential neighborhoods.

The Municipality of Anchorage's (MOA) Anchorage 2004 "Wildfire, Dare to Prepare" Program Report, describes their efforts to reduce conflagration threats to the community.

> ***Managing for fire and forest health***
>
> *[Anchorage Fire Department] AFD uses science to make management decisions for fuel treatment projects. AFD Foresters work cooperatively with State Forestry fire behavior experts to assign prescriptions to forested areas. In addition, mitigation strategies focus on the home ignition zone for residential areas. This 100-200 foot radius around a structure has been proven time and again to be the most influential zone determining a home's ignition potential. Case studies from across America, Canada, and Australia show repeated accounts of homes burning to the ground while trees and surrounding vegetation remain green. Furthermore, documented research conducted by Jack Cohen of the Missoula Fire Sciences Laboratory substantiates efforts to reduce home ignitions through extending vegetation treatment and landscape management to the 100 foot radius. Source:* https://www.muni.org/Departments/Fire/Wildfire/Documents/ANCHORAGE_WILDFIRE_May_2004_Program_Report.pdf*)*

See Figure 6-96, page 6-143, Historical Wildfire Locations image depicts wildland fire prevalence as it could indicate urban interface fire potential that if not properly planned for could prove catastrophic.

### Extent

Urban interface fires generally follow similar patterns as a wildland fire; however, the fire engages with close proximity to infrastructure, utilities, and residential properties.

Fire susceptible fuels (e.g., slash, dry undergrowth, flammable vegetation) in close proximity to residences and infrastructure, coupled with weather and topography, influence fire behavior, potential threat, and community impact extent.

### Impact

Urban interface fires threaten Alaska's population centers if not properly controlled. A small fire can threaten lives and resources and destroy property. In addition to impacting people, these fires may severely threaten livestock and pets. Such events may require owners to consider evacuation and emergency shelter or determine how they will be able to provide emergency watering and feeding if their structures are destroyed or substantially damaged.

### Recurrence Probability

Increased community development, fire fuel accumulation, and weather pattern uncertainties indicate that seasonal wildfires will continue into the future. Communities and individuals need to develop plans to address this ever increasing threat.

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