PREPARATION OF CHANNEL MIGRATION ZONE (CMZ) STUDY AND MAP

SECTION I: Purpose

The purpose of this appendix to the King County channel migration public rule is to provide specific channel migration designation, classification and mapping criteria for use in preparation of Channel Migration Zone (CMZ) studies and maps along King County river channels. The channel migration designation, classification and mapping criteria are intended to be consistent with the Washington Department of Ecology guidance on CMZ mapping (WA State Department of Ecology, Shorelands and Assistance Program website, copyright 1994-2013; herein referred to as "Ecology 1994-2013").

CMZ mapping criteria described in this appendix identify the Channel Migration Zone as the combination of the Historic Migration Zone (HMZ) plus Avulsion Hazard Zone (AHZ) plus Erosion Hazard Area (EHA) minus Disconnected Migration Area (DMA) (Ecology 1994-2013), as shown in Figure A-1.

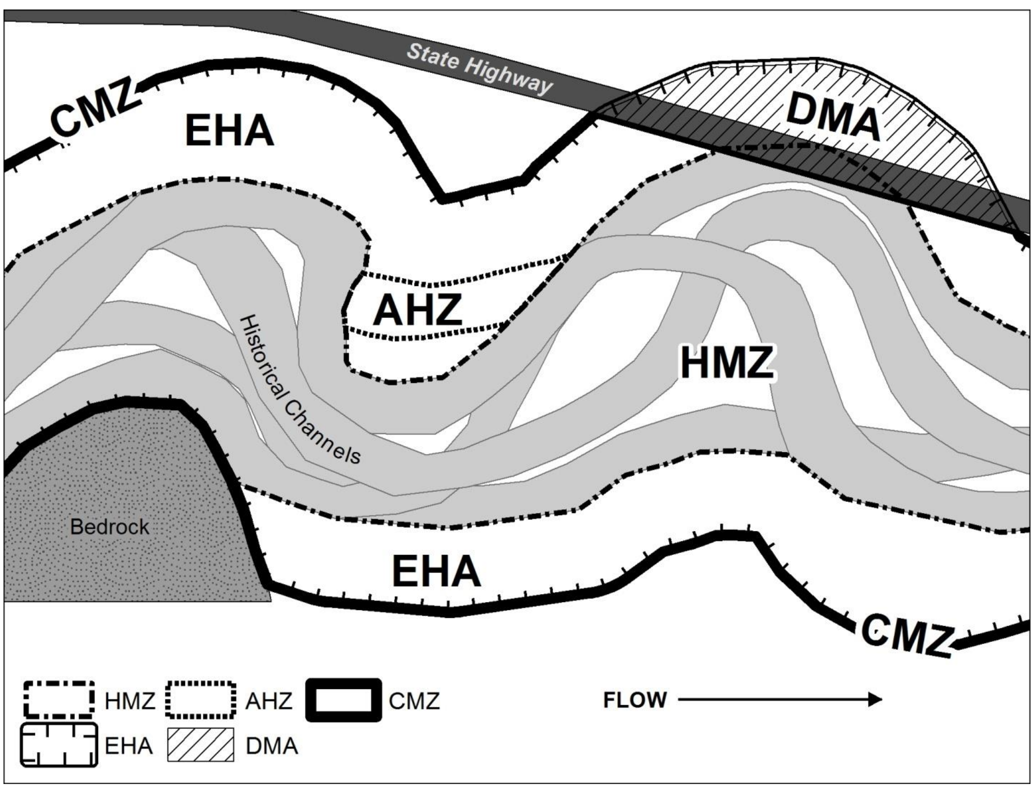

Figure A-1. Planview schematic of the Channel Migration Zone (CMZ) as the combination of the Historical Migration Zone (HMZ) plus the Avulsion Hazard Zone (AHZ) plus the Erosion Hazard Area (EHA) minus the Disconnected Migration Area (DMA). Modified from Rapp and Abbe (2003).

Each of the CMZ components is defined in section II and mapping criteria for each CMZ component are specified in section IV of this appendix. For each CMZ component, there is a subsection that describes the minimum analyses and procedures that should be used to map that component and a subsection that describes additional analyses and procedures that may be used.

SECTION II: Definitions

A. Active Channel. "Active Channel" means the portion of the channel that is inundated at high flows, is capable of bedload transport, and lacks continuous or significant woody vegetation Rapp and Abbe (2003) For the purposes of this public rule, the active channel typically is mapped from aerial photos as the composite of low flow channel(s), exposed sediments (unvegetated bars and other fluvial sediment) and areas of shrubby herbaceous or sparse, immature woody vegetation (e.g., Collins and Sheikh 2004; Konrad et al. 2011).

B. Alluvial Fan. "Alluvial Fan" means a low, outspread mass of loose materials (sand, gravel, cobbles, boulders) with variable slope, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain or upland valley; or where a tributary stream is near or at its junction with the main stream. It is steepest near its apex which points upstream and slopes convexly outward (downstream) with a gradual decrease in gradient (Ecology1994-2013). The reduction in gradient results in a loss of sediment transport capacity and bed material rapidly builds up in the stream channel, eventually causing the stream to jump to a low lying area. Through this process, the stream moves radially about its apex building up the alluvial fan. For the purposes of this rule, active alluvial fan surfaces are those areas that have been subject to fan-building processes within the historical record, as indicated by sediment deposition, sediment build-up and shifting of channel locations.

C. Avulsion Hazard Zone (AHZ). "Avulsion Hazard Zone" means the portion of the CMZ that delineates avulsion hazards not within the HMZ (Ecology 1994-2013).

D. Channel migration. "Channel migration" means the lateral or downstream shifting of a river channel within a river valley (Ecology 1994-2013).

E. Channel migration hazard area, moderate. "Channel migration hazard area, moderate" means a portion of the channel migration zone, as shown on King County's Channel Migration Zone maps, that lies between the severe channel migration hazard area and the outer boundaries of the channel migration zone (Ord. 15051 § 17, 2004) (King County Code (K.C.C.) 21A.06).

F. Channel migration hazard area, severe. "Channel migration hazard area, severe" means a portion of the channel migration zone, as shown on King County's Channel Migration Zone maps, in which there is a higher level of channel migration hazard due to a high likelihood of continued, progressive bank erosion, rapid shifting of channel location or other imminent channel changes (Ord. 17485 § 14, 2012: Ord. 15051 § 18, 2004) (K.C.C. 21A.06).

G. Channel migration zone. "Channel migration zone" means the area along a river channel within which the channel can be reasonably predicted, based on best available science, 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 (K.C.C. 21A.06).

H. Channel Reach. "Channel Reach" means a specific portion of the length of a channel that has similar physical features, such as gradient and confinement (Ecology 1994-2013). For the purposes of this public rule, the minimum length of a channel reach should be one meander wavelength.

I. Department. "Department" means the King County Department of Permitting and Environmental Review or its successor agency (K.C.C. 21A.06).

J. Disconnected Migration Area (DMA). "Disconnected Channel Migration Area" means the area located landward of man-made structures that restrict channel migration (Ecology 1994-2013) and meet criteria prescribed in W.A.C. 173-26-221(3) and K.C.C. 21A.24.274.C.

K. Erosion Hazard Area (EHA). "Erosion Hazard Area" means the area of the CMZ where the channel could move in the future, lying outside of the Avulsion Hazard Zone or the Historical Migration Zone. The EHA includes areas that are susceptible to bank erosion from stream flow, which are delineated as the Erosion Setback (see below). The EHA also includes areas susceptible to mass wasting triggered by channel migration, which are delineated as the Geotechnical Setback (see below). The EHA is defined as the combination of the Erosion Setback and the Geotechnical Setback (modified from Ecology 1994-2013).

L. Erosion Setback (ES). "Erosion Setback" means the part of the Erosion Hazard Area that encompasses the area outside of the Historical Migration Zone and Avulsion Hazard Zone that is susceptible to channel erosion. The ES includes those areas that are not at risk of avulsions, but are susceptible to stream or river erosion (Ecology 1994-2013).

M. Geotechnical Setback (GS). "Geotechnical Setback" means the part of the EHA that extends from the outer boundary of the Erosion Setback that is susceptible to mass wasting induced by channel migration. GS delineation accounts for the lateral component of slope adjustment that an embankment over-steepened by channel erosion is likely to undergo (modified from Ecology 1994-2013).

N. Historical Migration Zone (HMZ). "Historical Migration Zone" means the portion of the CMZ study area that the channel occupied in the historical record (Ecology 1994-2013).

O. Historical Record. "Historical record" means the period of time during which channel locations have been recorded reliably in historical maps and aerial imagery.

P. Holocene. "Holocene" means the period of time that includes approximately 8,000 years ago to the present; also, the corresponding series of rocks and deposits from that time. The Holocene is an epoch of the Quaternary period.

SECTION III: Applicability

Channel migration designation, classification and mapping criteria specified in this public rule apply to preparation of CMZ studies and maps along channels located within King County's shoreline jurisdiction, consistent with section 21A-24-276 of this public rule.

SECTION IV: Criteria for channel migration designation, classification and mapping

A. Overall channel migration zone study and mapping methods

1. For the purposes of this rule, preparation of the CMZ study and CMZ map should include, at a minimum, the following analyses or procedures:

    a. Identify the purpose of the CMZ delineation (Ecology 1994-2013).

    b. Compile and review available data to characterize basin-scale conditions that are relevant to channel migration such as geology, soils, topography/gradient, hydrology, land use, existing infrastructure, and vegetation (modified from Ecology 1994-2013).

    c. Characterize processes operating within the basin relevant to channel migration; including sediment regime and sediment sources, status of large wood in channels, flow regime, climate and land use changes (Ecology 1994-2013).

    d. Identify the location of the CMZ study area within the Quaternary landscape, i.e., as a (Pleistocene) glacial valley, alluvial fan within a glacial valley or a (Holocene) post-glacial valley (Collins and Montgomery 2011), and recognize the influence of this setting on channel migration processes.

    e. Describe the basin history and basin-scale changes relevant to channel migration (Ecology 1994-2013). Identify, at the basin-scale and reach-scale, past and present disturbances and changes that may influence existing channel conditions and responses (Ecology1994-2013). Consider trends in conditions that could be used to predict future channel conditions and responses (Ecology 1994-2013).

    f. Select data that will be used to evaluate channel migration using a Geographic Information System (GIS) and resources including but not limited to orthorectified aerial photos, vertical aerial photos and historical maps, Digital Elevation Models (DEMs) and Light Detection and Ranging (LiDAR) (Ecology 1994-2013). Maps and remote imagery used for CMZ mapping should be evaluated using National Standard for Spatial Data Accuracy methods (e.g., Minnesota Planning Land Management Information Center 1999) to ensure that resolution and horizontal accuracy are appropriate in comparison to the magnitude of observed channel movement.

    g. Document/digitize historical channel locations and conditions using digital, orthorectified or georeferenced, mosaicked aerial orthophotos in a GIS platform. Include aerial photos that span from earliest available to most recently available, with at least one but preferably several sets in between. Utilize appropriate LiDAR imagery. Map channel features in each set of aerial photos through the historical record of the CMZ study, including bar forms and extents, the edge of the active channel, large wood and hydromodifications such as bank armoring (Ecology 1994-2013). Map the Holocene valley bottom (Ecology 1994-2013).

h. Evaluate conditions in the field along the entire length of channel(s) to be mapped for channel migration hazard. Map bank erosion and materials, hydromodifications and geomorphic conditions (Ecology 1994-2013).

i. Quantify measurement errors and define data uncertainty (Ecology 1994-2013).

j. Determine channel reach boundaries for the channel migration analysis (Ecology 1994-2013).

k. For each reach, evaluate through the period of record those metrics that are informative to channel migration, such as channel sinuosity, active channel width, channel confinement and channel gradient. Describe present-day geomorphic conditions in each reach, including but not limited to type and direction of channel migration, erodibility of bank materials, dominant channel pattern and channel forming processes, sediment regime and primary constraints to channel migration. Identify variations in geomorphic conditions within a reach to the extent it is possible and relevant to channel migration.

l. Analyze and determine the extent of components of the CMZ, using methods described in the following subsections of this appendix, and combine the results to delineate the CMZ based on this relation: CMZ=HMZ+AHZ+EHA-DMA (Ecology 1994-2013).

2. Preparation of the CMZ study and CMZ map may include the following additional steps or analyses:

   Relevant technical analyses beyond those conducted in section IV.A.1.

B. Historical Migration Zone (HMZ)

1. For the purposes of this rule, mapping the HMZ should include, at a minimum, the following analyses or procedures:

   a. Map the HMZ in GIS as the collective area occupied by active channel locations (based on imagery identified in section IV.A.1.f) throughout the historical record.

   b. Locations of relict river channels evident in topographic information such as LiDAR that predate the historical record should not be included in the HMZ (Ecology 1994-2013).

2. Mapping the HMZ may include the following additional analyses or procedures:

a. Prepare a valley occupation map in GIS, which illustrates the relative number of times within the full historical record of historical aerial photos or maps that a specific geographic location was occupied by the channel (e.g., Collins and Sheikh 2004).

b. Channel locations from historical maps, e.g., General Land Office maps (circa 1870s) may be included in the HMZ if the accuracy of their channel locations can be corroborated by other sources such as LiDAR.

C. Avulsion Hazard Zone (AHZ):

1. This section is organized so as to list analyses or refer to information that proceeds from general to specific in subsections (a) through (d) to support the mapping of the Avulsion Hazard Zone in subsection (e). Subsections (f) and (g) apply to specific situations affecting AHZ mapping. For the purposes of this rule, mapping the AHZ should include, at a minimum, the following analyses or procedures:

a. Prepare a digital map in GIS depicting the difference in elevation between the valley bottom land surface and a selected water surface elevation profile for use in evaluating avulsion hazard in section IV.C.1.e. The valley bottom land surface typically is obtained from a LiDAR Digital Elevation Model (DEM); the water surface may be that at time of LiDAR flight or another specifically selected water surface. The resulting digital map is referred to as a Height Above Water Surface (HAWS) map (Jones 2006) or a Relative Water Surface Elevation (RWSE) map (Ecology et al. 2012).

b. Consult existing sources of information that may inform the evaluation of avulsion hazard, including analyses conducted for section IV.A existing hydrologic or hydraulic models, flood studies, topographic survey of channels, data from ongoing channel monitoring (including from U.S.G.S. channel gages), data or evaluations of sediment transport and deposition, etc.

c. Consider the effect of the following conditions on potential avulsion hazard:

i) Basin-scale and reach-scale conditions relevant to channel migration (including avulsion) such as geology, soils, topography/gradient, hydrology, hydraulics, land use, as characterized in section IV.A.1.b (Ecology 1994-2013).

ii) Basin-scale and reach-scale processes including sediment regime and sediment sources, status of large wood in channels, and flow regime, as characterized under section IV.A.1.c (Ecology 1994-2013).

iii) The location of the CMZ study area and channel reaches within the Quaternary landscape and its potential influence on avulsion hazard (modified from Ecology et al. 2012).

iv) Potential changes in channel bed and water surface elevations, as influenced by large wood accumulation (Brummer et al. 2006) or other factors.

v) Historical channel patterns and channel locations that may indicate past avulsion activity (Ecology 1994-2013).

d. Evaluate information from sections IV.C.1.a, b and c to identify areas that exhibit the following indicators of avulsion hazard.

i) Low, frequently flooded floodplain areas with or without relict channels (modified from Ecology 1994-2013)

ii) Past meander-bend cutoffs (Ecology 1994-2013)

iii) Main channel aggradation, particularly medial bar formation or growth, in the upstream limb of a bend (Ecology 1994-2013)

iv) Evidence of aggradation in a reach (vertical variability) (modified from Ecology 1994-2013)

v) Lower elevation of relict channel than active channel bed (LIDAR or other finer resolution DEM) (Ecology 1994-2013)

vi) Partial to full channel spanning large woody jams at the upstream intersection of the main channel and relict channels (Ecology 1994-2013)

vii) Channel damming by bank slumps or landslides (Ecology 1994-2013)

viii) Present and former distributary channels on alluvial fans, deltas, and estuaries (Ecology 1994-2013)

ix) Channels that diverge from the main channel in the downstream direction (Ecology 1994-2013)

x) Creeks that run somewhat parallel to main channel (Ecology 1994-2013)

xi) Meanders that show progressive growth and consequent lengthening of the mainstem channel

xii) Meanders with large amplitude and small radius of curvature (Nanson and Hickin 1983).

e. Evaluate information from sections IV.C.1.a, b, c and d to identify areas that exhibit indicators of avulsion hazard and that meet all of the following criteria. Include those areas in the Avulsion Hazard Zone.

i) Low lying ground or channel that is equal to or lower than the water surface elevation of frequent flooding in the current main channel (modified from Ecology et al. 2012), and

ii) The length of the potential avulsion pathway follows a shorter distance (and steeper gradient) than the main channel (modified from Ecology et al. 2012), and

iii) The substrate in the banks and bed or floodplain of the potential avulsion pathway is erodible material (modified from Ecology et al. 2012), and

iv) The potential avulsion pathway is a likely avulsion route based on consideration of Quaternary history (as in section IV.A.1.d.), avulsion history in the basin, flow regulation, channel alteration, sediment trends and large woody debris loading.

See section IV.H.2 for details on mapping the AHZ and its component severe and moderate hazard areas.

f. A potential avulsion pathway that meets all of the criteria in section IV.C.1.e and that has an artificial structure or structures that obstruct the pathway should be mapped within the Avulsion Hazard Zone if the top of the structure(s) is lower than the elevation of the 100-year flood and the structure(s) is not likely to restrain channel migration (per criteria in section IVF.1.e). Severe and moderate hazard areas within this AHZ, and their corresponding Erosion Setbacks, should be delineated consistent with mapping criteria in section IV.H.2 and section IV.H.3.

g. Active alluvial fan surfaces formed by a channel within state shoreline jurisdiction should be mapped within the AHZ (modified from Ecology et al. 2012). See section IV.H.6 regarding the delineation of severe and moderate hazard areas on alluvial fans. (Note that channel migration hazard along the distal portion of a tributary alluvial fan that may be eroded by a mainstem channel will be evaluated as part of the EHA/ES or EHA/GS of that mainstem channel, as described in section IV.D and section IV.E.)

2. Mapping the Avulsion Hazard Zone may include the following additional analyses or procedures:

a. Consider the variability in factors that influence avulsion hazard, including but not limited to basin-scale, channel reach-scale and subreach-scale conditions described in section IV.C.1.a, b, c and d. The extent of the Avulsion Hazard Zone may be modified as appropriate due to the variability of such factors. If such a modification is made, it should be identified clearly as an exceptional condition, be based on best available scientific or technical information and remain consistent with provisions of this appendix and the CMZ mapping methods of Ecology (1994-2013).

b. Evaluate avulsion hazard based on hydraulic analysis of erosion potential, shear stress, stream power or other relevant parameters.

c. Date floodplain features using radiocarbon or other dating techniques. Such dating may be used, if interpreted and applied appropriately, to determine the age of occupation of relict channels and thereby assess the frequency of channel shifting.

D. Erosion Hazard Area / Erosion Setback (EHA/ES):

1. For the purposes of this rule, mapping the EHA/ES should include, at a minimum, the following analyses or procedures:

   a. Use the historical channels and features digitized in GIS from aerial imagery and maps (in section IV.A.1.f and IV.A.1.g) for calculations to establish the Erosion Setback.

      i) Historical channel locations from multiple sets of aerial imagery and historical maps (with adequate accuracy, as described in section IV.A.1.f) should be used for this analysis, i.e., not only the earliest and most recent aerial photos. Time intervals between sets of historical channels should be selected that are appropriate for use in calculating long-term average channel migration rates, e.g., at approximately decadal time intervals, if possible.

      ii) Basin-scale impacts and influences should be considered when selecting aerial photos to use in analyzing historical channel migration, such as the date of completion of a dam that has altered basin hydrology or the timing of widespread, systemic installation of bank armoring.

   b. For each channel reach, use the following procedures to measure historical lateral channel migration and calculate channel migration rates (for use in establishing the Erosion Setback in the next subsection):

      i) Measure lateral channel migration distances using methods consistent with Ecology (1994-2013), including but not limited to:

         (a) Transect Method (Ecology 1994-2013): Measure historical channel migration along a set of transects drawn at regular intervals perpendicular to the centerline of the HMZ,

         (b) Historical channel migration at each meander bend (Ecology 1994-2013): Measure historical channel movement from specific points along a meander bend in one aerial photo to analogous specific points along the same meander bend in a subsequent aerial photo, or

         (c) Other functionally equivalent method(s).

      ii) Calculate lateral channel migration rates from the measurements of lateral channel migration taken in subsection IV.D.1.b.(i). Lateral channel migration rates should be calculated separately for each of the following categories of migration measurements, for each channel reach and for each time interval between successive aerial photos or maps:

         (a) Measurements taken where the banks not armored

         (b) Measurements taken where the banks are armored

(c) Measurements taken only where channel migration occurred, and

(d) All measurements taken within the channel reach.

For each channel reach and for the combined period of all time intervals, calculate a channel migration rate as the time-weighted mean of the absolute value of migration rates from each time interval. Select a representative channel migration rate based on rates thus calculated for use in establishing the Erosion Setback (below). The representative channel migration rate should be selected from those that include channel areas where channel migration occurred.

c. For each channel reach, establish an Erosion Setback and apply it to the Historical Migration Zone and Avulsion Hazard Zone. See section IV.H.3. for details on delineating severe and moderate hazard areas within the Erosion Setback as measured from the Historical Migration Zone and the Avulsion Hazard Zone.

i) The Erosion Setback should be established as the greater of the following two distances (see Figure A-2):

(a) Calculate a setback distance by multiplying the representative channel migration rate (distance/year) times 100 years. Apply one half (i.e., 50 years of lateral channel migration) to each side of the HMZ and AHZ.

(b) Calculate a setback distance by multiplying the representative channel migration rate (distance/year) times 200 years. Apply one half (i.e., 100 years of lateral channel migration) to each side of the most recent mapped active channel location.

See also section IV.D.2.a and IV.H.3.f regarding variations in Erosion Setback distances and their application.

d. Where the Erosion Setback intersects an erodible landform that is more resistant to erosion than Holocene alluvium near the channel, the width of the portion of the Erosion Setback within the more-resistant landform should be calculated using an appropriately lower channel migration rate. The resulting Erosion Setback width will be narrower than in Holocene alluvium (Figure A-3). The appropriately lower channel migration rate should be based on measurements taken in the same or a similar landform that the active channel encountered, within the same river channel reach, and during that part of the historical record of the study during which the active channel eroded that landform.

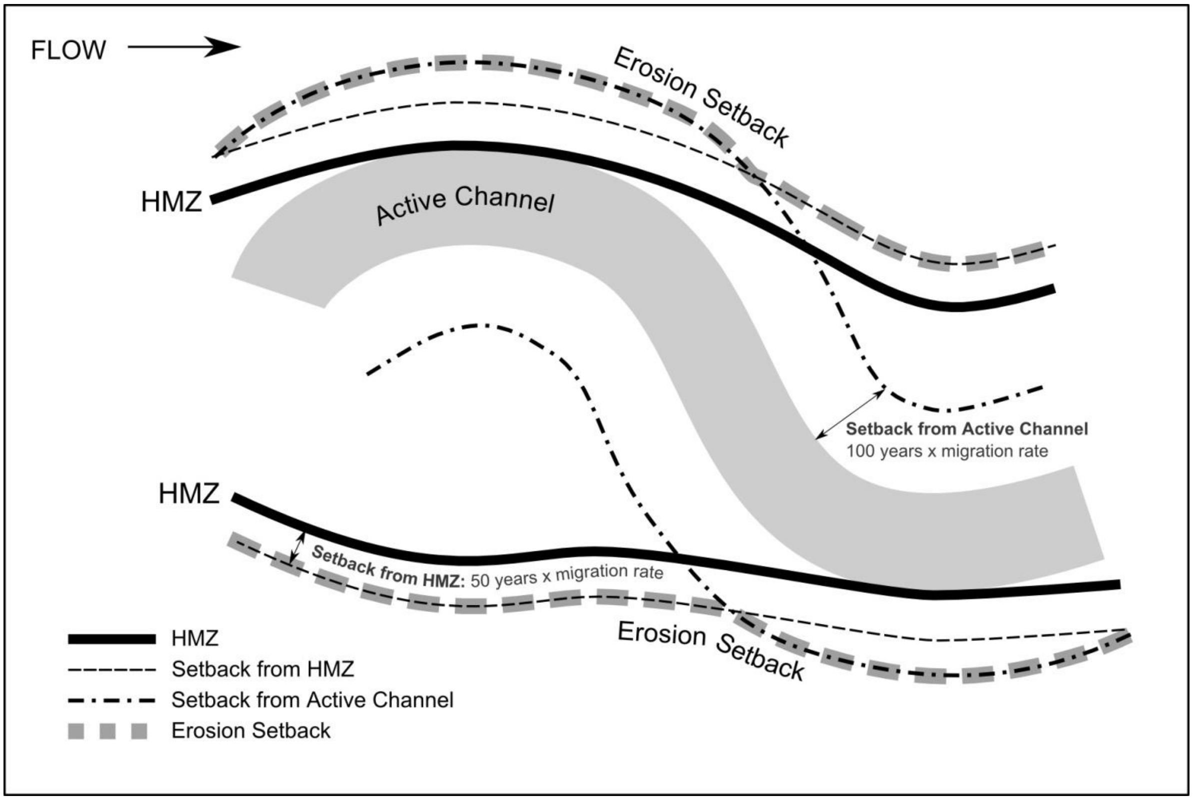

Figure A-2. Planview schematic of the Erosion Hazard Area/Erosion Setback, delineated as the greater of the two distances calculated in section IV.D.1.c.(i)(a) and IV.D.1.c.(i)(b).

2. Mapping the Erosion Hazard Area / Erosion Setback may include the following additional analyses or procedures:

   a. Consider variability of factors affecting channel migration within each channel reach, including but not limited to erodibility of bank materials, channel migration type and direction, channel-forming processes and constraints on channel migration, based on analyses in section IV.A.1.k. and information from section IV.A. The Erosion Setback distance may be modified on each side of the HMZ and AHZ as appropriate, due to differences in channel conditions and processes within the reach.

   b. Calculate channel migration distances, channel migration rates or an Erosion Setback distance for comparison to the results of section IV.D.1, using methods such as:

      i) Calculate migration rates by the polygon analysis method (Ecology 1994-2013).

      ii) Calculate migration rates using the National Center for Earth-surface Dynamics Stream Restoration Toolbox (Lauer 2006).

      iii) Calculate the maximum short-term episodic distance migrated (e.g., GeoEngineers 2009) and compare it the Erosion Setback distance of section IV.D.1.

iv) Measure the maximum channel migration distance in each meander bend, as observed from the earliest to most recent aerial photos. For each river channel reach, calculate the average of the maximum channel migration distances and compare it the Erosion Setback distance of section IV.D.1.

v) Computer modeling of channel migration, e.g., Larsen et al. (2006).

c. Compare channel migration rates to the occurrence of peak flow events to see if migration rates increase as a function of peak flow. If sufficient information exists, compare the duration of high flows to channel migration rates.

E. Erosion Hazard Area / Geotechnical Setback (EHA/GS):

1. For the purposes of this rule, mapping the EHA/GS should include, at a minimum, the following analyses or procedures:

a. Where the outer edge of the Erosion Setback encounters an erodible land surface that is greater than 20 feet in height above Ordinary High Water, a Geotechnical Setback should be applied to the outer edge of the Erosion Setback at a 1:1 slope measured from the predicted toe of slope after applying the Erosion Setback (Figure A-3).

b. No Geotechnical Setback or Erosion Setback is necessary for geologic materials that are highly resistant to erosion, such as sound bedrock showing no signs of slope retreat (e.g., in Figure A-1).

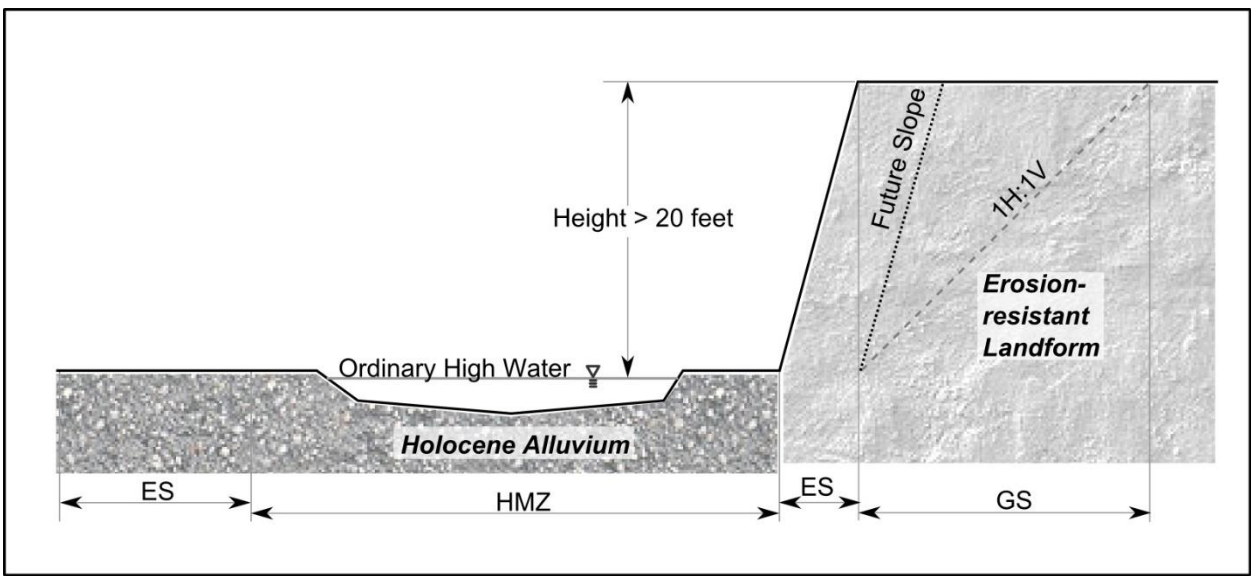

Figure A-3. Cross-section schematic of Erosion Hazard Area/ Geotechnical Setback illustrating that a Geotechnical Setback (GS) should be measured at a 1Horizontal:1Vertical (1H:1V) slope at the outer edge of the Erosion Setback (ES), as described in section IV.E.1.a. The narrower ES on the right side of the Historical Migration Zone (HMZ) illustrates an ES calculated using a lower channel migration rate in an erosion resistant landform, as described in section IV.D.1.d.

2. Mapping the EHA/GS may include the following additional analyses or procedures: Analysis of bank erosion and slope stability using an analytical model such as the Bank Stability and Toe Erosion Model (U.S. Department of Agriculture, Agricultural Research Service 2013).

F. Disconnected Migration Area (DMA):

1. A DMA may be mapped in areas landward of an artificial ("man-made" in the section II definition) structure such as a levee, revetment and other infrastructure if the artificial structure is likely to restrain channel migration. For the purposes of this rule, mapping the DMA should include, at a minimum, the following analyses or procedures:

   a. Evaluate an artificial structure with regard to mapping a DMA landward of the structure using criteria based on Washington State Department of Ecology channel migration assessment guidelines (Ecology 1994-2013) and regulations in the Washington Administrative Code and King County Code, the relevant sections of which are included in Appendix C to this public rule.

   b. The area landward of the following legally existing, publicly maintained artificial structures (e.g., revetments, levees) should be mapped as a DMA.

      i) Within incorporated areas and urban growth areas, an artificial structure that limits channel migration,

      ii) In all areas, an artificial structure that is likely to restrain channel migration and is built above the one hundred-year (100-year) flood elevation,

      iii) Within unincorporated areas, an artificial structure that is likely to restrain channel migration and is built below the 100-year flood but scientific or technical information demonstrates that it is constructed to remain intact through the 100-year flood, or

      iv) State highways or sole-access major county roads.

   c. Legally existing active railroads should be mapped as a DMA (Ecology et al. 2012).

   d. The area landward of the following artificial structures should not be mapped as a DMA.

      i) An artificial structure that is not legally existing,

      ii) An artificial structure that is not publicly maintained, i.e., it is privately maintained, or

      iii) Any artificial structure that is not likely to restrain channel migration.

   e. Information from the following sources should be used to evaluate an artificial structure for its likelihood of restraining channel migration and for mapping a DMA:

i) Publically maintained:

Ecology (1994-2013) identifies "constructed structures with no public commitment for maintenance" as being an "ineffective barrier to channel migration (Not part of a DMA)".

ii) Artificial structure likely to restrain channel migration:

An artificial structure should be considered likely to restrain channel migration if its construction, condition and configuration are consistent with information in both of the following subsections (a) and (b):

(a) Relevant design and construction standards, including but not limited to those in King County (1993), U.S. Army Corps of Engineers (2000), or Washington Department of Fish and Wildlife et al. (2003).

(b) Sources of information on the potential for the channel to migrate landward of the structure. These may include but are not limited to the analyses conducted for Avulsion Hazard Zone mapping in proximity to this structure, pursuant to section IV.C, or other relevant geomorphic, hydraulic or sediment analyses.

iii) Built above the 100-year flood elevation:

(a) The 100-year flood water surface elevation computed by hydraulic modeling from the applicable flood study, or

(b) Empirical information if relevant and credible, such as high-water mark elevations.

If a structure is not built above the 100-year flood elevation then it is built below the 100-year flood elevation.

iv) "Scientific or technical information" means the following investigations or analyses:

(a) Geotechnical, slope stability, hydraulic or other relevant technical analyses that evaluate the stability of the artificial structure in conditions during a 100-year flood, or

(b) Analyses conducted for design and construction of the structure that are functionally equivalent to those in section IV.F.1.e.(iv)(a).

v) State highways, active railroads or sole-access major county roads:

Ecology et al. (2012) defines this infrastructure as a barrier to channel migration.

2. Mapping the DMA may include the following additional analyses or procedures:

Relevant technical analyses beyond those conducted in section IV.F.1.

G. Channel Migration Zone (CMZ):

1. For the purposes of this rule, mapping the CMZ should include, at a minimum, the following analyses or procedures:

   a. Map the CMZ as the sum of its component parts: CMZ=HMZ+AHZ+EHA-DMA.

   b. If conditions are encountered for which mapping criteria have not been specified in this appendix, delineation of the relevant CMZ component should be made based on best available scientific or technical information, consistent with CMZ mapping methods in this appendix and Ecology (1994-2013).

2. Mapping the CMZ may include the following additional analyses or procedures:

   a. Documentation of historical channel locations along relatively small channels using aerial photos may result in unacceptably high inaccuracy due to the channel being obscured by overhanging vegetation. Along such channels, it may be necessary to rely more on evaluation of present-day conditions characterized by LiDAR and field observations to map the CMZ, application of channel migration rates from more-visible analogous reaches or channels, or other approaches that rely less on calculation of channel migration (GeoEngineers 2012; Ecology et al. 2012).

   b. If consideration of site-specific variability within the channel reach (conducted in section IV.D.2.a) and professional judgment indicate that the mapping methods in this appendix are not appropriate in a specific location and condition, then the delineation of a CMZ component and its severe and moderate hazard areas may be modified. If such a modification is made, it should be identified clearly as an exceptional condition, be based on best available scientific or technical information and remain consistent with provisions of section IV.G.1 of this appendix and the CMZ mapping methods of Ecology (1994-2013).

   c. Other relevant technical analyses beyond those conducted in section IV.G.1.

H. Severe and moderate channel migration hazard areas:

Severe channel migration hazard areas and moderate channel migration hazard areas should be mapped so as to recognize that channel migration hazard is not equal throughout the CMZ. If not specified below, any part of a CMZ component that is not mapped as a severe hazard area should be mapped as a moderate hazard area. In this section, analyses or criteria that should be applied and analyses or criteria that may be applied are identified in the subsections for each CMZ component.

1. Historical Migration Zone:

   a. All of the Historical Migration Zone should be mapped as a severe hazard area.

b. All or part of the HMZ may be mapped as a moderate hazard area landward of an artificial structure where the width of the severe hazard area has been reduced to match the HMZ pursuant to section IV.H.3.b. The portion of the HMZ that may be mapped as a moderate hazard area should be based on the extent to which the artificial structure's construction, condition and configuration are consistent with information from section IV.F.1.e.(ii)a or section IV.F.1.e.(ii)b.

2. Avulsion Hazard Zone:

a. Portions of the Avulsion Hazard Zone should be mapped as severe channel migration hazard area if they meet any of the following criteria in addition to all criteria in section IV.C.1.e.

i) Potential avulsion pathways have little or no vegetation, or show evidence of fresh scour, channel widening or oversteepening, consistent with erosion from recent flood events, or

ii) Potential avulsion pathways have a direct, low-elevation surface connection to the main channel such that it is flooded deeply and frequently (which may be indicated by surface flow through the pathway even during periods of low river flow), or

iii) Indicators of avulsion hazard (listed in section IV.C.1.d) regarding accumulation of sediment or large wood in the main channel, or changes to main channel meander geometry, exist in close proximity to a potential avulsion pathway.

b. An Avulsion Hazard Zone mapped as a severe hazard area should be delineated as follows:

i) Map the severe hazard AHZ along the avulsion pathway with a width equal to the average Active Channel width of the present river channel reach in which the avulsion pathway is located.

ii) The severe hazard AHZ (and its associated Erosion Setback, the width of which is specified in section IV.H.3.d) should be centered along the avulsion pathway centerline unless conditions indicate otherwise, including but not limited to variable erodibility of substrate, topography, or other constraints.

c. Portions of the Avulsion Hazard Zone that meet all of the criteria in section IV.C.1.e. (but not criteria in section IV.H.2.a) should be mapped as moderate channel migration hazard and delineated as follows:

i) Map the moderate hazard AHZ along the avulsion pathway with a width equal to the average Active Channel width of the present river channel reach in which the avulsion pathway is located.

ii) The moderate hazard AHZ (and its associated Erosion Setback, the width of which is specified in section H.3.e) should be centered along the avulsion pathway centerline unless conditions indicate otherwise, including but not limited to variable erodibility of substrate, topography, or other constraints.

3. Erosion Hazard Area/Erosion Setback:

a. Erosion Setback from Historical Migration Zone, severe hazard area: The landward edge of the severe hazard area within the Erosion Setback should be delineated as the greater of the following two distances:

i) The distance calculated by multiplying a representative channel migration rate (from section IV.D.1.b(ii)) times 50 years and applying half of that distance (i.e., 25 years of lateral channel migration) to each side of the HMZ, or

ii) The distance calculated by multiplying a representative channel migration rate (from section IV.D.1b(ii)) times 100 years and applying half of that distance (i.e., 50 years of lateral channel migration) to each side of the most recent active channel.

b. Erosion Setback from Historical Migration Zone, reduction in severe hazard area:

i) The width of the severe hazard area measured from the HMZ may be decreased in the area landward of an artificial structure that is built above the 100-year flood if the structure meets the standards of either section IV.F.1.e.(ii)(a) or section IV.F.1.e. (ii)(b). The extent to which the severe hazard area may be reduced should be based on the extent to which the artificial structure's construction, condition and configuration are consistent with the standards in section IV.F.1.e.(ii)(a) or section IV.F.1.e. (ii)(b).

ii) The width of the severe hazard area measured from the HMZ may be decreased in the area landward of an artificial structure that is built below the 100-year flood if the structure meets the standards of both section IV.F.1.e.(ii)(a) and section IV.F.1.e. (ii)(b). The extent to which the severe hazard area may be reduced should be based on the extent to which the artificial structure's construction, condition and configuration are consistent with the standards in section IV.F.1.e.(ii)(a) and section IV.F.1.e. (ii)(b).

c. Erosion Setback from Historical Migration Zone, moderate hazard area: The moderate channel migration hazard area is the portion of the Erosion Setback that lies between the severe channel migration hazard area and the outer boundary of the Erosion Setback.

d. Erosion Setback from a severe Avulsion Hazard Zone: An Erosion Setback distance should be added to each side of a severe AHZ to a width equal to a range of 25 years to 50 years times a representative channel migration rate (as calculated in section

IV.D.1.b.(ii)). The number of years should be based on the extent to which criteria in section IV.H.2.a are met. The area within this Erosion Setback from a severe AHZ should be mapped as a moderate hazard area.

e. Erosion Setback from a moderate Avulsion Hazard Zone: An Erosion Setback distance should be added to each side of a moderate AHZ to a width equal to 25 years times a representative channel migration rate (as calculated in section IV.D.1.b.(ii). The area within this Erosion Setback to a moderate AHZ should be mapped as a moderate hazard area.

4. Erosion Hazard Area/Geotechnical Setback:

   The entire area within the EHA/GS should be mapped as a moderate channel migration hazard area.

5. Disconnected Migration Area:

   A DMA is the area landward of an artificial (man-made) structure that restricts channel migration (Ecology 1994-2013). There will be no CMZ, and therefore no severe or moderate channel migration hazard area, mapped within the DMA. (Note that areas riverward of an artificial structure likely to restrict or restrain channel migration, such as within a levee setback project area, should be mapped as a severe hazard area unless analyses consistent with methods in this appendix indicate otherwise.)

6. Severe and moderate channel migration hazard areas on alluvial fans should be delineated as follows:

   a. All active alluvial fan surfaces should be mapped as a severe hazard area, unless scientific or technical analyses demonstrate otherwise.

   b. An Erosion Setback from the Avulsion Hazard Zone on alluvial fans should be mapped using the same mapping methods and criteria as an Erosion Setback within areas of the Holocene valley bottom (as per section IV.D , section IV.H.2 and section IV.H.3.

   c. Mapping an Avulsion Hazard Zone outside of active alluvial fan surfaces on an alluvial fan may be based on the following additional analyses or procedures:

      i) Topographic expression of the fan and geologic materials

      ii) Historic evidence of aggradation rates and channel shifting

      iii) Hydraulic or geomorphic investigation

      iv) Numerical modeling (e.g., Kerr-Wood-Liedal Associates 2003)

      v) Radiocarbon or other dating of depositional surfaces.

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