Chapter 4:

CHANNEL MIGRATION ZONES

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4.1 INTRODUCTION

Areas affected by channel migration, the movement of a river or stream channel across its valley bottom, are called Channel Migration Zones (CMZs). CMZs are a type of flood hazard area and therefore a critical area under the proposed Critical Areas Ordinance (CAO). The flood hazard to people and structures within a CMZ is due to bank erosion or outright channel relocation rather than getting inundated by overbank flow (King County 1993). Although both channel migration and flood inundation are hazards due to flooding, there is no specific correlation between the mapped boundary of the two hazard areas. The area within a CMZ and its associated flood hazard may extend beyond the 100-year floodplain (described in Chapter 3 – Flood Hazard Areas), or the 100-year floodplain may extend beyond the CMZ. Therefore, it is necessary to map CMZs as a hazard area separate from floodplain mapping.

The 1993 King County Flood Hazard Reduction Plan states that channel migration hazard areas should be identified through geomorphic analyses and land use regulations should be adopted and applied in order to preclude unsafe development in these hazard areas (King County 1993). At the same time, protection of channel migration zones maintains floodplain connectivity and benefits habitat protection. CMZs are protected, whether for public safety or habitat protection purposes, by delineating the outer boundaries of channel migration and regulating land use within those boundaries.

CMZs currently are protected along King County channels where CMZs have been mapped under provisions specified in the King County channel migration public rule (King County 1999). CMZ provisions in the proposed CAO do not change the CMZ standards and regulations specified in the 1999 public rule. Existing and proposed King County CMZ regulations are equivalent. The change that will occur with CAO adoption is procedural: the CMZ provisions proposed in the CAO will be adopted by Council and codified by ordinance whereas the existing CMZ regulations currently are being implemented as enacted by an administrative public rule.

Section 2 of this chapter starts with a review of scientific literature that describes CMZ functions, including physical processes of channel migration, types of channel migration, and some natural factors that influence channel migration. There follows a review of scientific literature on mapping channel changes and on definitions and delineation of CMZs. This scientific information is taken to be Best Available Science (BAS) on CMZs to the extent that it meets guidelines in WAC 365-195-900. Section 3 provides a summary and conclusion to this chapter.

4.2 REVIEW OF LITERATURE

The reader is referred to existing literature for thorough background and context on fluvial system, channel form and process, geomorphology, and factors that affect channel migration (e.g., Leopold et al. 1964, Schumm 1977, and Knighton 1998). Rapp and Abbe (2003) provide a thorough framework for delineating CMZs that should be consulted for a more complete treatment of topics described in this chapter.

4.2.1 Channel Migration Physical Processes

Channel Migration Overview

Channel migration is the process of a river channel moving across or within its valley bottom. Channel migration occurs over variable timeframes, ranging from the gradual lateral progression of meander bends to the abrupt shifting of a channel to a new location. In general terms, a CMZ is a corridor of variable width that includes the current river channel plus the adjacent area through which the channel has migrated or is likely to migrate within a given timeframe. Within the CMZ corridor, water, sediment, and organic material are moved by fluxes between river and floodplain and are routed from headwaters to mouth on time scales of days to centuries.

A basin-scale perspective of channel migration provides an initial overview. Drainage basins can be broken into three zones in the downstream direction: the rugged headwaters dominated by erosion and sediment production; a middle zone of sediment transport; and a downstream zone of deposition (Schumm 1977). These three subdivisions of the fluvial system may seem like a simplification, because sediment is eroded, transported, and deposited in all three zones (Schumm 1977). These three zones are similar to the source, transport, and response segments of a watershed described by Montgomery and Buffington (1993), with channel changes such as channel migration most commonly occurring in the generally downstream response segments where areas of sediment deposition predominate (Montgomery and Buffington 1993).

Channels in the steeper erosion and sediment production zone and areas dominated by sediment transport may not show significant channel migration over time scales of a few decades. Areas of deposition, especially the transition from a transport to a depositional zone, would be areas of likely channel migration (Church 1983; Montgomery and Buffington 1993). These conditions exist where channel gradient and confinement decreases markedly, such as where a steeper river emerges from foothills onto a broad, flat floodplain. In the major King County rivers, most of which flow from headwaters in the Cascades to mouths at or near sea level, the segments with a history of channel migration typically are located in just such depositional areas.

The footprint of a channel can be expressed as a percent of the total floodplain area in plan view. As the channel migrates, the composite footprint of its sequential locations will occupy an increasing percentage of the floodplain. By extension, the timeframe needed for a channel to migrate and occupy its entire floodplain can be calculated as a “floodplain turnover rate” (O’Connor et al. 2003), which might be on the order of hundreds to thousands of years in an alluvial channel of western Washington. Given time and without obstruction, a natural, unimpeded, meandering channel can swing and shift across its valley and the entire pattern may sweep downstream, resulting in a complete reworking of the alluvial floodplain (Schumm 1977).

Hence the generally flat floor of a valley, its alluvial floodplain, was constructed by the river during lateral channel migration and by deposition of sediment. In alluvial floodplains, the river has occupied or migrated through every position of the valley floor at some point in the past (Dunne and Leopold 1978). The river channel moves laterally by erosion of one bank and simultaneous deposition on the other. As a channel migrates, there may be physical features evident in the floodplain such as progressive erosion and deposition at meander bends (Figure 4.1). Other features, such as side channels or oxbow lakes (crescent-shaped body of standing water situated in an abandoned meander) may be evidence that a channel has moved by shifting abruptly or by cutting off a meander bend. Though such field conditions provide evidence of channel migration, the actual boundary of the CMZ may not be readily evident in the field because the lateral extent of the CMZ typically depends on selection of a timeframe within which migration occurs (as described further below).

Figure 4.1. Aerial Photographic Evidence of Channel Migration (WA DNR 2001)

Types of Channel Movement

A thorough description of types of channel movement is provided by Rapp and Abbe (2003).

Channel movement can occur in both vertical and horizontal directions to produce channel migration. Vertical channel movement occurs as either a raising or lowering of the channel bed. Increases in channel bed elevation result from sediment deposition and aggradation. Significant increases in bed elevation allow a given flood flow to gain greater access to side channels and overbank areas, or increase exposure to erodible banks, all of which increase the likelihood of horizontal channel movement. Decreases in channel bed elevation result from channel incision, local or general channel scour, and degradation. Significant decreases in bed elevation lead to bank collapse and channel widening.

Horizontal channel movement includes lateral channel migration, avulsions, channel widening and channel narrowing, and involves erosion of the existing floodplain and terraces (Rapp and Abbe, 2003).

Lateral channel migration results from erosion of floodplain material along one bank concurrent with deposition of sediment along the other bank. Bank erosion is the primary channel process necessary for channel migration to occur (Leopold et al. 1964). Ongoing lateral channel migration typically results in development of meander bends, which themselves may migrate in a downstream direction. Rivers tend to establish secondary circulation patterns of flow that moves downstream in a generally spiraling motion, where a descending flow pattern encourages scour and an ascending flow direction favors deposition. The scour and deposition from secondary circulation is associated with development of bed forms such as pools and riffles. As pools alternate from one side of the channel to the other, they scour and undermine the outside banks, initiating meander development (Knighton 1998). If the processes of erosion and deposition are in rough equilibrium, there may be little net change in cross sectional area even as the channel meanders or migrates across the floodplain (Dunne and Leopold 1978).

An avulsion is an abrupt shift of the channel to a new location, often with little erosion of the land between the old and new channel locations. An avulsion can happen during a single flood event, e.g., if a mainstem river is obstructed by a woody debris jam and reroutes the river into a side channel during high flows. Another type of avulsion is the neck cut-off of a meander bend, which can occur as a meander bend increases in sinuosity until parts of the meander loop connect and bypass the longer, circuitous path of the entire meander. Chute cutoffs cut across a point bar and may occur more commonly than a neck cutoff (Rapp and Abbe 2003). Conditions that would favor the occurrence of avulsion include the existence of side channels accessible to frequent flows, or the ongoing development of sinuous meander bends.

Channel widening and channel narrowing result in horizontal changes to the channel dimensions, although channel alignment may not change. Channel widening might occur with channel aggradation and/or channel braiding. Channel narrowing can result as a response to upstream decreases in sediment or water discharge.

Channel movement is difficult to predict with certainty on alluvial fans (WA DNR 2001). An alluvial fan is a fan-shaped feature composed of streamflow and/or debris flow sediments deposited usually at a topographic break such as the base of a mountain or a valley floor at the outlet of a steeper tributary. The alluvial fan is formed as the tributary deposits sediment to the point where its channel elevation is higher than the adjacent fan; the channel then shifts location to flow to the adjacent, lower elevation. As this ongoing process continues, the channel shifts to deposit sediment in an arc radiating from the tributary outlet. A braided channel or channel network is common on an alluvial fan. By its inherent tendency to shift channel locations, and resultant uncertainty in predicting channel migration, the entire surface of the alluvial fan is considered a channel migration zone of its source tributary (WA DNR 2001).

Some Natural Factors that Influence Channel Migration

A thorough description of factors affecting channel migration is provided by Rapp and Abbe (2003).

Lateral channel migration meets a solid boundary in bedrock. In areas where the river channel is in direct contact with bedrock, bank erosion is assumed to be minimal over scales and timeframes typically used in channel migration study.

Channels confined by narrow valleys are less likely to move laterally and so may have little or no channel migration zone. The degree of channel confinement can be expressed as a ratio of valley floor width to channel width, where a ratio of less than 2:1 indicates high confinement and lack of a CMZ (WA DNR 2001). A CMZ also is interpreted to not exist where there is a consistent lack of evidence of channel movement in the historic record, in current aerial photos, and in field observations (NMFS 2000).

A valley wall may appear to be the boundary of a CMZ as the de facto edge of a floodplain, but the greater elevation of a valley wall does not preclude channel migration. An eroding vertical bank of unconsolidated material such as a terrace of older alluvium or glacial deposits does not prevent toe erosion, transport of sediments, and lateral channel migration (Rapp and Abbe 2003). Lateral channel migration into such terraces or unconsolidated bluffs may proceed at a slower rate than through younger floodplain alluvium (Shannon and Wilson 1991).

The susceptibility of riverbanks to slope instability and mass failure depends on their geometry, structure, and material properties (Knighton 1998). Undercutting the toe of tall, steep slopes by the river decreases slope stability and can result in landslides directly into the channel, particularly in geologic units predisposed to landsliding (see Chapter 5 – Geologic Hazard Areas. At that point, hillslope delivery of sediment and fluvial sediment transport may become coupled in a “pseudo-cyclic process” of basal erosion, upper bank failure, lower bank accumulation, and removal of failed material by river transport (Knighton 1998). The river’s flow may erode and remove relatively small deposits, but a landslide mass that blocks the channel and is not eroded will reroute the channel as an avulsion.

Slope failure by landslide or mass wasting introduces both sediment and woody debris to the channel. Other input sources of woody debris to the channel include wind throw, bank erosion, and fluvial transport from upstream, in both chronic and episodic time scales (Bilby and Bisson 1998). Leaching, fragmentation, decay, consumption by invertebrates, and fluvial transport all contribute to the export of wood from a channel (Keller and Swanson 1979). Studies that reconstruct historic channel conditions document prodigious amounts of woody debris in mainstem channels of the Pacific Northwest and Puget Sound lowlands (Maser and Sedell 1994, Collins et al. 2003).

Present-day accumulation of large woody debris (LWD) as stable, in-channel structures can influence channel hydraulics, channel morphology, sediment accumulation, channel migration, and riparian forest development morphology at the sub-reach and reach scale (Abbe and Montgomery 2003, O’Connor et al. 2003, Collins and Montgomery, 2002, Bilby and Bisson 1998, Abbe and Montgomery 1996). Stable LWD structures can resist channel migration, forming a revetment that halts local bank erosion, often altering the orientation of flow relative to the jam. Stable LWD jams that persist long enough to be buried in a floodplain are associated with anomalous forest patches older than the surrounding floodplain forest (Abbe and

Montgomery 1996), indicating long-term resistance to lateral erosion. The type of debris jam and the presence, number, size, stability, and orientation of the key pieces of LWD will determine the stability of the jam and the effect of the jam on channel stability (Abbe and Montgomery 2003, Abbe and Montgomery 1996).

The effects of LWD accumulations on channel stability can vary, e.g., either increasing or decreasing bank stability depending on the specific setting (Keller and Swanson 1979). Bank erosion and channel shifting that entrain floodplain sediment and LWD can promote channel movement and instability by diverting flows that in turn causes further bank erosion and entrainment of sediment and wood. Woody debris jams in low gradient meandering channels of moderate size may facilitate formation of meander cutoffs, increase channel width, produce mid-channel bars, and affect channel morphology (Keller and Swanson 1979). LWD can be a primary determinant on channel form in small streams; wood has less of an effect on channel form in larger streams (Bilby and Ward 1989, Bilby and Bisson 1998) (see also Chapter 7 – Aquatic Areas).

Woody debris accumulations appear integral to formation and maintenance of an anastomosing (i.e., branching and recombining) channel pattern (Abbe and Montgomery 2003) and to causing avulsions, maintaining multiple channel morphology, and regulating flow from main channels to perennially flowing floodplain sloughs (Collins and Montgomery 2002). Wood jams are often the mechanism that triggers a channel to avulse or switch flow from one channel to another (Collins and Montgomery 2002, Collins et al. 2003). May (2002) states that channels with abundant accumulation of in-channel LWD often have more active channel migration.

Accumulation of LWD induces upstream deposition of sediment and thereby can raise the elevation of the channel bottom and water surface for channel distances on the order of 1-10 channel widths (Abbe and Montgomery 2003). Increases in channel bottom and water surface elevations in turn allow flows into previously inaccessible side channels and thereby increase the likelihood of horizontal channel movement, as described in “Types of channel movement”, above.

Channel Migration, Floodplains, and Habitat

A migrating channel will sweep across and rework its alluvial floodplain, entraining sediment, organic material, and wood in the process. Within the corridor affected by channel migration, water and entrained materials are moved by fluxes between river and floodplain. Materials are routed from headwaters to mouth over time scales that vary from days to centuries. Because of the dynamic nature of such fluxes and routings, channel migration poses a hazard to public safety. But in the *context* of natural resource protection (as described in Chapter 2 – Scientific Framework), the dynamic fluxes and routings caused by channel migration benefit the habitat of many species of fish and wildlife, especially salmon.

The flux of gravel and wood to the river due to channel migration is an example of the *connectivity* between a river and its floodplain (as described in Chapter 2). The morphology of a migrating channel may include accessible side channels and/or multiple channels, both of which increase channel *complexity* (as described in Chapter 2) and benefit salmonid spawning and rearing habitat. Bank erosion from both gradual and abrupt channel migration recruits spawning gravel from alluvial riverbanks. With bank erosion, trees often topple into the channel and become LWD, creating high quality, diverse habitat for rearing, spawning, migration and refuge purposes (see Chapter 7 – Aquatic Areas).

4.2.2 Mapping Channel Change

A common starting point for mapping channel movement and delineating CMZs is a compilation of archival records to document change in location from historic to contemporary channels. The floodplain turnover rates and channel and floodplain dynamics described earlier were calculated for the Quinalt and Queets Rivers by comparison of up to nine sets of channel locations dating from 1900 to the present (O'Connor et al. 2003). Methods in development in the Puget Sound area characterize historical river landscapes and aquatic habitat using a geographic information system (GIS) as well as modern topographic information, aerial photography, and field studies (Collins et al. 2003).

Ham and Church (2000) mapped channel features for five dates between 1952 and 1991, using GIS to analyze changes in erosion and deposition volumes and relate those volumetric changes to riverbed material transport via a sediment budget approach. While the focus of Ham and Church (2000) was on sediment volumes, their characterization of plan-form changes in channel conditions through time used the same methods and tools employed in a channel migration analysis. Graf (1984) measured the change in channel locations through time with a grid framework of cells superimposed on the floodplain to calculate the probability that any given floodplain cell will be eroded. Comparison of channels over a number of time intervals from 1871 to 1978 showed that the probability of a cell being eroded within a given period of time is directly proportional to the sizes of the annual floods during the period and inversely proportional to the distance upstream and the distance lateral to the channel (Graf 1984).

These studies and others suggest that at least 50 years of remote sensing data such as aerial photos (at intervals of five to 10 years) are necessary to reveal meaningful trends in channel change and bed material transport rates (Rapp and Abbe 2003).

4.2.3 CMZ Definition and Delineation

There are few examples from scientific literature that define CMZs with specificity. No studies were found that identify various CMZ definitions and evaluate the adequacy of resulting CMZ delineation in protecting the affected area from channel migration hazard; e.g., as is reported with regard to riparian buffer widths in Chapter 7 – Aquatic Areas. References that address CMZ definitions and delineation are described here.

"Definitions that can be used to unquestionably identify exact undisputed boundaries of stream corridors or riparian areas or channel migration zones are hard to come by. Clear identification of boundaries is difficult because streams and riparian areas are not fixed in time and space" (Bolton and Shellberg 2001). Because stream channels are naturally areas of disturbance, floods, droughts, fires, and landslides can all affect the location of the wetted stream channel and adjacent riparian areas over time (Naiman et al. 1992). A time period needs to be specified when defining a channel migration zone or area through which a channel is expected to move. The extent of channel migration will vary depending on the time frame of interest (Bolton and Shellberg 2001). Delineation of a CMZ boundary identifies the area in which channel processes will occur during the selected period of time; the CMZ boundary is stationary for the design life of that CMZ delineation (Rapp and Abbe 2003).

A period of 100 years often is identified as an appropriate timeframe (Bolton and Shellberg 2001). Reasons for using this timeframe may include that the 100-year floodplain is mapped to identify flood hazard due to inundation, or it may be because CMZ mapping relies on assembly of archival material and the record of relevant information often dates back about 100 years (NMFS 2000). There is evidence that 100 years provides sufficient time for the growth of a tree to the height that it would be functional LWD were it to fall into the channel (NMFS 2000), which indicates a scientific basis for selecting the 100-year time period. However, most CMZ definitions that incorporate a time period do not indicate a scientific basis. For example, FEMA (1999) states that "there is no apparent scientific basis to choose 60 years" as the time period used to define erosion hazard areas in the National Flood Insurance Reform Act of 1994. The same could be said about selection of any specific time period for a CMZ definition (unless it is tied to a physical process of specific duration): it is more of a policy decision than science-based determination.

Pollack and Kennard (1999, in Bolton and Shellberg 2001) defined the channel migration zone as the area that the stream and/or its side channels could potentially occupy under existing climatic conditions. If "existing climatic conditions" includes the period since the last glaciation, then the CMZ would likely encompass the entire valley bottom, along with lower terraces and hillslopes adjacent to the floodplain where the stream is likely to meander. Such a CMZ definition, which uses a geologic timeframe, would be consistent with sweeping channel of Schumm (1977) and the river constructing its full alluvial floodplain per Dunne and Leopold (1978). It also may be the most science-based CMZ definition and would render moot the selection of a timeframe tied to a specific number of years.

Skidmore et al. (1999) mapped four different boundaries of the lateral extent of likely channel movement along a seven-mile stretch of the Nooksack River using four criteria: a corridor based on meander amplitude, a composite of historic channel locations, the area within geologic controls such as alluvial terraces features and geologically defined valley margins, and the 100-year floodplain. The outer edge of channel movement under these four mapping approaches could each be taken to be a CMZ boundary. The four CMZ boundaries were largely coincident along one bank defined by geologic controls. There was no consistent trend in the CMZ boundaries along the other bank except that the 100-year floodplain was generally the widest. Skidmore et al. (1999) concluded that channel migration corridors are best delineated from a combination of methods.

FEMA (1999) reviewed a dozen case studies nationwide to evaluate the feasibility of mapping riverine erosion hazard areas (REHAs; assumed to be equivalent to CMZs). All of the case studies characterize riverine erosion hazard in some way; five of the 12 case studies (including King County) result in erosion hazard area delineation that is presently used to regulate land use in REHAs. FEMA concluded that it is technologically feasible to conduct riverine erosion studies and establish conclusions regarding the likelihood of future erosion (FEMA 1999).

CMZs were mapped along parts of four rivers in King County (Shannon and Wilson, 1991; Perkins 1993; Perkins 1996) using a combination of historic studies and field investigation. A compilation of historic channel locations is prepared, from which representative historic channel migration patterns and rates are characterized. The potential for avulsions is identified from maps and aerial photos and verified in the field. An unconstrained probable outer limit of future channel migration is predicted based on representative historic channel migration patterns and rates, potential avulsion sites, meander amplitudes, and the width of the historic meander belt. Relative levels of channel migration hazard are mapped as severe hazard areas, based on 100 years of predicted channel migration, and moderate hazard areas, which is the area between the severe hazard area and the predicted outer boundary of future channel migration. Lastly, constructed features such as infrastructure, levees, and revetments that pose legitimate constraints to channel migration are taken into account and the CMZ boundaries are modified accordingly (Perkins 1993, 1996).

CMZs were mapped along parts of three rivers in Pierce County (GeoEngineers 2003). The CMZ is delineated based on several factors, including the river's Historic Channel Occupation Tract (HCOT) over the observable period of record, its unconstrained character and rate of channel migration, and the locations of ancient and historic abandoned channels. The CMZ is delineated as the area through which lateral migration would proceed over 25 years landward in each direction from the edge of the HCOT, assuming that levees and revetments do not constrain channel migration. To recognize relative hazard within the CMZ, three Migration Potential Areas (MPAs) are also delineated. The severe MPA includes the HCOT plus the area through which the river could travel in five years of steady lateral migration. The moderate MPA is generally the HCOT plus 15 years of channel migration. The low MPA is the area landward of the moderate MPA to the outer boundary of the CMZ (GeoEngineers 2003).

Rapp and Abbe (2003) define the CMZ as the geographic area where a stream or river has been and will be susceptible to channel erosion and/or channel occupation during a specified period of time. The CMZ is the sum of several different components of the river landscape, some which may not apply in every CMZ study:

CMZ = HMZ + AHZ + EHA – DMA

and EHA = GS + ES

where HMZ = historical migration zone (the collective area the channel occupied in the historical record), AHZ = avulsion hazard zone (the area not included in the HMZ that is at risk of avulsion over the design life of the CMZ), EHA = erosion hazard area (the area not included in the HMZ or the AHZ that is at risk of bank erosion from stream flow or mass wasting over the design life of the CMZ), and DMA = disconnected migration area (the portion of the CMZ where man-made structures physically eliminate channel migration). The EHA has two components: the Erosion Setback (ES) and the Geotechnical Setback (GS). The ES is the area at risk of future bank erosion by stream flow; the GS is defined by channel and terrace banks that are at risk of mass wasting (due to erosion of the toe). The GS projects from the ES at a side slope angle that forms a stable bank configuration, thereby accounting for mass wasting processes that will promote a stable angle of repose (Rapp and Abbe 2003).

4.3 SUMMARY AND CONCLUSION

There is much scientific literature on channel dynamics, movement, and factors affecting channel migration. There are few examples from scientific literature that define CMZs with specificity or evaluate the effectiveness of various CMZ delineations in reducing flood hazard due to channel migration. Some key terms and definitions affecting CMZs typically are not based specifically on scientific research, such as the selection of a timeframe to determine the lateral extent of a

CMZ. Currently there is no national standard, unique definition, or single method to delineate CMZs, as there is for flood inundation hazard (FEMA 1999). However, the literature examples that do address CMZs specifically, in combination with the large body of literature on channel dynamics, etc, provide an adequate scientific framework to define and delineate CMZs.

4.5 REFERENCES

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