GEOLOGICALLY HAZARDOUS AREAS

SKAGIT COUNTY

DISCUSSION AND
BEST AVAILABLE SCIENCE REVIEW

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GEOLOGICALLY HAZARDOUS AREAS
Introduction

The Washington State Growth Management Act (GMA) mandates that cities and counties adopt policies and regulations to protect the function and values of critical areas. Among these critical areas mandated for protection by the GMA are geologically hazardous areas. Skagit County's Comprehensive Plan states "*Geologically hazardous areas include areas susceptible to the affects of erosion, sliding, earthquakes, or other geologic events. They pose a threat to the health and safety of citizens when incompatible residential, commercial, industrial, or infrastructure development is sited in areas of a hazard. Geologic hazards pose a risk to life property, and resources when steep slopes are destabilized by inappropriate activities and development or when structures or facilities are sited in areas susceptible to natural or human caused geologic events. Some geologic hazards can be reduced or mitigated by engineering, design, or modified construction practices so that the risks to health and safety are acceptable. When technology cannot reduce risks to acceptable levels, building and other construction in above, and below geologically hazardous areas should be avoided.*"

Skagit County's Critical Areas regulations designate Geologically Hazardous Areas (SCC 14.24.400) based on the following definition (Skagit County Code (SCC) 14.04.020): "*Areas that, because of their susceptibility to erosion, sliding, earthquake, or other geological events, are not suited to the siting of commercial, residential, or industrial development consistent with public health and safety concerns.*"

The Washington State Department of Community, Trade and Economic Development (CTED), administrator of the GMA, describes geologically hazardous areas as those areas that "pose a threat to the health and safety of citizens when incompatible commercial, residential or industrial development is sited in areas of significant hazard." CTED further describes geologically hazardous areas as having "an important function in maintaining habitat integrity. Mass wasting events such as landslides and debris flows, contribute sediment and wood for building complex instream habitats, estuarine marshes and beaches important for fisheries, wildlife and recreation. At the same time, mass wasting events can harm habitat and lead to the need for stream restoration."

These definitions and descriptions by Skagit County and CTED indicate that the primary purpose of the geologically hazardous areas code is not necessarily to protect areas from development but to protect development from geologically sensitive areas. Identification of geologically hazardous areas provides local governments with a means to protect life and property from development of lands that are unsuitable due to geologic and hydrogeologic characteristics or features. Geologically hazardous areas designation provides protection to the individual and the general public by identifying and restricting development in areas that are geologically sensitive to development.

In some cases the preservation of geologically sensitive areas is managed by the federal government or the State of Washington, however under the Growth Management Act, it is the responsibility of local government to ensure protection from geologically hazardous areas within their individual jurisdictions. As the administrator for the Growth Management Act, CTED provides guidance for jurisdictions to consider the designation of Geologically Hazardous Areas.

CTED suggests the local jurisdictions to consider the following areas for designation as geologically hazardous areas:

- Erosion hazard areas (including river and coastal stream bank erosion areas and channel migration zones).
- Landslide hazard areas.
- Seismic hazards areas.
- Areas subject to other geological events such as mine hazard areas, volcanic hazard areas, rock fall areas, areas susceptible to debris/mud flows, differential settlement and liquefaction areas.

CTED further suggests that local government classify geologically hazardous areas as either known or suspected risk depending on the geologic information available to the local jurisdiction, or unknown risk where information is not available to determine the presence or absence of a geologic hazard.

Existing Conditions

Skagit County is an area of diverse geologic conditions which, under CTED's suggested designations, represent a known, suspect and unknown risk to development and public health. These geologic conditions include orogenic and volcanic forces in the Cascade Range and foothills of eastern Skagit County. The topographic extremes created by these mountain building forces have been further sculpted by ice, wind, and water, including multiple stades of glacial advance and retreat, resulting in the steep slopes, narrow river valleys, and broad "U" shaped glacial valleys characteristic of Skagit County. Sediments eroded from the mountains and valleys have been transported west by fluvial geomorphic processes for deposition in the deltaic environment of western Skagit County.

Glacial isostatic rebound and/or a subduction zone compression bulge in the lowlands of Skagit County may represent Holocene uplift. This uplift, combined with the erosion forces from the ocean, has resulted in the many coastal bluffs present along the coastline of Skagit County. The sediment eroded from the coastal bluffs are transported via drift cells and deposited on the many coastal beaches.

The geologic conditions of this region are further complicated by the presence of oceanic spreading centers off Washington's coast. The spreading centers create new ocean floor and continually push older oceanic crust to the west, resulting in some of the islands in western Skagit County. Oceanic crust pushed to the west eventually collides offshore with the thicker North American continental crust and is subducted. The compression associated with subduction results in a multitude of geologic events including seismic activity and the development of faults. As the crust is thrust downward toward the earths mantle, the oceanic crust melts forming the magma which is responsible for the orogenic and volcanic forces present in the Cascade Mountains. The diversity and complexity of these geologic characteristics and events give rise to a multitude of geologically hazardous conditions present within Skagit County.

Code review and comparison

The multitude of geologically hazardous conditions within Skagit County can be classified into the four separate categories recommended be CTED (2003). Those categories include Erosion Hazards, Landslide Hazards, Seismic Hazards, and Volcanic Hazards. Skagit County developed a fifth category which addresses those miscellaneous geologic hazards not specifically related to the four primary categories. The fifth category primarily includes alluvial fan deposits, which may indicate an area of mud or debris flow deposition, and mining hazards resulting from construction and/or operation of mines.

In order to utilize the information available to the County in identifying the five categories of geologically hazardous areas (and as further recommended by CTED), each category is elaborated to include descriptive elements provided by Skagit County's "Best Available Science" (BAS) review. Each of the elements described does not necessarily indicate a geologically hazardous area but may represent a known or suspect geologic condition commonly associated with geologically hazardous areas. The following is representative of the categories followed by the supportive elements. The data or BAS source for each element is included in parenthesis.

Erosion hazard elements include:

- Severe soil erosion areas (Soil Survey of Skagit County),
- Slopes greater then 30% (Soil Survey of Skagit County),
- Coastal beaches (geologic maps),
- Coastal bluffs (DOE Coastal Atlas), and
- Channel migration zones (geologic maps).

Landslide hazard elements include:

- Landslide hazard areas (Soil Survey of Skagit County, geologic maps, and DOE Coastal Atlas).

Seismic hazard subcategories include:

- High liquefaction areas (geologic maps),
- Active fault zones (geologic maps), and
- Tsunami and seiche hazard areas (geologic maps).

Volcanic hazard subcategories include:

- Volcanic debris flows/lahars (geologic maps).

Other geologically hazardous areas subcategories include:

- Alluvial hazards (geologic maps), and
- Mining hazards (geologic and mining maps).

The geologic conditions indicated in each of the elements may represent a risk to public health and property in the event that development encroaches into geologically hazardous areas. Skagit County's Comprehensive Plan includes a *Supplemental Map Portfolio* which includes a map illustrating potential geologically hazardous areas. Various other resources including geologic maps and studies identify additional suspect or known geologically hazardous areas within Skagit County (see references).

Jurisdictional Comparison of Landslide/Erosion Hazard Buffer Regulations

A review and comparison of critical areas codes for other local government jurisdictions indicate a variety of approaches for protection of geologically hazardous areas. However, two components are present in all of the local government jurisdictions. The two similar components present in the codes of other counties include: 1) all jurisdictions include at least erosion and landslide hazards as geologically hazardous areas, and 2) each local government jurisdiction has developed some methodology for establishing a buffer from landslide/erosion hazards or some site specific mitigations.

A comparison of what constitutes a geologic hazard is discretional to each jurisdiction depending on the characteristics of that jurisdiction. For example, Island County will not likely experience lahar inundation resulting from a volcanic eruption where Snohomish and Whatcom County have that risk. Therefore Island County may not include Lahar inundation or even volcanic hazards as geologically hazardous areas. Snohomish and Whatcom County would include volcanic hazards as geologically hazardous areas. Given the jurisdictional differences in geologic conditions, it does not appear a comparison of each category of geologically hazardous areas is warranted. Suffice to say that each jurisdiction has identified what geologic hazards pertain to their jurisdictions and have developed a buffer or mitigation system for protection of developments from geologically hazardous areas.

In contrast, given the diversity of measures utilized by local jurisdictions for protection of development from geologically hazardous areas, a comparison of buffer or mitigation methodologies utilized by other jurisdictions for protection of developments from geologically hazardous areas appears warranted. Skagit County's current Landslide Hazard mitigations require a minimum of a 30-foot buffer from the top, toe and all edges of landslide hazard areas. This buffer maybe reduced to 10 feet when an applicant demonstrates to the Administrative Official that the reduction will adequately protect the proposed development, adjacent develops and uses and the subject critical areas (SCC 14.24.430 (1)(h)). In the event site conditions warrant additional study, demonstration may include a slope stability model and quantitative analysis to meet the requirements of buffer reduction.

The following represents the minimum buffer/mitigation requirements for other Western Washington County jurisdictions:

- Whatcom County's Critical Areas Ordinance does not have a minimum buffer standard from landslide/erosion hazard areas. Whatcom County utilizes a variable buffer option which is dependent on the recommendations of a qualified professional and approval from the administrative official.

- Snohomish County's Critical Areas Ordinance for landslide hazard areas utilizes International building code standards for development from high gradient slopes. The International Building Code requires that setbacks/buffers from slopes shall be consistent with 1/3 to 1/2 the height of the slope, depending on the slope gradient and whether development is at the top or the base of the slope.

- Island County's Critical Areas Ordinance does not have a minimum buffer standard from landslide/erosion hazard areas. Island County utilizes a variable buffer option which is dependent on the recommendations of a qualified professional.

- King County requires a minimum building setback of 50 feet from the hazard areas or as prescribed by a critical area report prepared by a geotechnical engineer or geologist.

- Pierce County requires a minimum buffer of 50 feet or 1/3 of the height of the slope for descending slopes or 1/2 of the slope height for ascending slopes, whichever is greater, for development in the vicinity of landslide hazard areas.

- Kitsap County has multiple buffer requirements depending on a classification as high or moderate geologic hazards. Kitsap County requires a minimum buffer which is a distance equal to the height of the slope for areas of high geologic hazard or slopes greater then 30% and deemed or mapped as unstable. Moderate geologic hazards, described as slopes less then 30% and deemed or mapped as unstable, have a minimum setback of 40 feet from the top of the slope. All setbacks require a minimum of a 25 foot native vegetation buffer.

Skagit County currently prohibits development in landslide hazard areas unless the hazard can be fully mitigated to remove the risk. CTED recommends a 50 foot buffer from all landslide and erosion hazard areas to insure protection of developments from landslide hazard areas. Skagit County proposes to increase the buffer requirement from 30 to 50 feet from the top, toe and all edges of landslide/erosion hazard areas based on CTED's recommendation. Consistent with the current code, the buffer maybe reduced to 10 feet when a mitigation plan including quantitative analysis demonstrates that the reduction will adequately protect the proposed development, adjacent develops and uses and the subject critical areas (Proposed SCC 14.24.430 (2)(c)).

Best Available Science Review: Erosion Hazards

Undisturbed areas of the Pacific Northwest typically have dense vegetation and adequate organic debris. These characteristics decrease surface water runoff and reduce the risk of surface erosion. However, surface erosion can occur when the vegetation and organic debris are removed exposing the native soils. Low permeability soils generate greater surface water runoff which can initiate erosion or sediment transport quicker then higher permeability soils. In exposed areas, surface water runoff can concentrate and begin transporting sediment down gradient toward valley floors and eventually to sensitive receptors such as lakes, streams, wetlands and other undesirable deposition locations. Vegetation, slopes, gradients, soil type, rainfall, and other characteristics can be used to identify soil erosion hazard areas. Although most soil types are susceptible to erosion when subject to a disturbance, some soils are highly susceptible to erosion, depending on conditions and can encroach into developed areas rapidly presenting a risk to life and property. The following elements represent those areas or conditions that may be suspect or known erosion hazard areas.

(Erosion hazards and landslide hazards are both representative of mass wasting events and often occur together. In some cases landslide hazards become erosion hazards and erosion hazards become landslide hazards. As such, separating the two hazards becomes academic as both represent a risk to life and property. Although an effort has been made to separate the two hazards based on characteristics, some overlap in the "Best Available Science" documentation and discussion of erosion hazards and landslide hazards is unavoidable)

Severe Soil Erosion Hazard Areas

The Soil Survey of Skagit County (Natural Resources Conservation Service 1987) identifies soil formations that have severe erosion potential. These areas include soil formations identified by the Conservation Service as Andic Cryochrepts, Andic Xerocrepts, Birdsview, Dystric Xerochrepts, Dystric Xerothents, Guemes, Hoogdal, Lithic Haploxerolls, Marblemount, Mundt or Typic Croyorthods soil series.

Slopes in excess of 30%

Many of the erosion prone soils in Skagit County are associated with steep slopes. As indicated in the *"Severe Soil Erosion Hazard Areas"* section, the Soil Survey of Skagit County (Natural Resources Conservation Service 1987) identifies soil formations that have severe erosion potential. These areas include soil formations identified by the Conservation Service as Andic Cryochrepts, Andic Xerocrepts, Birdsview, Dystric Xerochrepts, Dystric Xerothents, Guemes, Hoogdal, Lithic Haploxerolls, Marblemount, Mundt or Typic Croyorthods soil series. All of the soils described by the Soil Survey of Skagit County as severe erosion potential are described as being present on slopes exceeding 30%. Although the 30% threshold does not apply to all soils in Skagit County, a 30% slope is a threshold which may be representative of a suspect or known erosion hazard area.

Coastal Beaches

Coastal Beaches (#9) are described by the Soil Survey of Skagit County as "*areas of long, narrow, and nearly level land and are 4 to 20 acres in size. Most areas are not vegetated but some areas support grasses…. Typically, beaches consist of multi colored, stratified sand with lenses of clam, crab, and oyster shells.*" Beaches represent dynamic systems where loose granular debris is moving steadily under the attack of waves and currents. If water motion could be held constant, beach deposits would stabilize and be molded into characteristic profiles that would be representative of the equilibrium between driving forces and the beach sediments. However, the driving forces of wind, waves, and currents do not remain constant but change seasonally, monthly, daily (Ritter, 1984) and even hourly which results in destabilization and transport of sediments. As such, coastal beaches are viewed as dynamic systems subject to varying degrees of erosion and represent suspect or known erosion hazard areas.

Coastal Bluffs

Skagit County's coastal bluffs are composed of a variety of material ranging from bedrock to glacially derived sediments consisting silt, sand and gravel. The coastal bluffs are subject to marine conditions and are under continuous attack from physical and chemical weathering processes. Wind, waves and ocean currents, as well as chemical decomposition, constantly break down basal geologic formations and transport the sediments away from the source. This constant attack removes support for the overlying geologic formations resulting in moderate to high angle slopes. Geologic formations of Skagit County's coastal bluffs are varied in composition and characteristically consist of either bedrock or glacially derived sediments consisting silt, sand and gravel or both. The glacially derived sediments were typically deposited as glacial advance sediments, glacial recessional sediments, glacial lodgement till, and/or glaciomarine drift (in addition the coastal marine bluffs may consist of glacially derived sediments that have been eroded and redeposited as colluvium, alluvium or as a result of some other geomorphic coastal process).

Although rock formations, as well as armored and consolidated glacial formations, are somewhat slow to erode, other geologic formations in Skagit County characterized with a high erodibility constant (K) (as indicated in the Soil Survey of Skagit County) combined with the moderate to high angle slopes and surface water runoff may result in rapid erosion of coastal bluffs through rill and gulley formation and other processes representing a risk to development and public safety.

Channel Migration Zones

The head waters of streams, rivers and creeks are often initiated in areas of moderate to high topographic relief. Streams and creeks in these areas are generally high energy and transport sediment down to valley bottoms where sediment may be stored, eroded or transported further down stream depending on the streams energy at a given time and point. The sediment stored in the valley bottoms builds the flood plains, terraces and other landforms along valley bottoms. As stream conditions increase energy, or when the morphology of the stream or river is conducive to meanders, the stream channel will tend to laterally migrate across the valley bottoms eroding and incising stream banks, depositing sediment and transporting sediment further downstream. The area within the valley bottoms that are subject to stream bank erosions, stream incision and shifts in the location of stream channels are the channel migration zones.

Development affects channel migration in a number of ways by modifying watershed and channel conditions. Encroaching into the channel migration zones may place development in the path of streams or rivers. Along some portions of streams, channel migration occurs gradually over several years; in others it can change rapidly during high flows. Although channel migration is a natural and ongoing process that constantly changes the stream character and renewing aquatic habitats, the process occurs through erosion and deposition. As the stream migrates laterally across the river valley it may erode the stream bank on one side of the river and deposit sediment on the other side of the stream. The installation of dikes and bank armor can reduce channel migration. Road construction over streams creeks and rivers through bridges and culverts can also restrict channel migration. These activities may result in changes to the morphology of rivers and streams resulting in or increased incision, bank erosion, sedimentation, or channel migration up or down stream of the development site. Consequently, development that is located within the path of channel migration may be subject to property damage and place public safety at risk.

Floodway and migration zone development that fails to acknowledge the dynamic nature of river and streams has led to a cycle of development and maintenance of protection projects. The most basic but least used approach to reducing problems related to channel migration is simply to allow adequate room for stream processes. Although this approach conflicts with historic development and property ownership, long term reduction of shoreline encroachment will greatly reduce flood and channel migration damage costs and will allow for restoration of aquatic habitat (Whatcom County BAS 2005).

Best Available Science Review: Landslide Hazards

Landslide hazard areas

Skagit County is an area of topographic extremes ranging from coastal bluffs to deltas and valley bottoms to mountainous areas. Skagit County is also in an area of rapid orogenic activity with mountain building in the east county to theorized isostatic rebound (and/or subduction compression bulge) in the west county. This rapid elevation gain of the terrain in Skagit County coupled with intensive erosion result in high gradient slopes.

Skagit County's high gradient slopes present a risk to development and public safety due to the presence of landslide hazards. Landslides include the downward movement of soil, rock and debris. Landslide hazard areas include those portions of the landscape that have existing landslides or are at risk of future failure.

Skagit County's coastal bluffs are typically an area of known or suspect landslide hazard areas. Coastal bluffs are subject to marine conditions and are under continuous attack from physical and chemical weathering processes. Wind, waves and ocean currents, as well as chemical decomposition, constantly break down basal geologic formations and transport the sediments away from the source. This constant erosion removes support for the overlying geologic formations initiating landslides along the face of the bluffs. The Washington Department of Ecology Coastal Zone Atlas indicates that landslide hazard areas occur along the coastal bluffs of Skagit County. The Atlas indicates that landslide hazard areas are present on Guemes, Fidalgo, Cypress, Samish, Vendovi, Allen, Goat, Ika and Sinclair Islands as well as on the mainland from the town of Blanchard north along Chuckanut Drive and North of the community of Bay View near Bay View State Park.

Although landslides can be classified as several categories or types, the three more common failures in Skagit County include shallow rapid translational slides, deep seated rotational failures and rock falls. Shallow rapid translational slides are generally shallow failures that occur on a plane surface, often along the contact between geologic formations. Common in the Pacific Northwest, these slides are typically present in areas of high gradient slopes. These slides are often rapid due to the presence of water and often become debris or mudflows downgradient of the transitional slide zone. Debris and mudflows may travel great distances down slope extending to low gradient areas before settling out. These slides are often initiated by development activities that result in increased slopes gradients and/or the discharge of concentrated surface water. Consequently, shallow rapid transitional slides and run out paths represent a risk to development and public safety. Although high gradient slopes may not necessarily represent a shallow rapid transitional slide area, Skagit County utilizes the Washington State Department of Community Trade and Economic Development (CTED) recommendations that slopes greater then a 40% gradient represent suspect landslide hazard areas (CTED 2003).

Another common type of landslide in Skagit County include deep seated rotational failures. Deep seated rotational failures are generally bowl shaped in a plan view. However, the cross-sectional configuration is generally semi-circular (half circle) with a steep headwall scarp. Although both shallow rapid transitional landslides and deep seated rotational slumps can be small in size, deep seated rotational slumps, as present along Gibraltor Drive in Skagit County, can be quite large covering several square miles. Rotational slumps are common in all types of poorly indurated geologic formations, however in the Pacific Northwest, rotational slumps are common in glacially derived sedimentary formations. Although the initial failure of rotational slumps may be fairly rapid, once equilibrium is achieved, the rate of failure may slow significantly in which movement is measured in years. One of the characteristics of rotational slumps is the constantly changing surficial conditions. Failure and the continued rotation of the slump poses a risk to development and public safety. Remedial actions to slow or stabilize rotational slumps are often costly and ineffective, with the most effective mitigating factor being avoidance.

The third and final type of landslide in Skagit County included in this discussion is rock falls. Areas at risk to rockfalls are generally located at the base of steep slopes or cliffs that consist of moderate to highly fractured rock outcrop, glacially consolidated sediments or other moderately well indurated geologic formations. Geologic material strength, surface gradient, joint pattern and spacing, geologic contacts, groundwater, freeze/thaw zones, and faulting are some of the characteristics of a rock fall zone. Due to the potentially energy associated rockfall areas, the run-out for a rockfall can extend quite far from source. Rock falls are common in mountain areas, along mountain highways and railroad lines, and along coastal bluffs in Skagit County. The potential energy released during can result in considerable damage to property and place public safety at risk. Again, the most effective mitigating factor for rockfall areas is avoidance.

The occurrence and severity of landslides is generally dependent on the slope gradient, slope shape, surface and subsurface materials, precipitation, surface and subsurface water conditions, vegetation conditions, and seismic events. Steep slope gradients are one of the main factors leading to landslides and are often the first level of screening fore identifying landslide hazard areas. Geologic contacts between relatively permeable loose granular formations overlying a relatively dense impermeable formation often lead to saturated contacts where failure planes can develop (Tubbs 1974). Under such conditions failure can occur on low gradient slopes of less then 40%. Although all slopes with the above referenced conditions may not necessarily represent a slide area, Skagit County utilizes the CTED recommendations that slopes greater then a 15% gradient with intersecting geologic contacts with permeable sediments overlying low permeability sediment or bedrock and springs or groundwater seepage are present, or slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials represent suspect landslide hazard areas (CTED 2003).

Vegetation is an important factor in the maintaining the stability of high gradient slopes. In additions to reducing the volume of near surface groundwater, the root structure of plants and trees form a mesh of roots that bind soils together. Unconsolidated soils with a low angle of internal friction may not posses the soil strength to remain stable on high gradient slopes. In such cases, the presence of plants and trees provide the extra binding strength necessary to maintain slope stability.

Although active or known landslide hazard areas are often easily identified, areas at risk of landsliding are more difficult to identify. In order to assist in identifying both known and suspect landslide hazards, Skagit County utilizes WAC 365-190-080 (4) recommendations or derivations of the recommendations. More specifically Skagit

County utilizes the following criteria for the identification of known or suspect landslide hazard areas:

- *Areas designated in the Department of Ecology, Coastal Zone Atlas, Washington, Volume Two, Skagit County (1978) as U (Unstable), UB (Unstable Bluff), URS (Unstable Recent Slide), or UOS (Unstable Old Slide);*

- *Slopes having the following characteristics: Gradients of 15% or greater intersecting geologic contacts with permeable sediments overlying low permeability sediment or bedrock and springs or groundwater seepage are present, or slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials;*

- *Slopes of 40% or steeper and with a vertical relief of 10 feet or more;*

- *Areas of pre-historic or historic failure such as earth slumps, earthflows, mudflows, lahars, debris flows, rock slides, landslides or other failures as indicated on maps or in technical reports published by the United States Geological Survey, the Geology and Earth Resources Division of the Washington Department of Natural Resources, or other documents authorized by government agencies;*

- *Potentially unstable areas resulting from rapid stream incision, stream bank erosion, and undercutting by wave action;*

- *Coastal bluffs;*

- *Slopes with a gradient greater than 80% and subject to rock fall;*

- *Areas that show evidence of or-are at risk from snow avalanches.*

- *Areas located in a canyon or on an active alluvial fan presently or potentially subject to inundation by debris flows or catastrophic flooding.*

- *Those area delineated by the US Department of Agriculture's Natural Resources Conservation Service Soil Survey of Skagit County as "severe" (Table 9) limitation for building development.*

The County Geomorphic Hazard Map (2005) shows areas with slopes greater then 15% and slopes greater then 30%. Site specific mapping and analysis of slide prone areas at the time of development application is the current mechanism for identifying and mitigating landslide hazard areas in Skagit County. Skagit County prohibits development in landslide hazard areas unless the hazard can be fully mitigated to remove the risk. As commonly used by other local government agencies, CTED recommends a 50 foot buffer from all landslide and erosion hazard areas to insure protection of developments from landslide hazard areas.

Best Available Science Review: Seismic Hazards

Western Washington, including Skagit County, is an area of high seismic activity as indicated by the many earthquakes, faults and the history of volcanic activity. Washington and Oregon experience approximately 1,000 to 2,000 earthquakes annually. Fewer then 25 % of the earthquakes generated are felt due to a low magnitude (<3 on the Richter Scale) and, with respect to earthquake location and depth, far fewer earthquakes are those with a high enough magnitude to cause damage (Galaster and McCrumb, 1989). Regardless of the intensity of an earthquake, some areas are more sensitive to seismic activity and are less suitable for development. These areas have been identified by Skagit County as seismic hazard areas

Seismic hazard areas are subject to a high risk of damage as a result of ground shaking. The areas sensitive to ground shaking include areas with soil and groundwater conditions conducive to liquefaction, active geologic fault zones and large water bodies with potential tsunami or seiche inundation (landslide hazard areas also present a seismic risk and were addressed in the previous section).

High liquefaction areas

Liquefaction is a phenomenon in which strong earthquake shaking causes a soil to rapidly lose its strength and behave like quicksand. Liquefaction typically occurs in artificial fills and in areas of loose sandy soils that are saturated with water, such as low lying coastal areas, lakeshores and river valleys. When soil strength is lost during liquefaction, the consequences can be catastrophic (Palmer et al. 2004).

The liquefaction susceptibility map of Skagit County was developed by the Washington Department of Natural Resources and finalized in September 2004. The Liquefaction Susceptibility Map of Skagit County indicates areas that are susceptible to liquefaction based on a rating of very low, low, moderate, and high. This map is utilized by Skagit County to identify areas of high liquefaction risk.

Active fault zones

Western Washington is an area of tectonic compression with the Juan De Fuca plate advancing east colliding with the thicker North American plate. The collision of these two plates has resulted in subduction of the Juan De Fuca plate under the North American plate (Cascadia Subduction Zone). The collision and subsequent subduction of the Juan De Fuca plate has resulted in stress and strain of both the North American and the Juan De Fuca plates. This stress and strain is expressed in the overlying crust as earthquakes and active fault zones.

Although geologic maps of Skagit County indicate an abundance of faults, historic and geologic information indicates that only a portion of these are currently active and fewer, if any, show any historic evidence of slippage or movement. One example of an active fault zone is Devils Mountain fault located in southern Skagit County. Although Devils Mountain fault has not indicated evidence of surficial movement, small earthquakes are consistently detected at a depth of approximately 15 kilometers. Devils mountain fault has been rated by the United States Geologic Survey as capable of producing an earthquake with a magnitude of 8.5 on the Richter Scale (Johnson, 2001). Regardless of the surficial expression of faults during the Holocene, active fault zones are common locations of shallow earthquakes and represent a risk to development and public safety. Skagit County's proposed and current Geologically Hazardous Areas ordinance does not allow the development of critical facilities within 1/4 mile of active fault zones.

Tsunami and seiche hazard areas

Tsunamis are waves formed by sudden impulses beneath the ocean that cause trains of waves to radiate in all directions from the point source. Tsunamis area generally a result of seismic activity and are identified by the Washington Administrative Code (WAC 365-190-080) as hazards associated with frequently flooded areas. Tsunamis are simply waves generated by a oceanographic event, such as the movement of portions of the ocean floor (often induced by earthquakes of a magnitude of 6.5 or greater (Richter scale) and a foci of less then 30 miles below the ocean floor). Submarine landslides and volcanic eruptions are other examples of ocean floor movement that have been known to induce tsunamis. Tsunami waves area generally very long wave length measured in miles (up to 150 miles). The speed at which a tsunami travels is proportional to water depth and may advance at velocities of 400 miles per hour. In the open ocean tsunamis waves may only be a meter high. As the tsunami waves approach shore they seem to develop a harmonic oscellation that is not representative of the ocean bottom. The ocean initially retreats followed by as many as five wave fronts that can be 30 feet or higher and capable of great destruction (Ritter, 1984).

As directed by Congress through the National Oceanic and Atmospheric Administration and the United States Geologic Survey to protect the West Coast against tsunami inundation, the Washington Department of Natural Resources, Geology division generated a Tsunami Hazard Map of the Anacortes –Whidbey Island Areas, Washington: Modeled Tsunami Inundation from the Cascadia Subduction Zone Earthquake. The map includes a great majority of the coastline of Skagit County and is a result of a computer model that simulates a magnitude 9.1 earthquake in the Cascadia Subduction zone off the coast of Washington. The model generally indicates tsunami inundation greater then 6 feet along the coastline from Blanchard to Bayview, from Bayview to March Point, and along the marine shoreline of Fir Island (Walsh et.al 2004). These areas are identified on the tsunami map as tsunami hazard areas.

A seiche is generally an oscillation of water in enclosed or semi-enclosed basin. A seiche is observed as a repeated rise and fall of water level (Ritter, 1984). The oscillation begins with some displacement of water from its equilibrium position and generally appears as something similar to the sloshing of water in a bath tub. Seiche hazard areas in Skagit County are generally limited to developable areas around large inland lakes and harbors.

Tsunami and sieche hazard areas are essentially frequently flooded areas and are subject to the code requirements of that section of Skagit County's Critical Areas Ordinance.

Best Available Science Review: Volcanic Hazards

Washington is home to five major composite volcanoes or stratovolcanoes and include Mount Adams, Mount Saint Helens, Mount Rainer, Glacier Peak and Mount Baker. These volcanoes, including Mount Hood in Oregon are part of a volcanic arc, The Cascade range that extends from British Columbia to Northern California. These volcanoes, along with numerous basaltic and basaltic-andesitic volcanoes, have been active for the past 12,000 years with more then 200 eruptions that have generated pyroclastic flows, lava flows, debris flows and lahars. All of Washington's volcanoes, except Mount Adams, have erupted at least once in the last 250 years (Pringle 1994).

Although none of these volcanoes occurs in Skagit County, two major stratovolcanoes, Mount Baker and Glacier Peak, are located just over Skagit County's jurisdictional boundaries in Whatcom County to the north and Snohomish County to the south, respectively. Mount Baker is reported to have a low incidence of explosive eruption with a frequency of once every 100 to 200 years (Waldron, 1989). Mount Baker is thought to have erupted in the mid 1800's and again in 1975 with a steam eruption. Glacier Peak is reported as a low to high incidence of explosive eruptions with a frequency of once every 900 to 1,100 years (Waldron, 1989). Glacier Peak is thought to have had at least one ash eruption some time before 1800. Both eruptions are thought to have sent lahars (debris flows) a distance of 60 miles down the Skagit River depositing volcanic sediments on the Skagit River delta (Pringle 1994) between Mount Vernon and the town of LaConner (Gardner et al, 1995, & Waitt et al, 1995). As indicated, Skagit Country has historically been impacted by both volcanoes during previous eruptions. Although historic information on the eruptions is limited to tephra fallout and lahars, both eruptions occurred at a time of sparse population in Skagit County. Since those previous volcanic events, development has significantly increased in the vicinity of the volcanoes.

The United States Geologic Service has developed two maps addressing potential volcanic hazards for both Mount Baker and Glacier Peak. The maps and associated reports indicate that the characteristics of an eruption from either Mount Baker or Glacier Peak could include debris flows/lahars, landslides and debris avalanches, tephra fallout, ballistic debris, lava flows, pyroclastic flows, and the lateral blast at eruption. The hazard maps predict that landslides and debris avalanches, ballistic debris, lava flows, pyroclastic flows, and the lateral blasts are likely to occur close to the volcano and will terminate near the jurisdictional boundaries of Skagit County. However, debris flows and tephra deposits are likely to significantly impact Skagit County during a volcanic eruption (Gardner et al, 1995, & Waitt et al, 1995). Tephra fallout, although important, are not included in the GMA guidelines and do not warrant further discussion. The volcanic hazard maps predict that debris flows/lahars remain a significant threat to the property and well being of Skagit County residents during future volcanic eruptions and does warrant further discussion of best available science.

Volcanic debris flows/lahars

Lahars or volcanic debris flows are rapidly flowing mixtures of rock debris mobilized by water that originates on the slopes of the volcano. As Lahars flow through vegetated areas it often incorporates organic debris as well. The water can come from a variety of sources including rainfall, melting snow and ice, and/or glacial outburst floods. Debris flows can be hot or cold depending on the conditions of their origin and can travel at rates approaching 60 miles per hour (Gardner et al, 1995). Lahars generally behave much like flowing concrete and are generally restricted to stream valleys. Inundation height, run out length, velocity and the duration of lahars varies widely. In general, relative risk decreases with the distance down valley and with the height above the valley floor (Pringle 1994).

Debris flows may not be limited to a single event but may continue for years with periods of intense rainfall re-initiating lahar events. The major hazard to life and property from debris flows/lahars is impact and burial. Small debris flows are the most frequent from Mount Baker and Glacier Peak and they generally only travel a few miles from the source. They may be caused be intense rainfall and are not associated with a volcanic eruption. Moderate and large size lahars are of special concern especially from Mount Baker. A lahar of significant size originating from Mount Baker could potentially impact Baker Lake and displace enough water to cause a wave (seiche) to overtop the Baker Dam and impact Lake Shannon. Failure of the Baker Dam would result in catastrophic flows and floods down the Skagit River. Geologic information suggests that at least one moderate to large lahar (volume of approximately .02 cubic miles of debris) has occurred on Mount Baker in the 10,000 years (Gardner et al, 1995). Two eruptive events from Glacier Peak occurred about 13,000 and 6,000 years ago and produced large lahars, some of which extended to Puget Sound (Waitt et al, 1995).

The volcanic hazard maps for Mount Baker and Glacier Peak indicate that the Skagit, Baker, Suiattle, and Sauk rivers including the Skagit River delta from Edison to Fir Island are representative of lahar flow paths. Because of the speed with which they can move and there possible large size, debris flows/lahars constitute a significant potential hazard to life and property. Areas within the flow path are potentially at risk to flooding and lahar inundation during a volcanic eruption of either Mount Baker or Glacier Peak and are included in Skagit County's critical areas ordinance as volcanic hazard areas.

Best Available Science Review: Other Geologically Hazardous Areas

Alluvial fans

During an unusually high precipitation event during January 1983, a farm located on an alluvial fan at the mouth of Mill Creek, tributary to the Samish River, in northern Skagit County was destroyed by a debris torrent that killed one person along with 200 head of cattle. The debris torrent consisted of a mass of mud and logs. Several farm buildings received significant damage or were destroyed and approximately 30 acres pasture land was buried. The Mill Creek debris flow had apparently been initiated by a landslide resulting from an abandoned road that crossed an old earth flow. The slide material entered Mill Creek during the rainstorm which generated a debris/mud flow which scoured the channel. A similar event occurred in 1984 as a result of a new road constructed uphill of the previous road (Gerstel, 1994).

Alluvial fans are geologic features resulting from the localized deposition of sediments in broad fan shaped features. Alluvial fans are generally located at the mouth of steep narrow valleys or at a point in which the hydraulic geometry changes to allow the stream or flow to broaden or fan out such as at a valley floor, a lake or the coast. The movement of sediment from source areas to alluvial fans involves a variety of transport mechanisms ranging from highly viscous debris/mud flows to normal stream flows (Ritter, 1984). During normal stream flows, the stream feeding the fan often migrates across the fan often encroaching into developed areas. In order to limit channel migration, development has included the construction of dikes and utilized dredging to protect developments on alluvial fans. Although maintenance intensive, dikes and dredging have proven effective in controlling channel migration on alluvial fans, however, they are often ineffective against debris/mud flows. Mud and debris flows are similar in characteristics to lahars. They consist of mud, rock, water and debris and appear as flowing concrete. The risk to development includes destruction and burial. As demonstrated by the Mill Creek tragedy, alluvial fan areas are generally viewed as geologically hazardous areas, not because of the alluvial fan itself, but due to the likelihood of the geologic event that created the fan to re-occur.

Mining Hazards

Mining is a human development operation which may involve removing thousands or even millions of tons of rock, sand and gravel for economic purposes. The process of removal includes surface excavation and/or subsurface excavation and tunneling Areas over subsurface mining operations can experience subsidence and slumping from the collapse of mining tunnels or air shafts. Areas adjacent to surface mines can experience erosion problems, landsliding or mass wasting resulting from mining operations. Risks associated with surface mining operations are often obvious, however, subsurface mining operations are often less obvious. Without knowledge of historic subsurface mining activities, property owners may not realize that mine workings underlie their land. . The disturbance associated with mining activities often results in conditions that can present a risk to development and public safety.

Summary

As indicated in the introduction, the primary purpose of the geologically hazardous areas ordinance is not necessarily to protect areas from development but to protect development from geologically sensitive areas. This is first accomplished by identifying geologically hazardous areas. In contrast to Skagit County's proposed fish & wildlife habitat conservation areas and wetlands ordinances, which tend to utilize BAS to establish buffers to protect critical areas, this section of the BAS document has primarily included a discussion of physical features and characteristics that are representative of suspect or known geologically hazardous areas. Once the geologic hazard has been identified on the subject site, mitigations or avoidance are often available to protect development and public safety. Mitigations tend to be site and engineering design specific and therefore it would be impractical to set minimum mitigation standards.

Minimum standards for avoidance are applicable for landslide and erosion hazards and have been included in this document and are proposed in the geologically hazardous areas ordinance. Review of "Best Available Science" has failed to consistently indicate a standard setback from landslide and erosion hazard areas. However CTED has recommended a 50-foot setback from landslide/erosion hazard areas and indicates the setback is the "industry standard" for local jurisdictions in Skagit County. Review of the geologically hazardous area ordinance for nearby county jurisdictions, as indicated on the jurisdictional comparison section of this document, does necessarily support CTED's recommendation of 50-feet, however, the jurisdictional comparison does indicate that a 50-foot buffer recommendation is within the range of buffers required by other county jurisdictions.

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