

Recommendations for the Inclusion of Channel Migration Zones in the Jefferson County Critical Areas Ordinance

Purpose and Intent:

Jefferson County is unique in both the state and the entire nation in that, due to low development pressures, our large lowland unconfined rivers remain in a generally healthy condition on both the east and west sides of the Olympic Mountains. In other Washington counties and states, river channel migration zones confined by levies, revetments (bank hardening like riprap), roads, and residential development have lost many of the physical components necessary to support healthy habitat and river function. River adjacent developments, roads, and revetments are frequently flooded, eroded, or destroyed by winter floods, which are predicted to increase in severity as a result of shifting climate patterns.

Information about the dynamic nature of channel migration zones and their importance to wild anadromous fish is herein provided in order that the Planning Commission and the public can make informed decisions on whether further development of these areas is in balance with goals to protect and preserve our environment.

Overview – Landscape Context:

Channel migration has occurred on unconfined rivers and streams over this region's geologic history, but definitions and methodologies for delineation have been developed only in the past ten to fifteen years, as development pressures have increased conflict between human uses and protection from flood and erosion hazards, and concerns about declining populations of salmon and bull trout have stimulated a response to habitat loss (FEMA, DOE, FPB).

Although channel migration zones (CMZs) not directly referenced in the 1990 Growth Management Act (GMA) – CMZs are clearly identified as important fish and wildlife habitat, resource, and hazard areas in the grey, white, and peer-reviewed scientific literature, in many studies from the Olympic Peninsula, as well as in regulatory policies (see BAS provided for CMZs, Thurston County BAS).

CMZs incorporate all five GMA-defined critical areas – wetlands, flood prone areas, geologically hazardous or erosion hazard areas, critical aquifer recharge areas, and fish and wildlife habitat conservation areas - in a mosaic of complex

habitat types. The locations of these CAs change over time as the river's active channel migrates across its valley. The interaction or rate of change between these CAs will vary depending on gradient, sediment supply, stream flow, vegetation, underlying and boundary geology, and degree of impact from natural instability or human development. On an undeveloped, unconfined forested river corridor with a braided, anastomosing (multiple channel), or migrating channel structure, the entire CMZ, river corridor, and riparian buffer functions as important and complex habitat unless replaced, constricted, or impaired by development.

Unlike the other critical areas defined in the GMA, they are not a landform, process, or habitat type in and of themselves because, while they develop and change within certain physical boundaries as do the other critical areas, they also incorporate the aspect of **time**. CMZs are a combination of physical components that create both excellent habitat for fish and wildlife, and dangerous conditions for human development, in an unpredictable time frame.

Besides providing important ecological services to fish, wildlife, and forests, CMZs in Jefferson County have historically been, and continue to be used for residential development, roads, agriculture (primarily for grazing of livestock), gravel mining, and recreational activities – including camping, fishing, and hunting. Another important aspect is the storage of water during floods which provides the dual benefit of reducing impacts of flooding and erosion, and increases aquifer recharge (Bolton 2001).

Context in the GMA:

The GMA provides for counties to add additional critical areas definitions to those referenced above. A number of Washington's counties have either included channel migration zones in their Critical Areas Ordinances or proposed them for updates – including Clallam, King, Thurston, Pierce, Mason, Snohomish, and Whatcom - under the headings of erosion hazards, geologic hazards, floodprone zones and fish and wildlife conservation areas, in concurrence that these critical areas coincide with channel migration.

When the GMA – RCW 36.70 - was legislated (1990), the term 'channel migration zone' was not widely in use, and methodologies for delineation had yet to be developed. Subsequent enabling and directive legislation has been developed over time to expand critical areas definitions, largely in the Washington Administrative Codes (WACs) and guidance documents developed by Community Trade and Economic Development (CTED). These include references to the importance of protecting channel migration zones from human development, and human development from the hazards represented

by channel migration. It is worth noting in the table below that counties with CMZs in their CAOs updated their CAOs in 2004 and 2005, AND, they have large migrating rivers in their jurisdictions. Two counties that do not include CMZs are San Juan and Island, but neither have CMZs.

County	CMZ included in CAO - YES	CMZ included in CAO – NO	No large CMZs in CO	FWHCA	Geohazard	Floodprone Zone	Update
Clallam ¹	X				X		2004
Clark	X						2004
Cowlitz		X					2005
Grays Harbor		X					2007
Jefferson	X						2004
Island		X	X				2007
King	X						2004
Kitsap	X			X			2004
Lewis	X						2005
Mason	X			X			2005
Pacific		X	?				2007
Pierce	X						2004
San Juan		X	X				2007
Skagit		X					2005
Skamania		X	?				2005
Snohomish	X						2004
Thurston	X					X	2004
Wakiakum		X					2007
Whatcom	X						2004

From: CTED Western Washington County Updates <http://www.cted.wa.gov/site/394/default.aspx>

Definition and Delineation of CMZs:

The following is excerpted from *Ecological Processes in Floodplains and Riparian Corridors* (Bolton et al., 2001):

In the February 17 1998 draft proposal of Oregon Forest Practice Rules the National Marine Fisheries Service (NMFS) defined the CMZ (in Pess 1998) as:

*...the area a stream is expected to occupy in the time period it takes to grow a tree of sufficient size to geomorphically function in the channel. Spatially, this area generally corresponds to the modern flood plain, but can also include river terraces subject to significant bank erosion. An acceptable method for delineating the CMZ at a particular site, involves delineating either the floodprone area or the approximate 100-year flood plain, whichever is greater. For larger streams, the 100-year flood plain may already be available on U.S. Army Corps of Engineers or county flood hazard maps. A field method for delineating the flood-prone area is approximated by Applied Fluvial (sic) [River] Morphology" (Rosgen 1996). The flood-prone area includes the estimated area that would be inundated by stream flows of two times the bank-full depth. **The objective of identifying the CMZ is to ensure that the stream has a protective buffer in the future, even if the stream were to move away from its present location.** (Emphasis added.)*

The US Fish and Wildlife Service (MBTSG cited in USFWS 1998) gave the following description and rationale for channel migration zones for bull trout:

The 100-year floodplain was chosen based on the need to fully incorporate the channel migration zone (CMZ) on low gradient alluvial streams. These stream channels provide critical spawning and rearing habitat for bull trout. An additional 150 feet on either side of the 100-year floodplain is required for the following reasons: 1) it encompasses one site-potential tree height at most locations; 2) provides sufficient width to filter most sediment from nonchanneled surface runoff from most slope classes; 3) provides some microclimate and shallow groundwater thermal buffering to protect aquatic habitats inside the channel and the channel migration zone; and 4) provides an appropriate margin of error for unanticipated channel movement, hillslope and soil stability, blowdown, wildfire, operator error, disease, and certain other events that may be difficult or impossible to foresee on a site specific basis.

The Tri-County effort in Washington states that CMZ do not exist everywhere, but where they do exist they define the CMZ as:

...the area within the lateral extent of likely stream channel movement over a given stream reach due to stream bank destabilization, rapid stream incision, stream bank erosion, and shifts in location of stream channels.

They intend to identify CMZ boundaries for all stream reaches where stream power, soil conditions, and valley-floor widths are sufficient to support significant potential migration. For regulatory purposes, the Tri-

county CMZ will be based on available historic records of channel migration, field indicators of the presence of the side channel in the last 100 years, or 100 years of calculated channel migration, whichever is greater, and will generally include those areas that encompass:

The limit of geologic controls, such as hillslope, bedrock outcrop, or abandoned floodplain terrace; the side channels, abandoned channels, and oxbows; and the outside edges of any signs of progressive bank erosion at the outside of meander bends.

The Washington Forest Practices Board (WFPB 2000) defined CMZ as the ...*area where the active channel of a stream is prone to move and thus results in a potential near-term loss of riparian habitat adjacent to the stream.*

The WFPB manual has descriptions and illustrations of CMZs and delineation guidelines, which include CMZs that have been modified by a permanent levee or dike.

Lastly, the Shoreline Master Program includes a specific definition in WAC 176-26-020(6) as “the area along a river within which the channel(s) can be reasonably predicted to migrate over time as a result of natural and normally occurring hydrological and related processes when considered with the characteristics of the river and its surroundings”, which is used by a number of jurisdictions and publications.

There are two delineation methods currently used in Washington State (Rapp and Abbe 2003, and Forest Practices Board Manual). Both rely on the same basic geomorphic and hydrologic principles, and direct users to rely on historic channel information such as aerial photos and determine the age of trees necessary to function in the river in question. A significant difference between them is that the FPB method allows for the CMZ to be delineated behind a levy where water and fish can access a break in the revetment, whereas the DOE method does not allow the CMZ to be delineated behind such structures.

Salmon Habitat and Ecological Context

The GMA requires that counties "... give special consideration to conservation or protection measures necessary to preserve or enhance anadromous fisheries", and the county Comprehensive Plan establishes the goal to "protect natural processes, natural conditions, and natural functions of the shoreline environment".

In his book, King of Fish: the Thousand Year Run of Salmon, Dr. David Montgomery (2003) identifies CMZs as the ultimate fish habitat. Because of

the high productivity of the forested channel migration zones, the Hoh River CMZ and some tributaries with CMZs have been designated as an important west coast salmon and wildlife refugia corridor.

Mature forests and the complex habitats and myriad functions they provide along rivers are the keystone to healthy salmon habitat in the Pacific Northwest. Large trees provide the structure upon and around which channels, pools, and islands are built, forming and protecting floodplain forests. Channels formed by erosion around large wood provide new and rich habitats for colonization by juvenile and adult fish. (Abbe 2002, Collins 2001, Montgomery 2002 and 2004, Rot 1996)

The greater the complexity provided by CMZ forests and floodplain vegetation, the greater the storage of water in a river channel. Standing vegetation and downed wood slows flowing water, and downed woody debris in the channel creates pools (pond storage) (Bolton et al. 2001) and stores sediments that become vegetated islands, restarting the succession of native plants that eventually become floodplain forests.

Sedell et al. (1982) in Ecology and Habitat Requirements of Fish Populations in South Fork Hoh River, Olympic National Park, concluded that:

*Habitat formed by the main river channel and its tributaries is controlled by the valley terrace structure and the modifying effects of large woody debris. Without large wood, spawning and rearing habitat quality would be poorer, even in the large channel. **Virtually all rearing of salmonids fish occurs in river off-channel areas** and tributaries. The main channel is used mainly for spawning and migration. Fish densities and biomasses area highest in streams along the valley floor (i.e. wall-based channels and floodplain side channels). Alteration of these areas will have the greatest impact on fish production.* (Emphasis and bracketed clarification added.)

Pess et al. (2002) demonstrated a positive correlation between increased coho salmon production to reaches on the Snohomish River where floodplains, mature forests, wetlands, and peat soils corresponded with riverine channels. While CMZs were not delineated (the TIME factor) on the study reaches, they can be inferred as present (Pess, Pers. comm. 11\04\06).

Due to its mostly forested and relatively healthy condition, the Hoh River on the west side has been the focus of a significant salmon refugia corridor conservation effort. The Hoh River's CMZ is a mile wide in some reaches! In reports to the Hoh Tribe, Rot (1996) and Jorgenson (1996) showed that just one floodplain complex in the Hoh River CMZ - the Elk Creek Floodplain Complex at RM 19 - produces a significant portion of the Hoh River coho and

chinook run – in some years up to 5% of the overall production in the entire watershed.

Regulatory Context:

The Shoreline Management Act, RCW 90.58 and WAC 173-18-040 - SMA jurisdiction provides a ‘jurisdictional boundary’ of 200 feet on shorelines and streams with flows greater than 20 cubic feet per second (cfs) mean annual flow.

Some streams in east and west Jefferson carry flows of less than the 20 cubic feet per second (cfs) mean annual flow, but still have CMZs, or will regain them when incision caused by a combination of increased flows and loss of large wood over decades of timber harvest directly adjacent to the stream is reversed when riparian forests are recovered, and the large wood necessary to store sediments in these low gradient channels is restored (Brummer et al, 2006).

The Growth Management Act, RCW 36.70A.060 (1), requires counties and cities planning under the GMA to adopt development regulations to conserve natural resource lands, and provides that those regulations “may not prohibit uses legally existing on any parcel prior to their adoption.” No similar language is found in RCW 36.70A.060 (2), which requires all counties and cities to adopt development regulations to protect critical areas. The GMA requires counties and cities to reasonably regulate existing activities that damage critical areas.

There is a clear and succinct definition of CMZs in the Shoreline Master Program guidelines, and direction for locating and protecting CMZ function in **WAC 176-26** – provisions for the update of Shoreline Master Programs as follows:

WAC 176-26-020(6) defines Channel migration zone (CMZ) to mean “the area along a river within which the channel(s) can be reasonably predicted to migrate over time as a result of natural and normally occurring hydrological and related processes when considered with the characteristics of the river and its surroundings”.

WAC 176-26-201(3)(c) (vii) requires local government “to the extent such information is relevant and reasonable available” to collect information on “[g]eneral location of channel migration zones and flood plains.”

WAC 176-26-201(3)(d) (i)(D) requires local government to analyze this information “as necessary” to “ensure effective shoreline management provisions...to supply amounts and distributions of woody debris sufficient to sustain physical complexity and stability”.

WAC 176-26-221(2)(iv) designates the CMZ as “critical freshwater habitat” and mandates protection of ecological functions associated with critical freshwater habitats “as necessary to assure no net loss”.

WAC 176-26-221(3)(b) requires shoreline master programs to include provisions to limit development and shoreline modifications that would result in “interference with the process of channel migration that may cause significant adverse impacts to property or public improvements and or result in a net loss of ecological functions associated with the rivers and streams” and goes on to explain:

The dynamic physical processes of rivers, including the movement of water, sediment and wood, cause the river channel in some areas to move laterally, or ‘migrate’, over time. This is a natural process in response to gravity and topography and allows the river to release energy and distribute its sediment load. The area within which a river channel is likely to move over a period of time is referred to as the channel migration zone (CMZ) or the meander belt. Scientific examination as well as experience has demonstrated that interference with this natural process often has unintended consequences for human users of the river and its valley such as increased or changed flood, sedimentation and erosion patterns. It also has adverse effects on fish and wildlife through loss of critical habitat for river and riparian dependent species. Failing to recognize the process often leads to damage to, or loss of, structures and threats to life safety...The channel migration zone should be established to identify those areas with a high probability of being subject to channel movement based on the historic record, geologic character and evidence of past migration. It should also be recognized that past action is not a perfect predictor of the future and that human and natural changes may alter migration patterns. Consideration should be given to such changes that may have occurred and their effect on future migration patterns... For management purposes, the extent of likely migration along a stream reach can be identified using evidence of active stream channel movement over the past one hundred years. Evidence of active movement can be provided from historic and current aerial photos and maps and may require field analysis of specific channel and valley bottom characteristics in some cases. A time frame of one hundred years was chosen because aerial photos, maps and field evidence can be used to evaluate movement in this time frame.

WAC 176-26-241(3)(h)(ii)(E) requires that mining within any channel migration zone within shoreline jurisdiction “shall require a shoreline conditional use permit” (which means Ecology must approve in addition to local government).

The CTED interagency Critical Areas Assistance Handbook mentions the CMZ as a component of frequently flooded areas and calls out its exceptional importance as fish and wildlife habitat, particularly regarding salmon.

Human Safety and Protection of Community Infrastructure:

There is a significant human safety issue involved in the regulation of CMZs that must be emphasized. As other critical areas focus on safety – i.e. Geological Hazard Zones, Flood Prone Zones, and Critical Aquifer Recharge Areas - the argument that human safety isn't relevant to CMZs within the context of Critical Areas designation is not particularly credible.

The Perkins Geosciences CMZ risk assessment for east Jefferson County rivers provides an excellent framework to explain that high-risk CMZs imply a high risk to human safety and investment. CMZ delineation manuals (DOE, FP Board) and the studies conducted in both east and west Jefferson County (Perkins Geosciences, Klawon et al.) identify erosion as a primary component in determining the hazard zonation of a CMZ. Erosion, either by lateral migration or avulsion – which is the jumping of a channel into an old channel or carving a new channel - is inevitable in the process of channel migration, and is especially prevalent where a mature riparian or floodplain forest and abundant sediment supply exists, as on rivers in Jefferson County.

Erosion is defined in **RCW 36.70A.030(9)**: "[g]eologically hazardous areas" means 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 or safety concerns."

Suggestions that removal of riparian vegetation and confinement of the river channel so as to protect private property from erosion are unfortunately in direct conflict with the goal of protecting and maintaining viable wild fish stocks.

Flood prone areas are another important component of CMZs within the floodplain and adjacent low terraces, and are addressed in **WAC 365-190-080**
- Critical areas:

(3) Frequently flooded areas. Floodplains and other areas subject to flooding perform important hydrologic functions and may present a risk to persons and property. Classifications of frequently flooded areas should include, at a minimum, the 100-year floodplain designations of the Federal Emergency Management Agency and the National Flood Insurance Program.

Counties and cities are directed by GMA and CTED to consider the following when designating and classifying frequently flooded areas:

- (a) Effects of flooding on human health and safety, and to public facilities and services;
- (b) Available documentation including federal, state, and local laws, regulations, and programs, local studies and maps, and federal flood insurance programs;
- (c) The future flow floodplain, defined as the channel of the stream and that portion of the adjoining floodplain that is necessary to contain and discharge the base flood flow at build out without any measurable increase in flood heights;
- (d) The potential effects of tsunami, high tides with strong winds, sea level rise resulting from global climate change, and greater surface runoff caused by increasing impervious surfaces.

Economic Costs to Jefferson County related to CMZs:

State, county, and private roads in the CMZs in Jefferson County are subject to damage or destruction from riverbank erosion on an annual basis. Farms and homes located within or at the outer edge of the CMZ are also prone to impacts from unpredictable channel changes and flooding. Costs to the public in terms of tax dollars – federal funding from FEMA, Federal Highways Administration, the NRCS, and Olympic National Park for emergency repairs, or property and sales tax funding to the County - must be included in a cost/benefit analysis of the reasonableness of adding new permanent structures within Jefferson County's CMZs.

Below are some estimates and reports of expenditures in Jefferson County for road repairs and reconstruction related to channel migration:

- WSDOT has spent an estimated 10 million dollars in the past seven years protecting Highway 101 at MP 175-176.
- Jefferson County has spent approximately 10 million dollars on the Oil City Road, Upper Hoh Road, and the Quinault Road to repair and protect road access to homes, businesses, and the Olympic National Park's rainforest and coastal strip lands. 50% of that has been reimbursed by FEMA. (Pers. comm. Monty Reinders, 2/18/07).

- Olympic National Park has spent an estimated 2 million dollars on road repairs to the Upper Hoh Road as a result of channel migration of the Hoh River.
- The Hoh Tribe at the mouth of the Hoh River was provided with engineering and construction services by the NRCS to protect the community water system from channel migration at a value of two hundred thousand dollars. The Hoh Tribe is actively working to move out of the active floodplain and channel migration zone.

Recommendations for CMZs

Jefferson County has a unique opportunity to protect the remaining functional CMZs from further encroachment by development that always results in diminishment of the trees necessary to maintain the CMZ in a healthy condition.

This information is intended to inform Jefferson County citizens about the benefits and hazards of channel migration zones. It is not intended to imply that existing uses should be reversed. Towns, homes, and agricultural uses that exist in channel migration zones should be supported, although existing roads should be routed way from high hazard migration areas whenever and wherever possible.

Due to the especially high importance of CMZs to fish and wildlife, and to the especially dynamic nature of CMZs in Jefferson County, it is our recommendation that Jefferson County incorporate CMZs in both the FWHCA and the Geological Hazards sections of the Critical Areas Ordinance.

We further suggest that the County investigate and pursue all possible opportunities to provide landowners with options for sensible and responsible use of these truly critical areas.

Appendix A:

WAC 173-18-200 Jefferson County.

Streams and Rivers meeting Shorelines of Statewide Significance Criteria
(> 1000 cfs mean annual flow)

http://www.ecy.wa.gov/programs/sea/sma/st_guide/jurisdiction/rivers.html
http://www.ecy.wa.gov/programs/sea/pubs/USGS_reports/WRIR%2096-4208.pdf

Appendix B:

Critical Areas as defined in RCW 36.70A, Growth Management Act
and WAC 365-190 – the implementing rules:

RCW 36.70A.030 Definitions.

(5) "Critical areas" include the following areas and ecosystems: (a) Wetlands; (b) areas with a critical recharging effect on aquifers used for potable water; (c) fish and wildlife habitat conservation areas; (d) frequently flooded areas; and (e) geologically hazardous areas.

(9) "Geologically hazardous areas" means 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 or safety concerns.

(21) "Wetland" or "wetlands" means areas that are inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands do not include those artificial wetlands intentionally created from nonwetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from nonwetland areas created to mitigate conversion of wetlands.

WAC 365-190-080 - Critical areas.. (3) (c)

(3) Frequently flooded areas. Floodplains and other areas subject to flooding perform important hydrologic functions and may present a risk to persons and

property. Classifications of frequently flooded areas should include, at a minimum, the 100-year floodplain designations of the Federal Emergency Management Agency and the National Flood Insurance Program. Counties and cities should consider the following when designating and classifying frequently flooded areas:

- (a) Effects of flooding on human health and safety, and to public facilities and services;
- (b) Available documentation including federal, state, and local laws, regulations, and programs, local studies and maps, and federal flood insurance programs;
- (c) The future flow floodplain, defined as the channel of the stream and that portion of the adjoining floodplain that is necessary to contain and discharge the base flood flow at build out without any measurable increase in flood heights;
- (d) The potential effects of tsunami, high tides with strong winds, sea level rise resulting from global climate change, and greater surface runoff caused by increasing impervious surfaces.

(4) "Geologically hazardous areas"

(a) Geologically hazardous areas include areas susceptible to erosion, sliding, earthquake, or other geological events. They pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices so that risks to health and safety are acceptable. When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided. This distinction should be considered by counties and cities that do not now classify geological hazards as they develop their classification scheme.

(a) Areas that are susceptible to one or more of the following types of hazards shall be classified as a geologically hazardous area:

- (i) Erosion hazard;
- (ii) Landslide hazard;
- (iii) Seismic hazard; or

(iv) Areas subject to other geological events such as coal mine hazards and volcanic hazards including: Mass wasting, debris flows, rockfalls, and differential settlement.

(b) Counties and cities should classify geologically hazardous area as either:

(i) Known or suspected risk;

(ii) No risk;

(iii) Risk unknown - data are not available to determine the presence or absence of a geological hazard.

(c) Erosion hazard areas are at least those areas identified by the United States Department of Agriculture Soil Conservation Service as having a "severe" rill and inter-rill erosion hazard.

(d) Landslide hazard areas shall include areas potentially subject to landslides based on a combination of geologic, topographic, and hydrologic factors. They include any areas susceptible because of any combination of bedrock, soil, slope (gradient), slope aspect, structure, hydrology, or other factors. Example of these may include, but are not limited to the following:

(i) Areas of historic failures, such as:

(A) Those areas delineated by the United States Department of Agriculture Soil Conservation Service as having a "severe" limitation for building site development;

(B) Those areas mapped as class u (unstable), uos (unstable old slides), and urs (unstable recent slides) in the department of ecology coastal zone atlas; or

(C) Areas designated as quaternary slumps, earthflows, mudflows, lahars, or landslides on maps published as the United States Geological Survey or department of natural resources division of geology and earth resources.

(ii) Areas with all three of the following characteristics:

(A) Slopes steeper than fifteen percent; and

(B) Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock; and

(C) Springs or ground water seepage;

(iii) Areas that have shown movement during the holocene epoch (from ten thousand years ago to the present) or which are underlain or covered by mass wastage debris of that epoch;

(iv) Slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials;

(v) Slopes having gradients steeper than eighty percent subject to rockfall during seismic shaking;

(vi) Areas potentially unstable as a result of rapid stream incision, stream bank erosion, and undercutting by wave action;

(vii) Areas that show evidence of, or are at risk from snow avalanches;

(viii) Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flows or catastrophic flooding;

(ix) Any area with a slope of forty percent or steeper and with a vertical relief of ten or more feet except areas composed of consolidated rock. A slope is delineated by establishing its toe and top and measured by averaging the inclination over at least ten feet of vertical relief.

(e) Seismic hazard areas shall include areas subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement, soil liquefaction, or surface faulting. One indicator of potential for future earthquake damage is a record of earthquake damage in the past. Ground shaking is the primary cause of earthquake damage in Washington. The strength of ground shaking is primarily affected by:

(i) The magnitude of an earthquake;

(ii) The distance from the source of an earthquake;

(iii) The type of thickness of geologic materials at the surface; and

(iv) The type of subsurface geologic structure.

Settlement and soil liquefaction conditions occur in areas underlain by cohesionless soils of low density, typically in association with a shallow ground water table.

(f) Other geological events:

(i) Volcanic hazard areas shall include areas subject to pyroclastic flows, lava flows, debris avalanche, inundation by debris flows, mudflows, or related flooding resulting from volcanic activity.

(ii) Mine hazard areas are those areas underlain by, adjacent to, or affected by mine workings such as adits, gangways, tunnels, drifts, or air shafts. Factors which should be considered include: Proximity to development, depth from ground surface to the mine working, and geologic material.