Fluvial Hazard Zone Delineation

A Framework for Mapping Channel Migration and Erosion Hazard Areas in Colorado

Prepared by:

Katie Jagt, P.E., Watershed Science and Design, PLLC.

Michael Blazewicz, Round River Design, LLC.

Joel Sholtes, PhD, Colorado State University

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List of Acronyms

CWCB	Colorado Water Conservation Board
DEM	Digital elevation model
EHA	Erosion Hazard Area
FEMA	Federal Emergency Management Agency
FHZ	Fluvial Hazard Zone
GIS	Geographic Information System
HGVC	Hydro-Geomorphic Valley Classification
LiDAR	Light detection and ranging
NFIP	National Flood Insurance Program
pCMZ	Planning-level Channel Migration Zone

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1. Overview

For most early settlements in Colorado, the benefits of settling near a river to serve as a source of drinking water, irrigation, power, mineral access, and navigation often outweighed the risk posed by flooding. Over the past century, settlements alongside Colorado's waterways have grown into large communities that have invested billions of dollars in infrastructure on or near rivers and streams. Despite warnings and destruction from periodic floods[1], development in stream corridors continues to grow and damages to infrastructure and economies continue to climb (Colorado Water Conservation Board, 2013). In addition to thousands of highway and utility structures, the Colorado Water Conservation Board (CWCB) estimates that approximately 65,000 homes and 15,000 commercial and industrial business structures are located in Colorado's floodplains[2].

The reaction to historic floods has typically been to straighten, dredge, armor, and levee streams, creeks, and rivers in an attempt to control their movement. For the majority of time, streams are docile and create a sense of security, allowing new development to creep into river corridors.

During the September 2013 flooding, flood-related impacts outside of the 100-year FEMA floodplain were observed throughout the Colorado Front Range[3] in spite of many peak discharge estimates having magnitudes less than or equal to the 100-year flood (Houck 2014, Yochum 2015). Indeed, nationally, nearly 25% of flood insurance claims come from areas outside of the 100-year floodplain[3].

Of particular concern for many Colorado communities is that FEMA's National Flood Insurance Program (NFIP) maps are elevation-based, delineating only flood inundation hazards by applying a water surface elevation based standard (i.e. the 100- and 500-year base flood elevations). The hazard depicted in these maps is always approximate because of uncertainty in topographic data and flow frequency estimates, and morphological change during floods. Moreover, the traditional method of mapping the floodplain assumes clear water conditions, ignoring the influences of sediment, ice, and debris transport and disregarding the fundamental, albeit complex, mechanics of river change during floods. NFIP maps are particularly inaccurate in Colorado's narrow, steep valleys which do not lend themselves to precise water surface elevation modeling exercises, and where debris flows and hillslope erosion may create channel blockages. While NFIP maps are an excellent planning tool they ultimately only represent a static, and in some cases limited, characterization of a dynamic system. Though recognized at

[1] Historic floods include but are not limited to Boulder (1894), Pueblo (1921), Denver (1912 and 1965), Big Thompson Canyon (1976), and Fort Collins (1864, 1923, 1997).

[2] http://www.coemergency.com/2010/01/historical-colorado-flood-events.html

[3] Gease, M. FEMA natural hazards specialist, quoted in Walker, R. (2014). Coming Home, a Calculation of Risk, Reward and Restitution in Flood Zones. Headwaters. Colorado Fnd. for Water Education. p 23-27.

the federal and increasingly local levels (FEMA 1999), floods hazards associated with river channel change are understudied, under-publicized, and often not planned for or mitigated.

River change occurs as a result of the interaction among incoming flow and sediment, channel geometry, and the relative resistance of the channel boundaries. River change occurs under natural conditions and can also be influenced, and in some cases exacerbated by human actions directly on a river as well as indirectly through flow regulation and land use change. Physical channel adjustments are constant and even “stable” rivers shift from year to year during annual or sub-annual runoff events. Streams naturally exist in a dynamic equilibrium where changes to form and location are normal in a stable system. Fluvial (river-related) erosion is a natural process but can become problematic during a flood event, which may cause excessive erosion of the streambed, banks, and hillslopes or wholesale change in the location of the channel via avulsion. Fluvial erosion becomes a fluvial hazard when an adjusting stream channel threatens public infrastructure, houses, businesses, property, and other private investments.

Awareness that hazards within the river corridor are not limited to floodwater inundation has been growing at a national and local level. The National Flood Insurance Reform Act (NFIRA 1994) called on FEMA to study the feasibility of mapping erosion hazards in addition to flood inundation hazards. Though FEMA has designated a special zone “E” for erosion hazards on floodplain maps, clear guidance is lacking on how fluvial erosion risks are to be mapped and managed. With this information gap in mind and at the request of the Colorado Water Conservation Board, we have developed a framework and protocol to map fluvial hazard zones for the state of Colorado.

Broadly defined, the **fluvial hazard zone (FHZ)** *is the area a stream has occupied in recent history, could occupy, or could physically influence as it stores and transports sediment and debris during flood events. The objective of a mapped* ***fluvial hazard zone*** *is to identify lands most vulnerable to fluvial hazards in the near term.*

Identification and management of these additional flood hazards can aid in reducing flood damage to vulnerable public and private infrastructure and the costs of future flood recovery. The FHZ delineation process and the maps it produces are intended to provide local land use and floodplain managers insight into the likely long-term behavior of their streams and serve as additional flood hazard information. They may also serve as supplemental information to landowners who may not be aware of these additional flood hazards and whose improvements may not be appropriately insured or protected. Combining flood elevation maps with fluvial hazard maps may help mitigate these hazards by guiding development, moving or protecting critical infrastructure, and encouraging long-term conversion of these areas as active river corridors. Preservation of these areas also results in concomitant gains in improved water quality, recreation opportunities and ecological function.

In this report we present the following:

1. A review of the demonstrated need for mapping FHZ's and the regulatory history of mapping them (Section 1)
2. A review and comparison of existing FHZ-related protocols and studies across the nation and abroad (Sections 2 and 3)
3. A discussion of the applicability of existing protocols to Colorado and a synthesis of existing approaches towards mapping the FHZ within Colorado (Sections 2, 3, 4)
4. A framework and proposed protocol for mapping FHZ's in Colorado (Section 4)
5. A discussion of the logistics surrounding FHZ map generation, practitioner qualifications, map maintenance, and limitations (Section 5)
6. A discussion on FHZ program implementation (Section 6)
7. Suggestions for follow-up studies necessary for further development and refinement of FHZ mapping in Colorado (Section 7)

1.1. Demonstrated Need

The September 2013 flooding exposed vulnerabilities in civil and residential infrastructure networks within Front Range river corridors. Though a number of Front Range streams experienced flood peaks in excess of the 1 percent annual chance return interval flood, many did not and flood-related impacts outside of the regulatory floodplain were observed in many locations. Uncertainties in flood-frequency estimates and hydraulic modeling techniques, in addition to out-of-date topography and land-use data, may account for some of this; however, dynamic river processes played the most significant role in the disparity between the mapped flood hazard zones and the damaged areas. River avulsion, erosion, and deposition all changed the boundaries of the river and the floodplain, leading to unexpected and unplanned flood impacts. Relying solely on the 1 percent annual chance floodplain to characterize flood hazards has resulted in underestimating our communities' vulnerability due to these unaccounted for fluvial hazards.

,During 2008, one-third of all flood insurance claims nationwide came from areas outside of the mapped floodplain[4], a fact that further illustrates the shortcomings of floodplain management that relies solely on the 1 percent annual chance floodplain and floodway to characterize flood hazards. The percentage of flood insurance claims outside the regulatory floodplain is larger in mountainous and arid regions where fluvial erosion may account for more flood damage than inundation. In settings where a channel is partially confined by its valley and where the valley wall material is erodible, the fluvial hazard zone may extend well beyond the 100-year floodplain boundary (Figure 1). However, fluvial hazard may not always exceed the 100-year floodplain boundary. An example of this might be a mild-sloped river in a wide, flat valley. River migration and avulsion may be limited to a narrower meander belt, whereas flood inundation may be much broader.

[4] http://www.floodsmart.gov/floodsmart/pages/flood_facts.jsp

The “no encroachment” limits defined by the NFIP floodway do not necessarily provide an adequate river corridor width for channel adjustment. FEMA and the State of Colorado’s regulations recognize that the NFIP standards offer *minimum* protection against inundation and erosion hazards, and they explicitly encourage communities to adopt more protective standards (National Flood Insurance Program 44 CFR 60.1(d)). With this in mind, in 2011 CWCB established more stringent floodplain management standards that all communities are required to adopt (CWCB, 2013). For inundation-related flood damage, NFIP maps provide a starting point to guide communities but are not without their limitations. For example, communities need only adopt FEMA and the State of Colorado’s minimum standards for flood hazard area regulation in order for their residents to be eligible to purchase flood insurance. Additionally, because FEMA and the State of Colorado’s minimum standards do not include consideration for fluvial hazards, new development may be allowed in mapped flood hazard areas without full regard for the river channel and floodplain dynamics, possibly exacerbating flood loss and increasing costs associated with future floods.

A framework and protocol for mapping fluvial hazards is an essential component of effective and comprehensive river corridor planning and should be used in conjunction with floodplain mapping. A program that supports mapping fluvial hazards will help to assure the protection of public health, safety, welfare, and property by better characterizing flood-related hazards in the river corridor and better informing the public of these hazards. Better informed floodplain management can lead to:

- reduced property loss and damage
- better river planning and management on a watershed scale
- reduced public expenditures for disaster response and recovery
- protected riparian habitat and multiple use opportunities for river corridors
- increased channel stability by improving floodplain connection and sediment transport

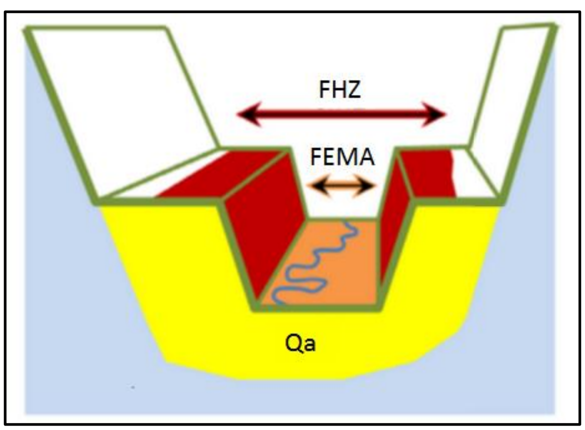

Figure 1: Example diagram depicting a semi-confined valley with quaternary alluvium (Qa) deposits where there would be a wider “fluvial hazard zone” (FMZ) compared to the FEMA regulated 100-year floodplain (adapted from Olson et al., 2014).

1.1.1. Vulnerability Reduction

Identification and management of channel migration zones is intended to reduce flood and erosion damage to public and private infrastructure which may be in jeopardy if the channel does migrate, widen, or suddenly avulse (Figure 2). Identification of fluvial hazards within the river corridor is currently not practiced in Colorado and therefore these hazards are not accounted. Identification may aid in limiting investment and development within a mapped FHZ in order to reduce vulnerability and achieve multiple secondary benefits (see Section 1.1.2). This information may also inform more resilient and robust infrastructure design (e.g., bridge span construction) as well as mitigation efforts for existing infrastructure. While the process of identifying fluvial hazards on a map may be a new endeavor, the mapping does not introduce a new hazard to a community or private landowner. The hazard has always existed; a map explicitly characterizes it. By identifying, mitigating, and planning for fluvial hazards, just as we do inundation hazards, our communities can reduce their vulnerabilities to floods in the river corridor and become more resilient.

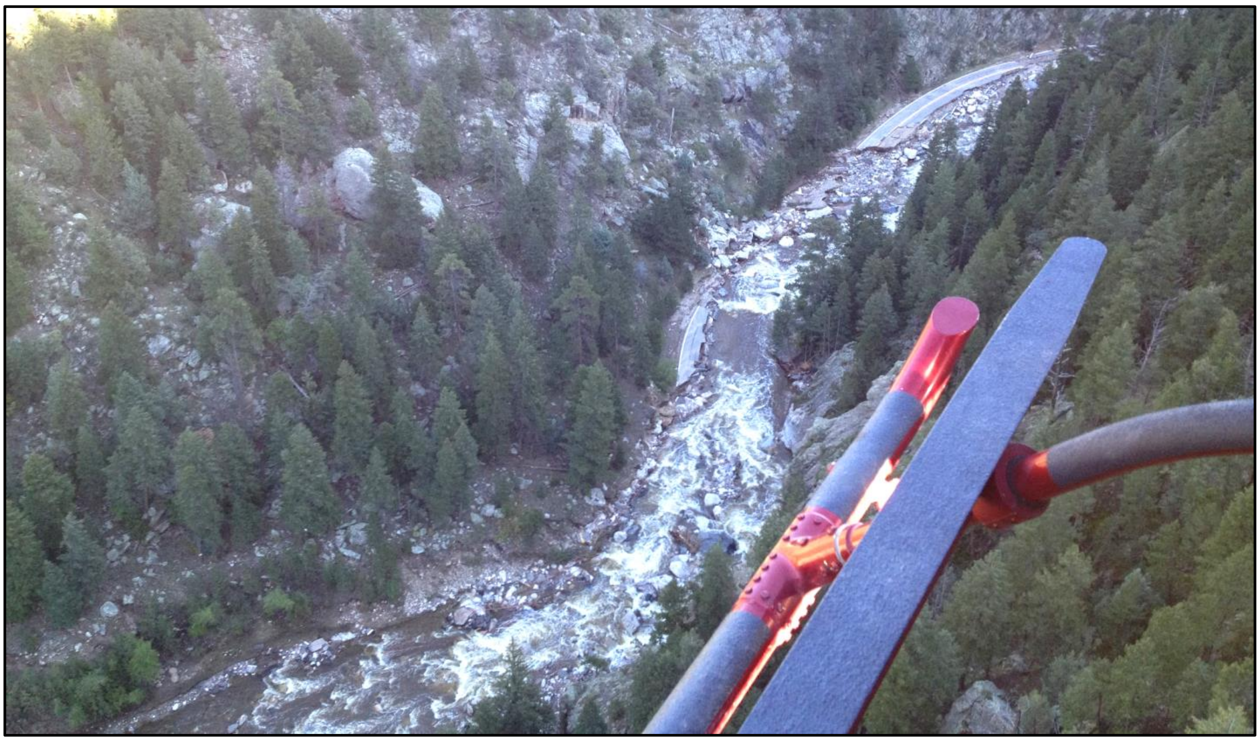

Figure 2: Public roadways located in fluvial hazard zones are at high risk from fluvial erosion (photo 2013 Colorado flood).

1.1.2. Additional Benefits of Resilient River Corridors

Complimentary benefits obtained as a result of planning for fluvial hazards may be additional protection of floodplain as well as riparian habitat and open space. These transitional lands are among the most diverse, dynamic, and complex habitats in Colorado. Riparian vegetation can act to protect (and improve) water quality and prevent thermal pollution, as well as aid in stream stability (Rupprecht et. al., 2009). Riparian corridors in turn provide habitat for birds, large mammals such as elk and bighorn sheep, as well as aquatic species, amphibians, and fish species. Protected and restored floodplains also serve as temporary flood storage, reducing flood peak flows downstream (Sholtes and Doyle 2009, Habersack et al. 2015). Protected fluvial hazard zones may also provide undeveloped areas for trails and recreational access. This “green infrastructure” can provide multiple benefits in the social, ecological, and hydrologic arenas.

1.2. Fluvial Hazard Mapping Precedence

Fluvial hazard mapping is a relatively new tool for land use planning. The following section identifies river erosion hazard mapping programs that have preceded the Colorado effort and from which the authors sought valuable guidance.

1.2.1. International precedence

Investigations for river erosion mapping programs abroad fell short of the authors expectations with the majority of worldwide attention still clearly on mapping inundation zones. In Europe, the European Union’s Flood Directive has not progressed beyond inundation mapping at the time of this report. Member nations have freedom to include erosion mapping but none have done so at this time (Mosselman, personal communication, July 2015). In recent years, bank revetments have been removed to restore natural stream processes and therefore stream ecosystems. The process typically requires purchase of the adjacent land into which the stream will be allowed to erode. Giving space for river migration thus becomes a negotiation with local stakeholders rather than a regional planning tool. Peigay et. al. (2005) reviewed a number of different methodologies for mapping this negotiated “erodible corridor” and provides examples used throughout Europe.

In the Province of Quebec, Canada, a hydrogeomorphic approach was taken to identify a river “Freedom Space” where channel processes are left to evolve naturally. Examples of this approach were found to have a net positive benefit to society given the ecological, water quality, and flood hazard reduction benefits that an active river corridor provides (Biron et. al., 2014). The delineation procedure used in this case combines flood inundation mapping with river mobility maps to identify three levels of freedom space. The “mobility space” component - equivalent to our proposed FHZ - combines calculated lateral migration rates with areas of high avulsion hazard and a meander belt-width to delineate the area where future erosion is predicted. The approach to combining flood inundation maps along with erosion hazard maps is novel and resulted in a more comprehensive characterization of flood hazards.

1.2.2. National precedence

As discussed above, the National Flood Insurance Reform Act (NFIRA 1994, §577) required FEMA to submit a report to Congress that evaluated the feasibility and cost of mapping “Riverine Erosion Hazard Areas” within the National Flood Insurance Program. A review of existing examples of fluvial hazard mapping as well as a feasibility study was released by FEMA (1999). However, since this effort no national-level FHZ mapping or planning effort has been undertaken. Rather, FEMA has partnered with local agencies to fund and support individual efforts, such as the case of Washington County, UT along the Virgin and Santa Clara Rivers[5].

Without national guidance, a wide range of approaches exists for mapping fluvial hazards within the U.S. at the state and local levels and an equally wide variety FHZ regulatory frameworks and levels of implementation exist (references to these can be found in a separate document produced for the CWCB, Draft Fluvial Erosion Hazard Area Regulatory Guidelines Memorandum, Sept 30, 2015, Appendix A). Washington State and King County, Washington, along with Vermont, have invested the most time and energy into their FHZ protocols, which have developed over a number of years. Indiana and New Hampshire have adopted similar approaches to Vermont, and consultants in Montana, Oregon, and recently in Colorado have used the approach developed in Washington in these respective states. Many counties and municipalities in the southwest (including Texas) have developed more narrowly-defined protocols for mapping stream erosion. These tend to focus on the confined, incising streams that have been problematic in their urban and arid settings.

In addition to fluvial hazard mapping, other geomorphic hazards such as coastal erosion and landslides have warranted the development of mapping protocols and maps. Examples of coastal hazard mapping include the Washington State Shoreline Management Act and the Hurricane Irene/Sandy Response. Examples of landslide hazard mapping programs can be found in Colorado[6], Oregon[7], Vermont[8], and Washington State, along with a national program led by the U.S. Geological Survey[9].

1.2.3. Colorado precedence

Several FHZ mapping pilot studies throughout Colorado, both ongoing and complete, have resulted from partnerships among FEMA, CWCB, and local agencies. Erosion hazard mapping efforts in Colorado include forays into a variety of protocols on a variety of stream types. An early effort was undertaken in Fort Collins but the protocol documentation was not published. El Paso County developed and adopted an erosion hazard setback protocol, called the “Prudent Line”, though information regarding its implementation is lacking (El Paso County, 2001). Following the September 2013 flood, preliminary planning-level erosion hazard maps (closely following the Washington State pCMZ protocol) were developed for Fish Creek and Fall River in Estes Park and the St. Vrain Creek by co-authors Jagt and Blazewicz. The preliminary pCMZ maps were created in conjunction with post-flood Watershed Master Plans that were developed following the 2013 Colorado floods and were offered as a planning-level tool for communities to begin to consider fluvial hazards.

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[5] “Mapping the 100 year floodplain is not the end of the story”. FEMA informational poster: https://www.fema.gov/ar/media-library/assets/documents/5941
[6] http://coloradogeologicalsurvey.org/geologic-hazards/landslides-2/
[7] http://www.oregongeology.org/sub/Landslide/Landslidehome.htm, http://landslides.usgs.gov/
[8] http://www.anr.state.vt.us/dec/geo/hazinx.htm
[9] http://landslides.usgs.gov/

In 2015, Larimer County funded a river corridor hazard study that involved delineating an "erosion hazard zone" using a buffered meander-belt method described in Vermont Stream Geomorphic Assessment Phase 2 Handbook, Appendix E, Rapid Stream Assessment Field Protocols and modified based on known flood-flow paths from 100- and 500-year floodplain maps, as well as topographic, man-made, and geologic features.

Two more recent efforts, both FEMA-funded, are ongoing in Mesa and Pitkin Counties. In the Mesa County town of Collbran, an erosion hazard map was produced using both the Washington pCMZ and Vermont River Corridor mapping process with the pCMZ process ultimately being recommended (with refinements). In Pitkin County, on-going field work is focused on predicting future channel adjustment through the development of mathematical models based on GIS and field-based analysis for a reach on the Upper Roaring Fork River. Results of this field-based assessment will be used to supplement planning-level channel migration zone guidance in order to recommend a procedure for developing locally-relevant channel migration zones.

2. Fluvial Hazard Mapping Framework

The following section details our review and synthesis of existing FHZ protocols and case studies organized by components of the FHZ framework. Under each sub-section we describe the decisions and outcomes made by the authors of this study leading to development of a framework and protocol for Colorado.

2.1 Geomorphic Context of Fluvial Hazards

A fluvial hazard zone delineation framework should begin with a consideration of the hydrologic and geomorphic settings of the river system of interest. Colorado hosts a wide range of hydro-geomorphic settings from steep headwater streams in the mountains; to canyon arroyos; to meandering gravel-bed rivers; to low gradient plains streams. The flow regime, geology, valley form, slope, and position within the watershed, not to mention any anthropogenic influences, ultimately create river form and influence how it can and will respond to a flood event. Through obtaining a better understanding of the types of geomorphic responses a river reach may have, a FHZ mapper will be better able to identify the correct method and delineate considering potential erosional responses.

Recognizing the need to have a straightforward though robust process to identify fluvial hazard zones, and also the need to be accurate and not overly conservative in our mapping, we recommend that the geomorphic context of each river system, at the reach scale, be considered via a comprehensive and qualitative classification scheme. Reach-scale geomorphic classification should incorporate channel geometry and bed material type, as well as other important boundary and driving variables such as valley type, local geology, flow regime, sediment supply, and relative position within a watershed. Many geomorphic river classification systems are in use within the river community and all have specific merits and limitations. We review several examples of valley classification tools and approaches amenable to the FHZ protocol in Section 2.2. While a comprehensive understanding of the geomorphic context of a reach is important for the reasons mentioned above, within the FHZ protocol we offer a more simple classification scheme that is based on channel confinement and slope.

2.1.1 Landscape Scale

A watershed of interest may be divided into “landscape units” broadly defined by their position within a watershed and the prevailing sediment transport processes of net erosion, transfer, or accumulation (Figure 3) [Note: while the figure shows a typical mountain to plains scenario, accumulation zones can be found in low gradient reaches within the higher elevation mountain reaches]. In mountains to plains settings, such as on the Front Range, landscape units might include steep headwater channels (sediment source or net erosional streams); canyon reaches (transport and erosional reaches); foothills reaches (transport reaches), and plains reaches (transport and depositional reaches). Within each landscape unit, prevailing sediment transport processes inform types of channel response to floods. Source or erosional units will most likely respond through channel incision, and hillslope failure. Transport dominated zones will respond with channel widening, some incision and hillslope failure, as well as lateral meandering migration. Net accumulation zones will exhibit some channel widening, but lateral migration and avulsion will likely dominate river response.

The hydrologic and anthropogenic settings may also be considered at the landscape unit scale. For example, flow regimes on the Front Range can vary dramatically from headwaters to foothills. The regional hydrology of the Front Range is dominated by snowmelt runoff peaks, but a separate population of lower frequency, high magnitude rain-driven events exists below a certain elevation threshold (Jarrett and Costa, 1988). Climate change may influence flow regimes by increasing the variability of precipitation (Kharin et al. 2013) and/or increasing the elevation above which convective precipitation flood events may occur. Channel disturbance through urbanization is also likely to change in intensity as one goes from the headwaters through small communities in the mountains to large cities and towns on the plains.

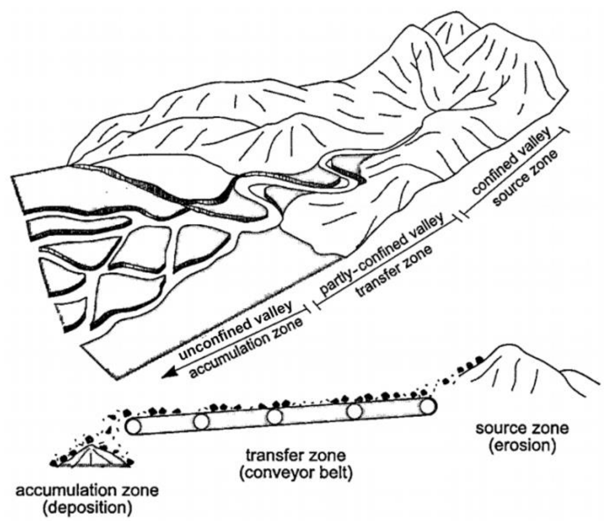

Figure 3: Example of landscape units and dominant sediment processes within a watershed. Adapted from Brierly and Fryirs (2005).

2.1.2 Valley Scale

Valley setting is the next level of classification within each landscape unit and focuses on the amount of room that exists between the river channel and its surrounding confining valley features as well as the slope of the valley and available energy for water to do geomorphic work. Confined valleys have walls that extend down to the stream banks or have only narrow floodplain benches. Here, the ratio of valley floor width to channel bankfull width ranges from 1 to 2. Semi-confined channels have valley walls set back a small ways from the channel and a discontinuous floodplain may exist. Bankfull channel widths to valley width ratios range from 2-10 or even greater depending on the setting. Unconfined channels have wide valleys that allow for ample meander room. Valley confinement ratios associated with confinement classifications are not firm values, and may vary depending on the river system. The topic of valley confinement requires additional research in Colorado.

Valley wall, or hillslope steepness and erodibility may also be an important factor to consider particularly when the channel is coupled with that feature. Hillslope channel-coupling means that debris flows or hillslope failures (whether independent of or a direct result of river movement) can introduce large amounts of coarse sediment into the channel. This excess material may introduce new fluvial hazards locally such as channel widening or avulsion, or accumulate downstream in areas of debris and sediment deposition.

2.1.3 Reach Scale

River reaches are defined within landscape units and valley settings. These are reasonably homogeneous lengths of river as determined by channel slope, bed material and bed forms, riparian character, and anthropogenic influence. For planning purposes it is important to delineate reaches with similar migration potential, river planform patterns, or valley characteristics. Within reaches it may be helpful to go one step further and delineate geomorphic units. These are sub-reach scale features formed by recent and historic flow and sediment regimes that can aid in mapping latent fluvial processes and hazard potential. Geomorphic units pertinent to FHZ delineation include meander scroll bars, oxbows, high flow channels, and terraces on or adjacent to the floodplain.

2.2 Valley Classification Tools

Here we introduce and review several valley classification tools that may be used to inform what FHZ methods are most applicable to particular reaches under investigation. These tools focus on valley classification, though a more comprehensive assessment of geomorphic setting is recommended in mapping the FHZ within a watershed, as described above.

2.2.1 Hydro-Geomorphic Valley Classification Tool

This tool has been developed at Colorado State University in partnership with the U.S. Forest Service National Stream and Aquatic Ecology Center (Carlson, 2009; Baker et al, 2014). It is an ArcMap® tool that classifies valley types based on the degree of channel confinement within a valley, the valley slope (energy), and the steepness of the adjacent hillslopes, which characterizes the level of hillslope coupling with the channel. This tool combines process-based geomorphic classification schemes developed for channels and floodplains in previous publications such as Nanson and Croke (1992), Whiting and Bradley (1993), and Montgomery and Buffington (2001). The confinement ratio is the valley bottom width divided by the channel bankfull width. This tool also maps valley bottoms using topographic (digital elevation models) and hydrologic (empirical flood regression equations) data. The valley classifications it generates (Table 1) align well with the classes used in the proposed FHZ protocol. An example output map is provided in Figure 4.

Table 1. *Hydro-Geomorphic Valley Classes*		
Classification	**Abbrev.**	**Criteria**
High Energy	HEC	Slope > 4%
Medium Energy Conf.	MEC	Slope: 0.1% to 4% AND Confinement Ratio < 7
Med. Energy Unconf.	MEO	Slope: 0.1% to 4% AND Confinement Ratio > 7
Canyon / Gorge	CAN	Hillslopes on both sides are vertical or near vertical (> 70% slope)
Glacial Valley	GLA	Slope < 4% AND Confinement Ratio > 7 AND above glacial elevation bndry.
Low Energy Floodplain	LEF	Slope < 0.1%

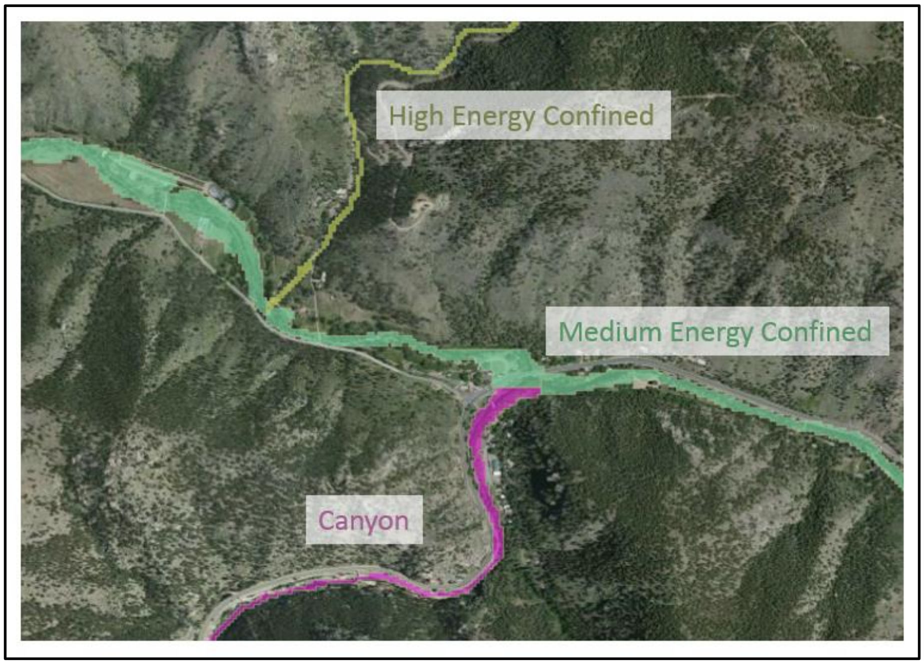

Figure 4: Example output and valley classification using HGVC tool.

2.2.2 River Styles

The River Styles Framework is a hierarchical approach to classifying rivers with the purpose of documenting the geomorphic structure and function of rivers, and appraising patterns of river types and their biophysical linkages. The River Styles Framework provides a description of river character and behavior, how rivers have evolved over time into their current form, and causes of any changes they are experiencing. These insights are useful in predicting likely future river conditions, recovery potential of any given reach, and an understanding of its trajectory of change (Brierly and Fryirs 2005). The River Styles Framework defines the valley setting (confinement) as a primary step in understanding the setting and potential of the reach. An example of River Styles implemented in Colorado can be found in the Left Hand Creek Watershed Master Plan (AMEC et al. 2014).

2.2.3 Rosgen Valley Classification

In addition to his widely applied channel classification system, David Rosgen has published valley classifications (Rosgen 1996). Rosgen defines 10 qualitative valley types based mainly on degree of channel confinement ,geology/geomorphology, and setting with an implicit incorporation of slope (Figure 5). These valley classes are defined below in Table 2. Rosgen assigns certain channel types to each valley type, but there is considerable overlap among channel and valley type, reducing the usefulness of this linkage.

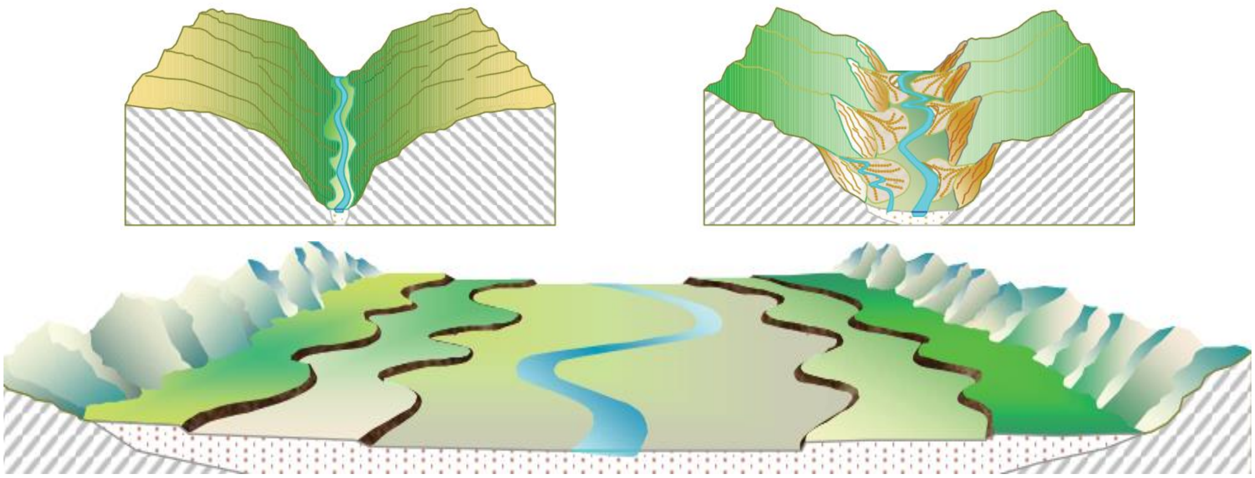

Figure 5: Examples of valley types ranging from confined (top left, valley type 1), semi-confined (top right, valley type 3), to unconfined and inset among terraces (bottom, valley type 8). From Rosgen (1996).

Table 2. Summary of Rosgen Valley Types

Valley Types	Summary Description of Valley Types
1	Steep, confined, V-notched canyons, rejuvenated side-slopes
2	Moderately steep, gentle-sloping side-slopes often in colluvium valleys
3	Alluvial fans and debris cones
4	Canyons, gorges and confined alluvial and bedrock-controlled valleys with gentle valley slopes
5	Moderately steep, U-shaped glacial-trough valleys
6	Moderately steep, fault-, joint- or bedrock-controlled valleys
7	Steep, fluvial dissected, high-drainage density alluvial slopes
8	Alluvial valley fills either narrow or wide with moderate to gentle valley slope with well-developed floodplain adjacent to river, and river terraces, glacial terraces or colluvium slopes adjacent to the alluvial valley

9	Broad, moderate to gentle slopes, associated with glacial outwash or eolian sand dunes
10	Very broad and gentle valley slopes associated with glacio- and non glaciolacustrine deposits
11	Delta

Outcome or Decision: We recommend the use of a geomorphic and valley classification scheme to guide FHZ mapping efforts. A general hydrologic and geomorphic classification at various scales is important in understanding the inherent sensitivity of particular rivers to change during floods as well as the type of expected response. We have incorporated a valley-slope classification framework to guide mapping methodologies as outlined in Section 4. Factors that should be considered in classifying a valley are the valley slope, the channel or valley confinement (valley width divided by bankfull width), and the level of coupling of the hillslopes to the channel, defined by the steepness of the hillslopes. Further investigation will be necessary to refine the valley classes used in our recommended FHZ protocol such as determining appropriate valley confinement ratio and slope ranges for each category.

The River Styles method (Brierly and Fryirs 2005) is not a prescriptive tool, rather a framework for approaching river classification. Its authors provide examples of reach-scale classifications but their framework may be adapted for the many geomorphic settings that may exist in Colorado. The Rosgen valley classification scheme (Rosgen 1996) is less quantitative and does not provide a strong correlation to geomorphic processes and hazard potential. The Hydro-Geomorphic Valley Classification (HGVC) method derives its class descriptions from geomorphic thresholds corresponding to significant transitions in the physical processes and boundary conditions that give rise to distinct floodplain and channel forms, disturbance regimes, and ecological attributes (Bledsoe and Carlson 2012). HGVC is a GIS mapping tool whose categories and assumptions can be modified and updated to suit the needs of FHZ mapping, including automated mapping of the active river corridor (note that any automated mapping tools should be vetted and verified on a reach by reach basis). As discussed above, this tool integrates several commonly used geomorphic classification schemes. This tool captures the same basic elements of valley class used in the proposed FHZ protocol and has been developed as a GIS platform, making it amenable to broad scale valley classification within a watershed. However, some effort would be required to fully develop the code of this tool for widespread use across the state as some inputs require considerable manual GIS work as well as interfacing with Python scripts in its current form. Updating this program to aid the statewide FHZ mapping efforts is recommended by the authors.

2.3 Fluvial Hazard Zone Delineation Approaches

Flood-related fluvial erosion processes can be summarized by four dominant classes:

1. Lateral and downstream meander migration via bank erosion and point bar deposition
2. Channel widening and/or incision via scour and transport of boundary materials
3. Local, reach, and regional scale channel avulsion via a combination of erosion and/or

aggradation processes, as well as topographic influences such as existence of alluvial fans, remnant channels, or gravel mining within an active floodplain.

4. Hillslope or terrace failures due to toe erosion and/or bed incision along confined and semi-confined reaches.

Existing fluvial hazard zone delineation approaches are all built on identifying the locations where each of these erosion processes may occur, where applicable. The combination of these areas defines the "fluvial hazard zone." State and local FHZ approaches tend to focus on certain flood-related fluvial processes that may dominate in a particular region or watershed. For example, FHZ protocols developed in the Cities of Austin, Texas and Albuquerque, New Mexico focus on channel incision and bank failure processes for smaller, confined streams. The Vermont protocol begins with identifying an area where lateral and downstream meander migration processes should be allowed to occur in order to promote long term equilibrium conditions. It then expands upon this meander belt to include both avulsion and slope failure areas where field investigations deem it is warranted and as time and funding allow. The Washington approach accounts for all four dominant flood-related fluvial processes described above. The protocol captures all possible areas of stream migration and is therefore considered by the authors to be the most conservative approach to identifying erosion hazards.

Fluvial hazard delineation protocols have primarily focused on one or more of the following technical approaches:

- Geomorphic and Geotechnical Analysis (Field Based and Remote Sensing)
- Engineering and Statistical Analysis
- Dynamic Numerical Modeling

These approaches are explored in more detail below:

Geomorphic and Geotechnical Analysis (Field Based and Remote Sensing): These methods rely primarily on the expertise of individuals trained in the subject areas of geomorphology, geology, and soil geotechnics. The experts may either use remotely sensed reconnaissance to identify historic and predicted river channel locations and migration rates based on (but not limited to): historic aerial photography and satellite imagery, LiDAR-based digital elevation models, soils and surficial geology maps, and stream networks. Field work related to geomorphic analysis of the FHZ focuses on verifying features delineated using remotely-sensed data, assessing bank and hillslope stability to inform erosion hazard characterization, as well as identifying man-made alterations to the channel, its banks, and floodplain.

Pros: Relies on field-derived data and observations.

Cons: Relies heavily on expert opinion. Historic and useful data (aerial photographs, maps, and LiDAR) may be lacking for many locations. Field access may be difficult to achieve.

Engineering and Statistical Analysis: These methods utilize engineering standards in statistical hydrology to estimate recurrence intervals for geomorphic events, hydraulic modeling for bed and bank scour analysis, and slope stability analysis. The approach may also include empirical equations relating meander belt-width as a function of drainage area, slope, or bankfull width.

Pros: Hydraulic modeling can provide objective assessment of physical conditions during flood flows. Empirical relations may be very easy to apply.

Cons: Many engineering and erosion/sedimentation analytical methods have unknown or limited applicability to natural systems during flood flow. Hydraulic modelling for scour analysis is highly uncertain with order of magnitude errors. Empirical relations developed for a particular region may not apply to regions not represented by the data used to create them. These methods are more costly in terms of time and money than geomorphic methods.

Dynamic Numerical Modeling: This method utilizes field based data and river mechanics theory to calibrate and then run time series dynamic numerical models to predict where stream migration is likely to occur.

Pros: Reasonably objective and repeatable analysis.

Cons: The nature of geomorphic hazards, including catastrophic erosion and channel movement which is the focus of this hazard identification effort is highly stochastic. Deterministic modeling of channel migration has had limited predictive success due to very large uncertainties. Additionally, these models are very expensive and time consuming to create and run.

Outcome or Decision: Recognizing the need for flexibility and applicability through all of Colorado's river systems, as well as the need for simplicity in executing the mapping on a large scale, we recommend two levels of effort that can be used for delineation of fluvial hazard zones. Level 1 of this approach calls for a geomorphic and geotechnical analysis of remotely sensed data combined with field-based verification. This analysis is intended to provide local jurisdictions with conservative FHZ maps to be used for land use planning purposes.

Level 2 FHZ mapping relies on an extended and more rigorous field-based geomorphic assessment, which may include mapping historic channel locations and migration rates, statistical hydrologic analysis, and in some cases engineering analyses to determine bed and bank stability and potential for scour. Level 2 analysis may be necessary when development or improvements are proposed for areas within the hazard zones, for cases where the Level 1 FHZ boundaries are believed to be overly conservative or not comprehensive enough, or when local conditions pose complexities that cannot be addressed without extensive field studies. Due to the diversity of Colorado's stream systems and need for localized calibration the authors do not recommend numerical modeling as a stand-alone delineation tool at this time.

2.4 Fundamental Components of Fluvial Hazard Zones

Background research and detailed review of existing fluvial hazard identification methods used throughout the U.S. was conducted by the authors. Correspondence and interviews with the developers and practitioners of these methods aided us in understanding the process behind their conception, implementation, relative level of use and acceptance. Fluvial hazard zone mapping methods reviewed ranged from comprehensive state and city level protocols, to city and county stormwater and erosion control design manuals, to detailed engineering and geomorphic studies. A brief summary of known existing regulations, ordinances, and published guidelines is included in Appendix A and a comparison of several methods is provided in Section 3.0.

Fundamentally, we distilled that each of the existing and previously published protocols is built around defining:

1) The ***active river corridor*** is land adjacent to the river that is alluvially-formed or prone to erosion or deposition by fluvial processes. The active river corridor interacts with the river channel both frequently and occasionally through channel migration and overbank erosion and deposition processes.
2) The ***erosion hazard area*** accounts for hillslopes and terraces adjacent to the active river corridor that may be susceptible to erosion and geotechnical failure as a result of river channel migration or toe erosion.
3) The channel ***avulsion hazard area*** identifies zones where a channel might occupy during a flood event based on relative elevations along a valley as well as identification of remnant channels.
4) ***Alluvial fans*** are areas where sediment has dropped out of flow due to abrupt changes in valley slope. Due to the concave shape of these features, the channel position is very unstable and may take multiple paths in a distributary fashion.

Active river corridor

The *active river corridor incorporates episodic as well as the continuous process of channel-floodplain interaction. These processes include lateral and downstream meander migration via bank erosion and point bar deposition as well as channel widening and/or incision due to scour and transport of bed and bank material.* It can be defined in various ways and each method results in a slightly different boundary depending on the reach characteristics, the reference conditions the method was built upon, and the assumptions made by each boundary delineator. There are three primary approaches used in the United States which tend to follow regional preferences:

1) **East:** Vermont, Indiana, New Hampshire. The *active river corridor* in these protocols is based on the river's meander centerline, that is, the centerline of the meander belt (Figure 6). The active river corridor is then mapped as a buffer from the meander centerline with a width that is set by empirical relations with several variables including the stream slope, geomorphic channel classification and its inherent sensitivity to change due to watershed and channel stressors. This approach seeks to define the minimum area that the river would need to adjust over time to maintain/achieve equilibrium conditions. The protocol was largely born from the dominating presence of historically straightened channels that have (or will during a flood) undergo a channel evolution process. This process (as outlined by Schumm et al. (1984) typically starts with incision and ends with planform adjustment as a new inset bankfull floodplain is created by channel migration and avulsion. The meander centerline buffer seeks to

predict the extent of this latter stage of channel evolution where active planform adjustment is a dominant process.

2) **Southwest:** Cities of Austin and Dallas, TX; Albuquerque, NM; Maricopa County, AZ; El Paso County, CO. The *active river corridor* in these protocols is primarily defined as the area that encompasses the active channel width and an assumed angle of repose for bank failure on both sides assuming incised or incising channel conditions. This approach is largely a response to acute bank failure resulting from incised channels widening as they attempt to form new inset floodplains in urban and arid settings located within the dominant southwest surficial geology.

   West: Washington, Montana, King County, WA, Pierce County, WA. The *active river corridor (as defined by the authors)* in these protocols is delineated as 1) the area where the river could re-occupy based on landform, regardless of lateral distance or 2) the area defined by the extent of the historic channel locations along with predicted migration rates.

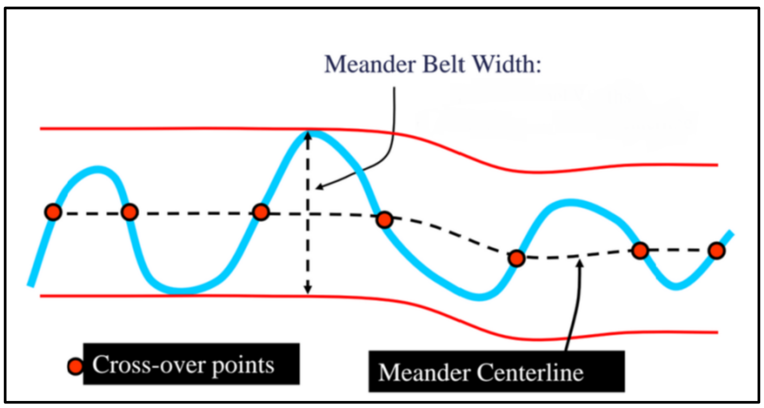

Figure 6: Meander Belt Width (from Vermont River Management Program).

A separate component of the Active River Corridor, the Disconnect Migration Zone (DMZ), is identified in Washington's protocols. Land in a DMZ would be mapped as part of the active river corridor, but are disconnected from most channel migration processes by man-made structures[10] such as levees, state highways, active railroads and major county roads. Identification of these areas may provide information to planners about potential risk, but also identify areas where river corridor reconnection might be beneficial.

Erosion Hazard Areas

Erosion hazard areas (EHAs) define regions adjacent to the active river corridor which may be susceptible to erosion and mass wasting induced by lateral migration, widening, and incision of

[10] In order to be considered a disconnecting feature it is recommended the structures are built to withstand hydraulic forces and be above the predicted water surface elevation during a 100-year flood and that they are publically maintained.

the river channel. These areas include stream banks for incised channels (e.g., arroyos and gullies), colluvium or cohesive hillslopes composed of erodible material, and remnant terraces. These areas are a critical component of the FHZ because improvements that may be outside of the 100-year floodplain due to elevation differences may be nonetheless vulnerable to fluvial hazards due to lateral channel migration that then triggers a bank/hillslope/terrace failure.

The *erosion hazard area* is defined primarily in three ways across the nation:

1) A specified and consistent setback from the stream centerline, ordinary high water mark, or top of bank (e.g., Town of Estes Park, CO 50' setback from ordinary high water mark for new development).

2) A range of buffer widths from the active river corridor manually assigned. These widths range from as small as half of a channel width for very resistant or mild hillslopes to a full meander belt width for highly erodible and susceptible hillslopes and terraces (e.g., Washington CMZ protocol).

3) A buffer width from the *active river corridor* toe that is determined by extending a sloped plane out at a specified angle until it intersects the hillslope or floodplain surface. This method relies on estimating the maximum depth of incision a channel may obtain as the base of this buffer. The angle of this plane generally ranges from 3:1 to 6:1 (H:V) and depends on properties of the hillslope or terrace material and vegetation, slope, channel width, meander amplitude, and relative likelihood of the channel encountering the valley wall (e.g., City of Austin, TX).

Ultimately, some level of expert opinion is required to determine appropriate erosion hazard area distances, especially for an FHZ protocol to be implemented using a Level 2 analysis. The width of the erosion hazard area should be a function of the relative erodibility of the adjacent hillslope or terrace, its steepness, available stream power during floods (related to valley slope and confinement), as well as the likelihood that the active channel will encounter the adjoining hillslope or terrace (related to valley confinement) (Olson et al. 2014a). Figure 7, (from Olson et. al, 2014a) draws a qualitative link between these factors and the erosion hazard area width which in this figure varies from one channel width to a meander belt width.

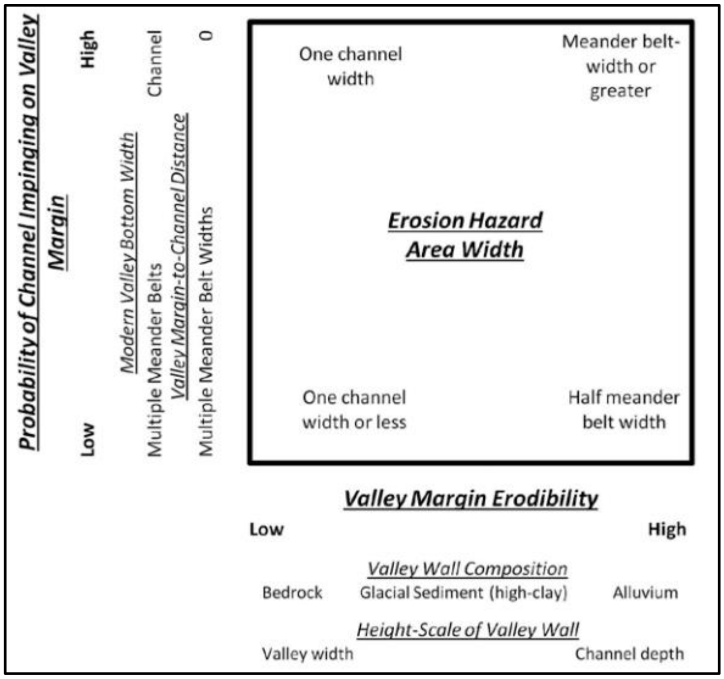

Figure 7: Qualitative chart relating the erodibility of the valley margin as well as probability of the channel encountering it to the recommended width of the erosion hazard area (from Olson et. al., 2014a).

Additional geomorphic hazard areas fundamentally associated with river corridors are those subject to ***channel avulsion*** and the dynamic nature of channels on ***alluvial fans***. These areas may be identified within or outside of the *active river corridor* and *erosion hazard area*.

Channel Avulsion Zones

Avulsions are a natural phenomenon that can have devastating consequences to streamside infrastructure particularly when communities are unprepared. Avulsions are defined as a wholesale shift in channel position on the valley floor (Brierley 2005) and can result from simple meander neck cutoffs or large island forming and valley-scale avulsions (Figure 8). The latter are particularly important to recognize as hazards and are identified based on relative elevation to the existing channel as well as the existence of relic channel beds, especially those that have a steeper gradient than the existing channel. Human activities, such as gravel mining, irrigation ditches, overly-constricted bridge crossings, and road networks can also create opportunities for channel avulsion. Avulsion may also be precipitated deposition of sediment or channel aggradation, during a flood event. For example, coarse bed material may rapidly accumulate near transitions from steep to mild sloped channels as well as at certain infrastructure within the channel such as jammed bridge crossings or flow diversion weirs.

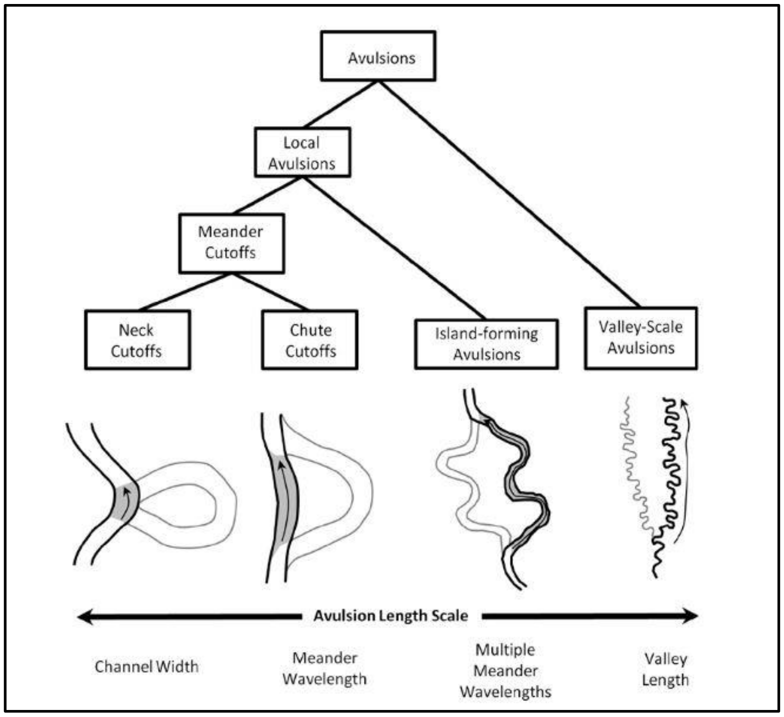

Figure 8: Channel avulsion classifications (from Olson et. al., 2014a).

Alluvial Fans and Debris Cones

Alluvial fans are depositional features that generally form where steep transport reaches meet an unconfined relatively flat river valley. Alluvial fans tend to occur within a river corridor at the confluence of a tributary stream to a main channel (also known as debris cones), at the outlet of a gorge or wash into a larger valley or plains area, at the foot of a topographic feature such as mountains or mesa, and at the outlet of confined rivers entering a milder sloped setting. Alluvial fans are often associated with ephemeral streams in arid settings in the West, but can exist in some form along perennial rivers at slope transitions or changes in valley confinement - particularly where upland sediments are easily produced and transported downstream. The channel alignment on an alluvial fan is highly susceptible to avulsion due to excessive deposition; therefore these zones represent a relatively higher fluvial hazard (FEMA 1989, French and Miller 2012). Alluvial fan deposits from tributaries entering a mainstem channel also represent areas where elevated erosion hazard may exist from the main channel given their unconsolidated nature or ability to push a channel into the opposite valley hillslope (Figure 9).

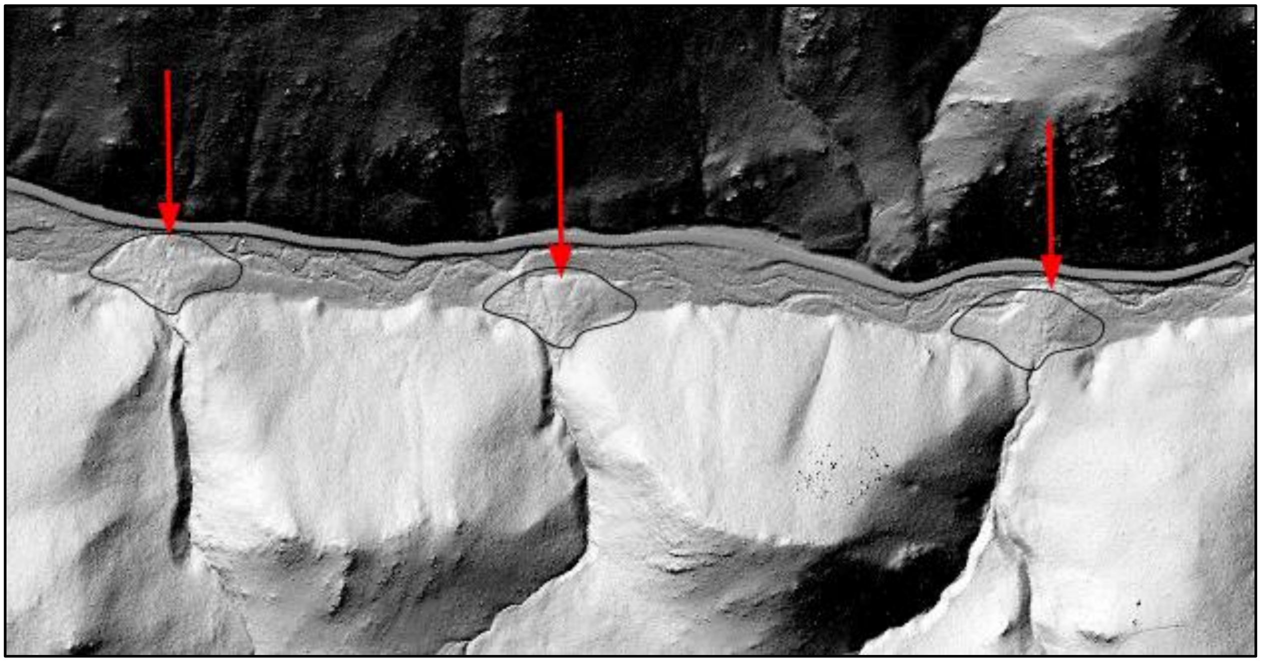

Figure 9: Alluvial fans or debris cones (red arrows) formed at the mouth of small side drainages as they enter the active river corridor of Colorado's Lefthand Creek.

Outcome or Decision: We have described the primary processes of river change resulting in fluvial hazards above. These include channel widening and incision, downstream meander migration, avulsion, and hillslope erosion or failure. From this synthesis we argue that delineating and then combining four fluvial hazard components—the active river corridor, an erosion hazard buffer, avulsion hazard zones, and alluvial fans—adequately captures fluvial hazards within the floodplain resulting in a comprehensive fluvial hazard zone map. The process for defining these fundamental parts, however, will vary according to the physical, geologic, and hydrologic classification of the river reach. As discussed in Section 2.2 classifying the geomorphic context of a river reach is an important component of mapping the FHZ, particularly due to the great diversity of stream systems in Colorado.

After deliberation, we have decided to exclude the concept of "disconnected migration zones" from the recommended Level 1 fluvial hazard zone identification structure in this document. It was shown that even large and strong infrastructure, such as armored roadway embankments, crumbled under the force of the flows sustained during the week of flooding in September 2013. Rivers across the Front Range tended to reclaim areas cut off by roads or railways that would have been mapped as disconnected. In these cases a special consideration for a disconnected migration zone would have given a false sense of safety to residents in these areas. For a level 1 analysis, if an active valley bottom is dissected by highways, certified levees, and/or railroad embankments, it will all be classified as part of the FHZ. A Level 2 analysis may determine that these structures are engineered to prevent channel migration and/or overtopping and therefore remove these zones from the active river corridor. If this path is pursued, some design standards should be developed to assess the stability of these features to withstand fluvial forces.

2.5 Additional Factors Influencing Fluvial Hazards

FHZ delineation begins with identifying the fundamental processes of river change. Eventually additional factors, both natural and human-caused, will create circumstances that either make delineation difficult or increase the uncertainty of how a channel will react during a flood. The tables in sections 2.4.1 and 2.4.2 below are our best effort to consider and account for the most common of these additional factors and to determine how they will be treated within the recommended methodology.

2.5.1 Natural Factors

Additional Factors	Description	Outcome or Decision
Stream Channel Evolution/Succession	The changes a channel undergoes to restore equilibrium following a major disturbance (whether natural or human induced) generally follow a recognizable pattern. These stages are summarized in stream channel evolution models (Schumm et. al. 1986, Cluer and Thorne, 2013). The ability to recognize a stream channel's stage in a channel evolution model has great utility for selecting appropriate restoration and management activities. It may also inform FHZ delineation as it may predict where reaches are likely to undergo widening and/or lateral adjustment.	Geomorphic investigation to identify and predict channel evolution should be reserved for Level 2 delineation which would seek to identify and compare reference vs. existing channel conditions, existing watershed and reach stressors, and predictive trends in the channel morphology.
Debris Flow Hazards and Other Hillslope Processes	Debris flows, are geological phenomena in which water-laden masses of soil and fragmented rock rush down mountainsides, funnel into stream channels, entrain objects in their paths, and form thick deposits on valley floors. Debris flows may occur on any steep slope, but tend to form in small to large drainage ways, which may be perennially dry with the exception of large rain events. In steep landscapes, there is no drainage area threshold below which the risk of a debris flows is less (Coe et al. 2014). Mass wasting of hillslopes may similarly deposit large amounts of sediment and debris into river channels. Both of these phenomena have the potential to cause channel damming and possible avulsion into mapped and unmapped river hazard zones. The proposed FHZ protocol does not attempt to map debris flows or landslides areas. The Colorado Geologic Survey is actively mapping these hazards. Future research may warrant the introduction of a special fluvial hazard area in vicinity of mapped or predicted debris flow zones and hillslope hazard zones.	Mapping areas prone to debris flows is currently being conducted by the Colorado Geologic Survey. While debris flows and mass wasting hill slope processes can significantly influence fluvial processes and overall watershed sediment budgets we expect specific correlations between debris flows and FHZ to be too difficult to obtain for a Level 1 delineation. For Level 2 analysis, debris flows and the amount of hillside coupling should be considered as these factors may influence local and downstream channel behavior if they activate during flood events.
Fire-Affected Watersheds	The combined effects of vegetation and ground litter removal, as well as the formation of a water-repellent (hydrophobic) soil layer following a severe burn, can significantly increase runoff in affected watersheds. Fire denuded soils (especially in severe burn areas with	We recommend in recently severe burn areas (to be determined by soil burn severity mapping, presence of hydrophobic soils, etc.) that fluvial erosion hazards be identified via the

	steep topography) may contribute significant amounts of sediment and debris into under-fit streams resulting in significant channel aggradation, activation of dormant alluvial fans, and avulsions. The inability of the watershed to retain precipitation effectively shortens the intervals between floods further creating management problems.	Level 2 process in order to better anticipate the effects of excessive sedimentation and debris flows from the burn scar area into the receiving river valley.
Forest Disease Affected Watersheds	The effects of live vegetation loss can increase runoff in affected watersheds. Loss of living canopy cover may increase soil erosion (especially in steep watersheds) resulting in channel aggradation, activation of dormant alluvial fans, and avulsions. The reduced capacity of the watershed to retain precipitation effectively shortens the intervals between floods, further creating management problems.	We recommend in watersheds with heavily diseased forests that coordination with local experts be conducted to understand if a Level 2 process is recommended to better anticipate the effects of forest die-off into the receiving river valley.
Confluence Areas	Confluence zones represent unique dynamic areas along rivers where fluvial hazards may be elevated or at least punctuated. River confluences create distinctive flow structures and sediment transport dynamics leading to the potential for significant deposition as well as localized scour (Benda et al. 2004). Geomorphic change at confluences depends largely on the ratio of drainage area of the two joining streams. The confluence of tributaries of similar stream orders tends to result in a widening of the channel and potentially the valley bottom (Rhoads 1987). Inputs of coarse material from steep, small drainage area tributaries to large drainage area main stem channels can cause local steepening downstream of the confluence and milder slopes and wider channels upstream as the mainstream channel is temporarily dammed and then forced to flow over or around the coarse deposit (Benda et al. 2003).	Although likely to exhibit some unpredictable hydro and geomorphic tendencies, designation of confluence areas as areas of special fluvial hazard zones will only occur in a Level 2 study. The analysis will likely utilizes a combination of mathematical, modeling and field-based data to determine fluvial hazards that may result from confluence dynamics.
Large wood	Large wood influences stream channels by changing sediment routing and storage, channel dynamics and processes, and channel morphology. While wood is frequently associated with causing jams and avulsions during a flood (particularly when undersized bridges and culverts are present) it has also been documented to promote stream stability and improve habitat diversity and is therefore critical to resilient stream systems (Montgomery 2003). The direct and indirect influences of wood vary across a wide range of scales. While single pieces of wood may be enough to form side channels and avulsions in a small stream in large channels it often takes a jam for wood to influence channel pattern and floodplain processes. Predictive modeling of stream adjustment as a result of large wood is a topic that warrants further study.	Designation of in-channel or floodplain wood jams as areas of special fluvial hazard consideration is not recommended for Level 1 analysis. Erosion hazard as a result of wood is an assumed factor in channel migration and avulsion and is accounted for in the Level 1 methodology.

Ice Jams	Temporary plugging of stream channels due to ice jamming is a special hazard not accounted for by inundation-based maps. Level 1 fluvial erosion maps assume ice damming could occur on any stream and that streambank erosion and/or avulsion associated with the temporary dam would occur within the delineated FHZ.	Though they may be responsible for localized fluvial erosion, designation of ice jams as areas of special fluvial hazard consideration is not recommended for Level 1 analysis. Local information may contribute to a Level 2 analysis that considers ice jams as areas of special hazard designation.
Beavers	Damming of stream channels and culverts by beavers results in backwatering and sediment deposition both of which may lead to dam failure, avulsion or side channel formation during a flood. The presence of beaver dams may also provide points of stability in an otherwise dynamic system and reduce fluvial erosion hazards.	Designation of beaver dams as areas of special fluvial hazard consideration is not recommended for Level 1 analysis because the erosion is likely to occur within the mapped FHZ.

2.5.2 Human Factors

Additional Factors	Description	Outcome or Decision
Undersized Bridges and Culverts	Traditional hydraulic-based design standards for the sizing of bridge and culverts have not considered the geomorphic setting, sediment and debris transport needs, and channel adjustments inherent in fluvial systems. The resulting designs (based on moving a prescribed amount of water through a structure) frequently result in undersized structures disrupt sediment and debris transport often causing localized and even reach scale instability. Plugged structures cause damage to surrounding infrastructure. There are many examples from the 2013 flood of undersized crossings that trapped debris of all types and caused creeks to carve new channels resulting in significant infrastructure damage in areas outside of mapped floodplains.	Until a protocol has been established at a State-level (see also additional data needs section 7.0) we recommend that all crossings that appear to be less than the average bankfull width or located at a tight bend or change in valley slope be flagged with a point file on an FHZ map. These points are intended to give landowners and planners a "heads-up" that disruptions in sediment and debris transport due to the structure may put nearby infrastructure at risk (this warning may be particularly important to homeowners that are outside of mapped floodplains but are in direct vicinity of a structure prone to plugging and therefore unpredictable fluvial hazards).
Road and Railway Infrastructure	Where roads and railways have encroached on the stream corridor they can act either as levees (when they run parallel to the valley) or dams (when they run perpendicular). Flow depths, shear stresses, and sediment transport capacities during floods may be altered as a result of these features. For example some reaches may be transformed from sediment storage areas to sediment transport reaches if their floodplains are cut off by a road/railway. This reduction in water and sediment storage potentially impacts downstream reaches where the excess material then deposits. Where damming from a road or railway occurs sediments	Designation of roads as areas of special fluvial hazard consideration are not recommended for Level 1 analysis. Level 2 analysis should consider at least qualitatively the ability of infrastructure to withstand flood related hydraulic forces (other than scour). In low gradient streams where streams are underfit to move the embankments they may be considered as confining features.

	may accumulate on the upstream side and scour heavily on the downstream side. In both instances the infrastructure itself and those structures that may have been built on the lee side may be susceptible to the stream retaking the pre-development active river corridor - a dominant theme during the 2013 Colorado flood.	
Diversion Infrastructure and Off-Channel Storage Facilities	It is recommended that low-head diversion dams be reconstructed to transport sediments and not cause excessive aggradation and scour that may re-direct flow into weak embankments or worse an irrigation ditch during a flood. New designs in low-head diversion structures have the additional benefits of allowing for passage of boats and fish and aquatic organisms, while reducing the sediment load into ditches.	Diversion structures should be flagged with a point file during a Level 1 analysis. These points are intended to give landowners and planners a "heads-up" that the structure may put nearby infrastructure at risk.
Fill and Development	Development and agriculture have filled the active river corridor in many creek corridors eliminating floodplain complexity, side channels, wetland, overflow relief channels and other important ecological and geomorphic components of a healthy functioning floodplain. Fill erases the evidence of past channel migration possibly creating a false sense of protection from fluvial erosion to those that own/occupy the land. Map delineation of these areas is difficult unless pre-development aerial photographs or other historical record exists or unless upstream and downstream features can be reasonably connected. In large urbanized areas delineation of the active river corridor may be impossible.	Mapping the active river corridor in previously-developed or highly altered river corridors may only be possible using more extensive field data collection, historical analysis, and potentially channel stability modeling. Where more detailed mapping is desired a Level 2 approach may be necessary.
Altered Hydrologic Regime	Changes in hydrologic regimes from climate change, land use change and/or flow regulation disrupt the water-sediment balance in river systems. Enhanced stormwater runoff from development within the river corridor may increase the volume and peak runoff rate of stormflow. Erosion, incision, and channel widening are often associated with increased stormwater resulting from watershed development. Conversely, reductions in flow either from diversions or impoundment can cause a river to narrow as vegetation and sediments encroach - this in turn may lead to increased channel erosion and bank failure during large flood events when diversions and impoundments are bypassed.	While not explicitly addressed in the Level 1 protocol, at a minimum, a qualitative assessment of the flow hydrology and any impacts that hydrologic alteration may have on the channel should be considered in an FHZ study.

Channelization, Armoring, and Levees	As channels are straightened, bermed, or armored excess energy confined in the channel typically causes erosion of the streambed, enhanced flooding downstream, or enhanced erosion on unprotected banks downstream. Therefore, these engineered reaches and those adjoining them likely behave distinctly from natural rivers both in their response to floods as well as their incremental evolution over time. Mapping the FHZ along armored or channelized reaches can be difficult using the data sources and low intensity of field data collection under Level 1 of this protocol.	Given the uncertainty of the effects of river engineering on a particular reach and those that adjoin it, as well as the difficulty in identifying engineered river treatments using remotely sensed data, we recommend that a cursory field verification be conducted under Level 1 FHZ analysis to identify where river engineering may exist and that a Level 2 analysis be conducted on all river segments where substantial river engineering exists. Level 2 analysis should consider, at least qualitatively, infrastructure's ability to withstand flood related hydraulic forces (other than scour).
Floodplain Mine Pits/Ponds	Mining pits/ponds located in the active river corridor are highly susceptible to being "captured" by the channel during a flood event. Evidence of this was abundant during the 2013 Colorado flood. Consequences range from creating a disruption in sediment transport leading to a temporarily more erosive channel downstream to cascading effects as channel energies are re-routed into connecting ponds and potentially endangering property not in a mapped floodplain or FHZ.	Floodplain mine pits/ponds will be included in a delineated Level 1 and Level 2 FHZ when reasonable evidence exists to suggest that they could "capture" a river channel during a flood.

2.6 Risk and Probability in Fluvial Hazard Zones

The 1994 National Flood Insurance Reform Act (NFIRA, Section 577) tasked FEMA to study the feasibility of mapping "Riverine Erosion Hazard Areas" within the National Flood Insurance Program. These areas were defined as, "an area where erosion or avulsion is likely to result in damage to or loss of buildings and infrastructure within a 60-year period." Fluvial hazard maps commissioned by King County, WA attempt to classify relative risk within the FHZ. These relative risk zones result from analysis of average channel migration rates based on aerial photos dating to 1936. Areas within the FHZ assigned to the highest risk category lie within the area predicted to be occupied over the next 50 to 100-years based on average historical migration rates. Original guidance for the State of Washington attempted to assign probabilities to hazards based on similar criteria (Rapp and Abbe, 2003); however, the state has moved away from this process in their more recent guidance (Olson et al. 2014). Conversations with the technical advising team as well as a review of existing science indicates that probabilistic risk methodologies for river migration are currently not sufficient to accurately estimate probabilities of fluvial hazards.

Quantifying relative or absolute hazard within the FHZ using, for example, either a return probability or a classification of high, moderate, and low probability of fluvial hazards within mapped areas is appealing and would aid in allocating scarce resources to mitigate fluvial hazards in river corridors. However, we have found that the science supporting relative hazard categories or absolute hazard characterization (e.g., 1% annual exceedance probability) to be insufficient, and overly complex for implementation on a large scale. Ongoing work by Colorado State University researchers is attempting to link probability and severity of river response to floods as a function of valley type among other explanatory variables (Sholtes and Bledsoe, 2014).

Outcome or Decision: We recommend that no relative or numeric classification of hazard probability be assigned to FHZ maps under the Level 1 analysis. Level 2 analysis on alluvial fans in arid regions of the western slope may have sufficient science to support relative hazard designations. All other Level 2 analysis should avoid relative and numeric classifications of probability of hazard until new science can support a standard and defensible methodology.

2.7 Automation, Transparency, and Subjectivity

Lingering questions remain on how best to use automation, create transparency, and deal with subjectivity within the FHZ mapping process.

The semi-automated Vermont approach can in some sense be seen as a benefit because it removes a level of subjectivity from the process while still fundamentally acknowledging and providing space for fluvial processes. Applying a channel-width multiplier off the meander centerline provides a precise (though perhaps not wholly accurate) delineation and may be helpful for defending boundaries in cases where historic migration evidence has been obfuscated. Similarly, by delineating the FHZ primarily to a pre-defined belt-width, Vermont is able to side step debates on fluvial forms being relics of different watershed conditions (i.e., deforestation), sediment regimes, hydrology, and climate (Kline, M. personal communication, July 22, 2014).

However, as was evident in the 2013 Front Range floods, Colorado rivers can be very dynamic, perhaps even more so than rivers of the east and Midwest where the Vermont approach has been implemented. Therefore, the full breathe of fluvial hazard prone land in a given river corridor may not be captured by an automated belt-width-based FHZ delineation and could thus leave property owners and community planners uninformed about the fluvial hazard potential. Where evidence of hazard prone land exists, the Vermont method allows for the corridor to be expanded to include existing meanders, meander scars, historic meander paths, flood chutes, and other fluvial indicators at the mapper's discretion, which ultimately re-introduces the subjectivity that the initial automation was designed to eliminate.

In contrast the Washington CMZ approaches do not attempt to eliminate the initial subjectivity via automation and instead acknowledge the importance of the user's expert knowledge in geomorphic interpretation. The method relies on manually-delineating the fluvial hazard zone and all of its components. Thus the mapper's experience, level of geomorphic understanding, and individual evaluations of landscape forms are of utmost importance from the first step in the process. Alterations to the landscape that obscure geomorphic evidence of channel movement potential, however, make delineation difficult and inject subjectivity into the maps.

In the end, for a full fluvial hazard zone map, both existing protocols have comparable levels of subjectivity and rely heavily on the experience and decision making capabilities of the mapper.

In the Otak report (Otak 2015), documenting the pCMZ and Phase 1 Vermont Study applied in Collbran, CO (see Section 3.1 for details) the authors suggested that this subjectivity in the FHZ delineation process might be best handled with a highly transparent mapping process within Level 1. Documenting in detail what decisions led to what outcomes when mapping an FHZ reach-by-reach can aid in identifying areas of greater uncertainty and aid in communicating this to FHZ map users. These areas of uncertainty might be candidates for follow-up field verification or more detailed Level 2 analysis if desired.

Outcome or Decision: At the moment, we are not recommending automation as a means to eliminate or reduce subjectivity or the reliance upon qualified individuals as the primary mappers. Subjectivity is inherent to the process, regardless of the method, and given the current status of automation software, we do not see an advantage to using existing software in Colorado. The creation and testing of automation software for the preliminary steps of the FHZ mapping process, such as valley classification, should be considered in Phase 2 of the Colorado protocol development. We propose to deal with the issue of subjectivity by encouraging the mapping process to be transparent with all major assumptions and decisions documented on a reach by reach basis.

3.0 Comparison of Existing Methods

At the time of this writing there are three primary methods used around the United States to delineate erosion hazard zones. Vermont has established a two phase protocol that has been adopted and amended for use in New Hampshire and Indiana. This method is meant to capture the minimum areal extent that the river would need to adjust over time to achieve and maintain equilibrium conditions. The width of this active river corridor is calculated based on a multiplier of channel widths to encompass the narrowest band of valley bottom and riparian land necessary to accommodate an equilibrium channel planform within a given valley setting and its hydrology (VT ANR 2015).

Washington State has adopted a two phase geomorphic-based protocol that identifies zones of historic channel occupation through remote sensing and field observations in order to delineate fluvial hazard areas. It has been amended for use by local jurisdictions within the state, such as King County. Studies in Montana have followed this protocol, though it has not formally been adopted by the State.

The arid southwest region and Texas have several city and county protocols that are in use and reflect the conditions in the region. These methods are built around an assumption of incising and subsequent widening of river channels (as opposed to significant meandering). These erosion hazard zones are delineated through the calculation of a setback distance based on an estimated final incision depth and the angle of repose of the bank material.

3.1 Vermont vs. Washington Comparison

Most rivers in Colorado are subject to lateral and down valley migration therefore the protocols developed in the Northeast and Northwest are most applicable. The authors delineated the FHZ for the Fall River, Estes Park using both the Vermont Statewide Corridor Mapping method and the Washington planning-level channel migration zone (pCMZ) mapping method to compare and contrast results. Although the comparison is limited in scope and breadth, it allows for some generalized conclusions which were useful in leading towards an overall recommendation.

Both protocols rely primarily on remote-sensing with a field verification component. Both methods capture the equivalent of the active river corridor (modern valley bottom for WA and river corridor for VT) for most reaches because of the semi-confined nature of the Fall River valley. In an area where the valley becomes unconfined, the Vermont belt-width approach failed to capture a channel avulsion (Figure 10) while in another area it did capture an avulsion but without further manipulation left a large area of river-worked sediments unmapped (Figure 11). For clarification, the predominantly GIS-delineated Vermont belt-width protocol does allow for the field scientist and map maker to expand calculated meander belts (where appropriate) to include existing meanders, meander scars, historic meander paths, flood chutes, and the like, where the evidence exists. It also allows for a greater multiplier to be used where evidence of instability exists. Our team did not take these extra steps given the rapid comparison we were looking for and our likely biased knowledge of the outcome of the 2013 event. Despite our own shortcomings in terms of applying the Vermont protocol it was clear that the Washington method takes a more conservative approach to mapping all areas with potential for fluvial erosion. As a drawback the Washington delineation required a great deal more time hand delineating and correcting the modern river valley (automation of this is explored in Section 3.3). Areas of fill and urbanization were particularly challenging to delineate using the pCMZ method as geomorphic signatures within the river corridor were obscured.

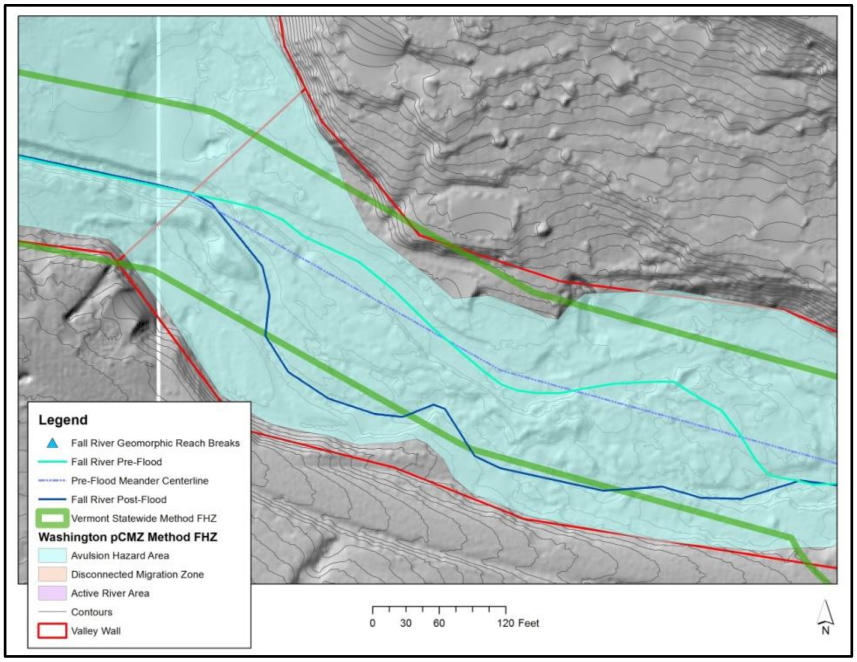

Figure 10: Fall River, Estes Park. Comparison of pre-flood and post-flood channel location and FHZ delineations using the VT and WA planning-level delineation methods. An avulsion that occurred during the 2013 flood fell outside of the belt-width delineated with pre-flood channel alignment. (Note: Additional buffers for delineation of Erosion Hazard setbacks are not depicted).

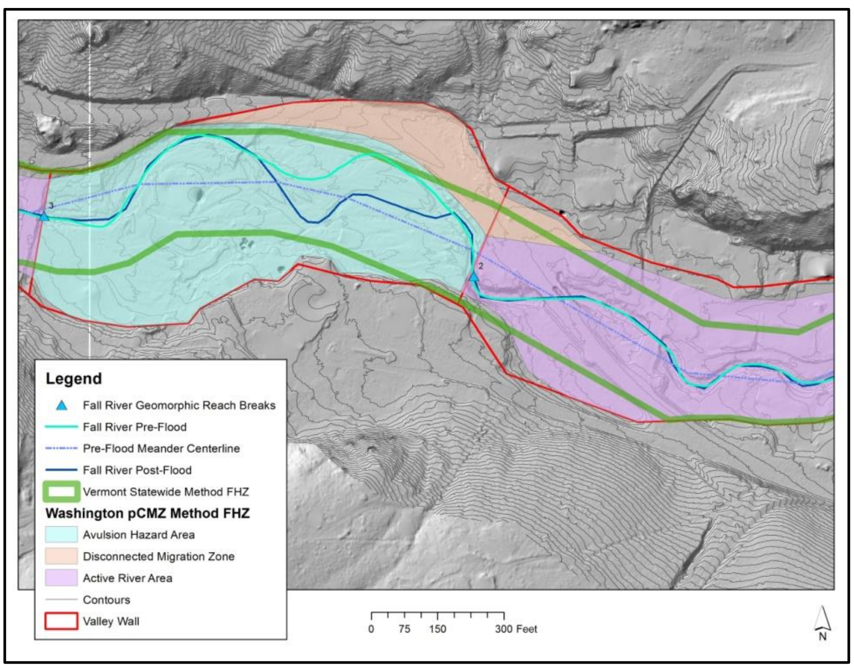

Figure 11: Lower Fall River, Estes Park. Comparison of pre-flood and post-flood channel location and FHZ delineations using the Vermont and Washington planning-level delineation methods. (Note: additional buffers for delineation of

A more thorough comparison of the Vermont and Washington FHZ methodologies was conducted along Plateau Creek and its tributaries in the vicinity of Collbran, CO on behalf of the

State of Colorado (Otak 2015) and this study was reviewed for this report. The Otak study provides valuable insight into the process behind implementing each method, where strengths and weaknesses exist, and the overall applicability of using each method to map the FHZ within Colorado. Though, it appears that the Vermont protocol used for comparison with the Washington State pCMZ method was the Phase 1 Stream Geomorphic Assessment protocol (Kline et. al., 2007) rather than the more appropriate "Vermont statewide river corridor mapping protocol" which is a planning level process for hazard mapping and best compares with the Washington pCMZ protocol – for this reason the comparison of the delineated fluvial hazard zone boundaries within the Plateau Creek Study Area was not used.

In the Plateau Creek study, the river corridor delineated using the Vermont method is defined differently than that of the Washington method. The former maps a minimum boundary on either side of a river within which it may achieve or maintain an equilibrium planform (S. Pomeroy, personal communication, April 1, 2015, quoted in Otak 2015) and the latter is a larger area that identifies the areas exposed to fluvial hazards. The intent of identifying each of these areas is very different and as a result, the most important revelation in the study was the discussion of how to frame the goals and objectives of a mapping effort.

The authors of the Otak report also echoed our experience with delineating erosion hazard area setbacks on hillslopes and terraces near river channels. Existing guidance from the Washington protocol for appropriate erosion hazard setback distances are too qualitative and lacking in detail. Establishing a methodology for determining appropriate erosion hazard setback distances is a high priority topic for follow-up study.

3.2 Southwest Method Comparison

In the Southwest United States fluvial hazard zone mapping studies and protocols have been developed and implemented at the local level and vary considerably. The Arizona, Department of Water Resources has a state standard for lateral migration setbacks on streams (AZ DWR 1996); however, this standard contains no methods relevant to Level 1 FHZ mapping. FHZ maps were created by a private consultant for Washington County, Utah (Fuller and Associates, 2005) using a detailed methodology relying on extensive geomorphic field assessments, historical mapping, and some engineering-based approaches including hydraulic modeling and scour analysis. Despite these efforts, no direct link between the mapped FHZ and these methods was provided as the FHZ was ultimately delineated using professional judgment.

Several protocols adopted for local governments in arid regions rely on linking estimates of sediment excavation by floods over a specified period of time to changes in channel geometry (AMAFCA 1994, El Paso County 2001). Though they correspond most with a Level 1 FHZ analysis in terms of effort, these methods cannot be readily applied across large scales. Furthermore, large assumptions about river processes must be made to apply these methods, further limiting their application.

The Cities of Austin, TX, Dallas, TX, and Maricopa County, AZ all have similar FHZ protocols developed for generally small, incising and confined urban streams (City of Austin 2013, City of Dallas 2013, Maricopa County, 2013). Though some details within each method differ, they generally involve estimating the maximum depth of potential channel incision for a given reach, mapping the channel toe width and elevation, and defining the FHZ using an erosion hazard setback approach (Figure 12). This approach assumes a conservative slope failure angle (3:1 to 6:1 H:V) extrapolated from the channel toe margins and up into the hillslope. This accounts for bank and hillslope failure resulting from channel incision and widening. The slope failure angles may vary according to the relative strength of the hillslope material. In some cases, a maintenance buffer of 10-25 feet is also added onto this erosion hazard setback to allow for equipment access to repair any channel margins as needed. One benefit to this method is the assessment of maximum channel scour depth. Because utilities are so frequently buried underneath stream channels in urban areas, estimating this depth and placing of utilities below it might help in reducing service shutdowns due to flood damage - an important resiliency benefit that none of the other methods offer.

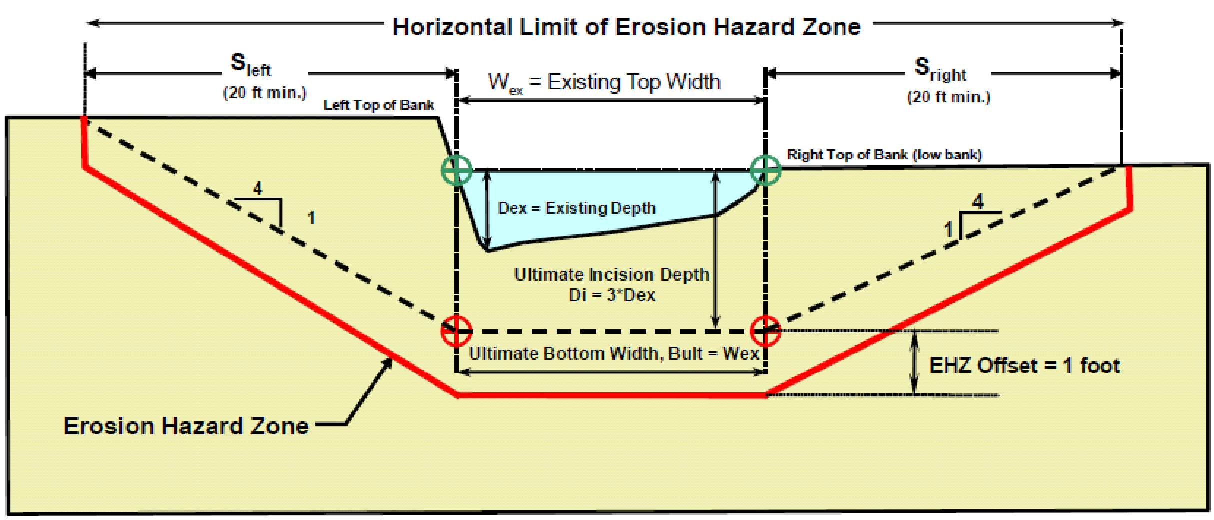

Figure 12. Example of erosion hazard area setback for urban and incising channels. From City of Austin (2013).

3.3 Active river corridor Mapping Methods

Several tools and methods exist to map active river corridors and we describe several methods below. Some are automated GIS tools built for ArcGIS® and others are manual methods using remotely sensed data.[11] All automated active river corridor mapping methods should be manually and field verified.

[11] LiDAR-derived DEMs with approximately 1x1m resolution or better are required for all methods utilizing DEMs.

3.3.1 Relative Elevation Models

The Washington State pCMZ and our recommended FHZ protocol for meandering streams relies on manual interpretation of relative elevation models to map the active river corridor. These are created by de-trending river corridor DEMs based on local river slope. This essentially “flattens out” the river within a DEM and all elevation values are relative to the river itself (Figure 13). These models can be created by a generic DEM de-trending tool or the “Riparian Toolbox[12] created for ArcGIS 10.1 (Dilts and Yang 2015). This method is recommended for delineating the active river corridor for all Level 1 FHZ analyses. (Note: Professional interpretation of the relative elevations may identify a consistent height that translates well into the active river corridor edge/valley wall toe. Vectorizing this depth into a polygon can be a useful first cut in working towards defining the active river corridor).

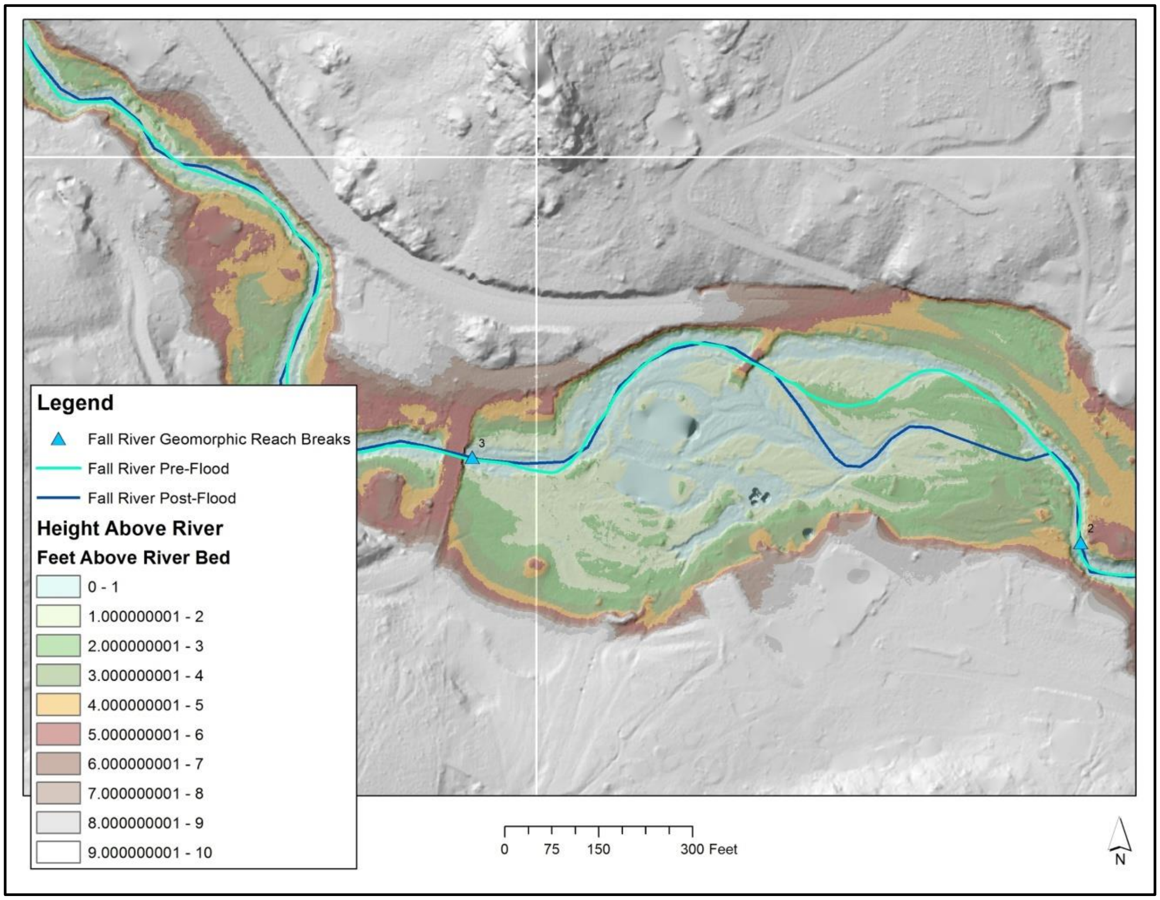

Figure 13: Relative elevation model output example for a reach on the Fall River, Estes Park.

3.3.2 Hydro-geomorphic Valley Mapper

Developed by Colorado State University in conjunction with the U.S. Forest Service National Stream and Aquatic Ecology Center, this ArcGIS tool delineates and classifies floodplains (Baker et al. 2014) along a river network at the watershed scale. Some manual manipulation and correction of intermediate data is required to produce the final product of floodplain

[12] http://www.arcgis.com/home/item.html?id=b13b3b40fa3c43d4a23a1a09c5fe96b9

shapefiles. The floodplain map produced by this tool is based on a geomorphic definition of the valley wall based on the location of maximum concavity within the landscape. This is then clipped by the extent of an approximated 100-year floodplain to account for, for example, wide glaciated valleys with small streams that do not occupy the entire valley floor. Floodplain boundary outputs should be manually adjusted using a relative elevation model as the automated procedure may not produce appropriate results in all occasions. Note that this tool was created primarily to classify floodplains rather than map them; however, it may be appropriate to use under Level 1 FHZ analysis as a first cut at active river corridor delineation.

3.3.3 The Active River Area

A generic approach to mapping ecologically important zones within the river corridor, the "active river area" delineates a geomorphic floodplain using the PATHDISTANCE tool in ArcGIS Spatial Analyst as described by Strager et. al. (2000). The complete active river area mapping methodology involves more detailed GIS analyses based on hydrologic and land cover data not applicable to mapping the active river corridor for the FHZ (Smith et al. 2008). For the FHZ the PATHDISTANCE tool in ArcGIS is appropriate (as demonstrated and utilized by the Vermont statewide mapping effort). The tool utilizes an algorithm that assigns a cost to cells in a DEM based on their distance from a stream centerline as well as the local slope of the cell. A calibrated cost value (unique to the grid cell size of the raster and region) is used as a threshold within which the floodplain is delineated. DEM grid cells that are both far away from the channel and steep are determined to be outside of the floodplain. This is a simple tool to implement requiring minimal pre-processing. However, the cost threshold for delineating floodplains must be calibrated for each region and is based on the resolution of the DEM raster used. This approach may be appropriate under Level 1 FHZ analysis with manual verification and correction.

3.3.4 Historic Migration Zone

Broadly defined as the area in which the channel has previously occupied, the historic migration zone must be mapped using ortho-rectified historical aerial photographs (Lagasse et al. 2004). Relative elevation models may also aid in this type of mapping to identify historic or high flow channels. Obtaining and ortho-rectifying historical channel extents can be labor intensive. Additionally, a long and regular record of aerial photos may not exist in many locations. Finally, historic channel location may not fully capture potential future locations. Some interpretation and extrapolation may be necessary to fully delineate the active river corridor using this method. It is best suited for more detailed Level 2 FHZ analysis especially where fill and development have obfuscated the active river corridor.

4.0 Recommended Methodology

After a comprehensive review of existing fluvial hazard mapping methods and available science, field testing, and discussions with the Technical Advisory Team the authors are recommending a hybridized approach to delineating fluvial hazard zones for Colorado that is based on a geomorphic framework. The diverse river types in the State of Colorado require different approaches to FHZ delineation based on the dominant processes of river change during floods within a particular geomorphic setting. We have endeavored to identify cost-effective approaches that can be widely deployed across the state. This framework and these approaches leave flexibility for adaptation to specific regions as well as for more detailed refinement when necessary. The recommended approaches to FHZ delineation are organized through a decision-tree, which begin with a more conservative and primarily GIS-based approach (Level 1) to be followed by a field-based geomorphic and/or engineering approach (Level 2) where necessary as discussed below.

Level 1 analysis involves a rapid methodology for mapping the FHZ resulting in a conservative delineation. It largely relies on remotely sensed data (aerial photography and LiDAR-based relative elevation models) with rapid field verification and is most appropriate for rural settings. Highly modified river corridors where river training and armoring are widespread may make the Level 1 analysis impractical or inappropriate. Level 2 FHZ delineation involves more detailed field and remote sensing analysis and, in some cases, hydraulic modeling for bed and bank stability analysis.

4.1 Process Overview

The objective of Level 1 analysis is to delineate a conservative FHZ using a basic level of effort. The Level 1 FHZ does not attempt to define probability of erosion or avulsion. They are conservative by nature, defining a zone within which a stream or river *may* occupy or indirectly impact via hillslope or bank erosion and mass wasting. Should a Level 1 FHZ be contested or determined to be unreasonable, then a more detailed Level 2 analysis may be performed to better confirm the potential for fluvial hazard within a river corridor (the results of which could either confirm, constrain, or expand the limits of the Level 1 FHZ)[13]. Level 2 analysis, which requires more field-based data collection, remote sensing analysis, and potentially modeling, is likely necessary in highly modified or urbanized areas where dense development within the river corridor impedes Level 1 delineation methodology.

Before FHZ delineation can begin, preliminary analysis steps are required (see below). This is largely a GIS exercise using LiDAR derived DEMs and other spatial information. These are used to generate a stream network, define geomorphic reach breaks along the stream network, calculate drainage area, and classify valley types for each unique reach. A qualitative hydrologic and geomorphic classification exercise at this initial stage is also recommended to guide the mapping effort. With this information compiled a decision-tree is then employed

[13] In some cases, a Level 2 analysis may result in a similar, narrower, or even expanded FHZ. Comparisons of planning level Channel Migration Zones (CMZs) (akin to Level 1 FHZs) and detailed CMZs mapped using Level 2 techniques in Washington State resulted in some local differences in the delineated hazard zones, but overall no significant differences in total CMZ area (Olson et al., 2014b).

(Figure 14) to determine which FHZ delineation method is most appropriate for the reach. An outline of each method is provided in Section 4.2.

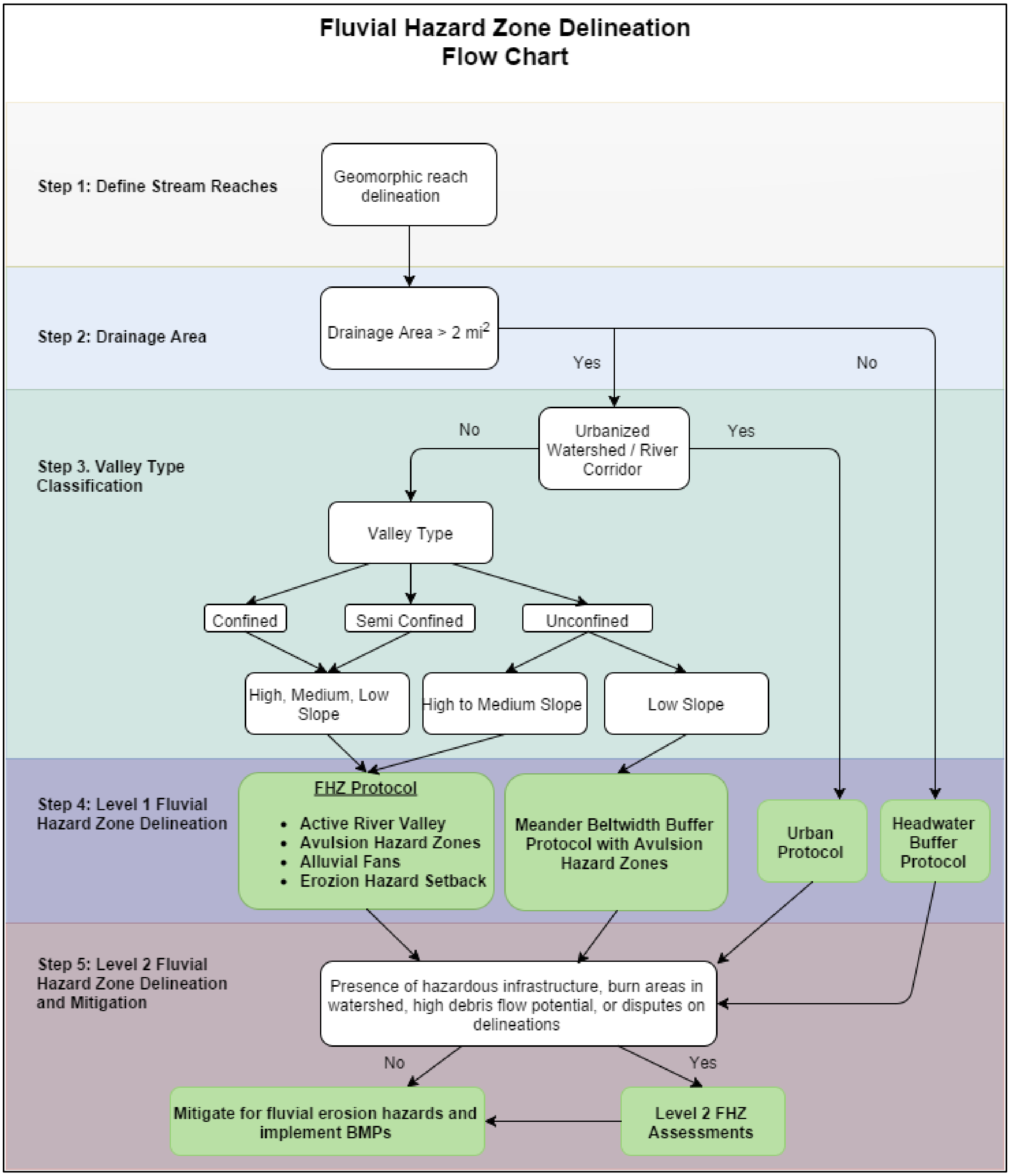

Figure 14: Colorado FHZ Decision Tree

Step 1: Reach Delineation

A reach is a section of river with roughly homogenous geomorphic characteristics such as slope, valley confinement, riparian land use, and local geology. For planning purposes it is important to delineate reaches with similar migration potential, river planform patterns, or valley characteristics. Geomorphic reach-break criteria include:

- Changes in gradient (proportional to sediment transport capacity)
- Changes in valley width and channel confinement
- Tributary junctions (changes in the ratio of sediment transport capacity to sediment supply)
- Changes in channel pattern
- Changes in infrastructure that control lateral erosion and migration
- Changes in geology/ erodibility of adjacent valley slopes or channel bed (e.g., presence of grade control)
- Changes in land use
- Changes in hydrology from the presence of dams or diversions that significantly alter the quantity, timing and/or duration of flows between two points along a channel

Step 2: Drainage Area Determination

The Level 1 FHZ decision tree begins with a determination of drainage area threshold, below which a simple buffer off of the channel centerline is recommended (see *Headwater Buffer Protocol*). We recommend the drainage area threshold be 2 mi^2 considering that most small streams are steep and in confined valleys where meander migration is limited. We acknowledge that fluvial hazards in streams may initiate at smaller or larger drainage area thresholds based on topography, hydrologic conditions, and local surficial geology. Ultimately, this drainage area threshold must be determined on a regional basis as communities identify the need and then find the resources to complete more detailed delineation for these upland reaches. In cases where channel incision is active or in drainages where urban development is pervasive, a comprehensive FHZ is recommended.

Step 3a: Level of Modification (Urbanization) Determination[14]

In developed or highly-modified river corridors, a standard FHZ delineation is not practical because superficial fluvial signatures are erased by channel bank armoring, channel modification, and floodplain development. Additionally during a flood event there is significant potential for human intervention to limit (or exacerbate) lateral migration and channel erosion. It is therefore necessary to flag reaches that have a high degree of channel modification or urbanization within the river corridor as the FHZ along these reaches will require a specific method for urban channels (see Section 4.2).

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[14] We have not found an appropriate pre-existing boundary that could delineate where an urban area begins and ends. For example, incorporated city and town limits often have undeveloped areas along river channels or on the fringes of the incorporated boundaries. Therefore, FHZ delineation may still apply within this boundary. Perhaps some threshold of developed area exists to trigger the urbanization category, but the value of that threshold has not been determined. As a placeholder, perhaps a rough estimate of 50% or more of the area of the 100 foot buffer on either side of the channel must be developed before a Level II type of analysis is required.

Step 3b: Valley Type Determination

For all reaches greater than the minimum drainage area threshold and without significant urbanization, a valley classification procedure is necessary. This provides important information on the geomorphic setting and appropriate FHZ methods to consider, which are organized by valley type. Valley classification involves calculating a channel confinement ratio, which is the valley width divided by the (reference) channel bankfull width[15], and a reach averaged slope. As previously described in Section 3.3, a number of methods exist to classify valleys. The hydro-geomorphic valley classification tool (Carlson 2009), is appealing as it already exists within a GIS framework and the valley classifications it derives largely parallel the classes used to guide the FHZ protocol. However, the basic measurements for valley classification (valley width, channel bankfull width, and valley slope) may also be estimated manually. From a qualitative standpoint, degree of hillslope coupling with the channel, a function of hillslope steepness and proximity to the channel (Whiting and Bradley, 1993), should be considered as well, as discussed in Section 2.1.2.

Step 3c: Slope Determination

A final critical piece of information to determine the appropriate FHZ method is the slope of each geomorphic stream reach. Combined with valley type, the average valley reach slope indicates the relative amount of erosive power available to do geomorphic work during floods.

In unconfined valley settings where the slope falls below 0.1%, we recommend a split from the comprehensive FHZ method to a buffered meander belt-width approach. This slope threshold should only serve as guidance as it may not be widely applicable across the state. In these lower sloped (and lower energy) unconfined streams, the dominant erosion processes evolve from avulsion, incision and widening towards lateral and downstream meander migration with some avulsion hazard. Bedform morphology in these streams transitions from riffle-pool to dune-ripple (Bison et. al., 2006, Buffington and Montgomery 1997). With less stream power, or stream power concentrated within an incised low-gradient channel, fluvial hazards typically are reduced to the zone closer to the banks of the main channel while inundation hazards extend far out onto a floodplain. The geomorphic river valley, defined by topography, may be much wider than the active river corridor, and land use practices might obscure geomorphic signatures within the floodplain used to delineate the active river corridor. Because of this, and based on previous experience in delineating the active river corridor in these low-energy stream reaches, we found it difficult to conceive that active river corridors delineated using the full FHZ approach would be prone to fluvial hazards. We therefore recommend a buffered meander belt-width approach to delineate the FHZ similar to that used in Vermont. We recommend increasing the meander-belt width where necessary to capture avulsion hazards as identified using aerial photography and relative elevation models, as this hazard may still exist in these river types. Appropriate values for the belt-width multipliers should be investigated in subsequent analysis.

[15] Reference bankfull width should be determined through locally derived or regional hydraulic relationship equations (e.g., Faustini et. al., 2009) or empirical data derived from cross-sections.

4.2 Level 1 Methodologies

The following are brief descriptions of the Level 1 FHZ delineation methodology based on the type of stream reach being considered (Table 3). Hard numbers given here such as the drainage area threshold, channel slope classes, and valley confinement ratios are suggestions and will likely require regional verification.

Table 3. Summary of Level 1 fluvial hazard zone delineation methodologies

TYPICAL CHANNEL BED MORPHOLOGY	VALLEY TYPE (CONFINEMENT)	FHZ METHOD	FHZ COMPONENTS
Colluvium-dominated. Cascade, Step-Pool	Confined (valley width <2 bankfull width (bfw))	Headwaters Buffer	50' buffer on either side of existing top of bank
Cascade/Step-Pool/Plane-bed	Confined (<2 bfw) and Semi-confined (2-10 bfw)	FHZ	Valley wall to valley wall + Erosion hazard area
Step-pool, Plane-bed, Riffle-pool	Unconfined - high/moderate slope (>10 bfw) (4%-1% slope)	FHZ[16]	Active river corridor + Avulsion Hazards + Erosion Hazards + Alluvial Fans
Riffle-pool, Ripple-dune	Unconfined low slope (>10 bfw) (<0.1% slope)	Buffered Meander Belt-width	2-3 x's BFW buffer from meander centerline + Avulsion Hazards
Urban	All	Urban	Scour depth plus setback slopes ranging from 3:1 to 6:1

<u>Headwater Buffer Protocol</u>

Geomorphic Setting: Small, Steep, and Confined Streams, generally stable

These channels are generally small (drainage area < 2 mi^2), and confined. This protocol only applies to headwater channels in rural areas.

- Drainage Area Threshold: 2 mi^2
- FHZ Buffer: 50' either side top of bank
- Not an urban channel.

[16] In certain instances (highly modified floodplains for example) the meander belt-width approach may sufficiently capture fluvial hazards. This should be explored further during the initial field testing of this protocol.

Comprehensive Fluvial Hazard Zone Protocol
Geomorphic Setting: Confined channels greater than the drainage area threshold, partially confined channels (all slopes), unconfined channels (medium to high energy).
These are larger streams and rivers in which there is an active river corridor and in which the channel may interact with the valley wall and floodplain to produce erosion hazards. Avulsion hazards may also exist within the floodplain.

- Delineate the active river corridor based solely on geologic/geomorphic evidence mapping areas susceptible to lateral migration, widening, and down valley meander migration
- Delineate the entire extent of avulsion hazard zones where the river may inhabit new channels historic channels during floods or create new alignments via meander bend cut-offs, local avulsions, and regional avulsions based on historic evidence of former channel locations or low areas visible in aerial photography or a relative elevation model
- Delineate the entire extent of alluvial fans both coming into the main channel from tributary drainages as well as in areas where the main channel itself becomes a fan
- Erosion hazard area: Delineation for erodible hillslopes and terraces. A function of valley margin erodibility and likelihood of channel impinging on the valley margin. This width has not been specified herein.

Meander Belt-Width with Buffer plus Avulsion Hazards

- *Geomorphic Setting:* Low energy (low gradient), unconfined streams, such as those found on the plains.
- Delineation of the meander belt-width centerline and an applied buffer from this centerline is recommended. The meander belt-width centerline is defined as the line connecting the points of inflection of channel meanders (Figure 6, above). Avulsion hazard zones should also be mapped and added to this buffer. This approach avoids the difficult and often uncertain task of delineating the active river corridor for low-sloped, unconfined streams using geomorphic signatures.
- Delineate the meander belt-width based on a channel width multiplicative factor. Where the meander belt extends a certain distance beyond the toe of a valley wall (including bedrock outcrops or ledge that limit river movement), the corridor is truncated at the valley toe, and that truncated distance is used to extend the meander belt laterally on the opposite side, to provide a total belt width (as described in VT ANR 2015). This extension may, in some cases, be limited by the valley wall on the opposite side of the stream as well; in which case the meander belt extends from the toe of one valley wall to the toe of the other and will be narrower than the multiple of channel widths prescribed above.
- This approach may be necessary for meandering streams moving through urban areas. Additional analysis likely necessary in urban settings or highly modified settings where channel has been straightened, leveed, or banks armored (or some combination of these).

- Consideration of avulsion hazards especially where channel lies at a major reduction in stream power (i.e., from confined to unconfined and/or steep to mild slope). If the initial meander belt delineation extends beyond an engineered levee, railroad, or federal aid highway, the FHZ shall be measured from the embankment toe of that infrastructure and extended laterally on the opposite side a width equal to that which was not allowed due to the infrastructure (as described in VT ANR 2015). This shift of the FHZ (which does not occur for steeper channels delineated with the *Comprehensive Fluvial Hazard Zone Protocol)* acknowledges the alignment of the infrastructure has been structurally maintained over time in those locations and there is an assumption that the embankment has been designed with adequate scour, breach and overtopping protection (this may need to be verified in the field or with local authorities). In this scenario the FHZ is shifted to optimize attainment of equilibrium conditions and the reduction of flood velocities and erosion potential within the stream reach. Over time, this will reduce erosion hazard to both the road and downstream properties. Alternatively, if the corridor was not shifted and new development was placed opposite the roadway, the river would become confined between the roadway and the new structures and become even more hazardous. Where state and federal infrastructure abuts, the FHZ planners should examine erosion hazards and consider where alternatives, including the relocation of the infrastructure, might mitigate future hazards (VT ANR 2015).

Urban Streams

The urban stream protocol is generally applied in settings where the primary mechanisms for fluvial hazards are channel incision, bank/hillslope failure, and subsequent channel widening. If the channel lies within an urban growth boundary, then it is likely that this may be the case for a particular channel. Some rapid field assessment will be required to determine the potential for a channel to incise and widen if it has not already.

Hillslope stability as well as an estimate of the maximum potential depth of erosion will be the primary factor in determining the appropriate width of the FHZ in these streams. The potential for hillslope failure and an appropriate setback to accommodate this failure is a function of the potential for horizontal erosion during a flood event and the competence of the hillslope material. Angles of repose can be estimated for unconsolidated material based on a grain size analysis, whereas slope failure angles for cohesive bank material depend on more variables such as root density, pore water pressure, and internal soil shear strength (Simon and Collison 2002). Existence of bank revetment or armoring may influence hillslope integrity and should be evaluated as to whether or not it has been appropriately engineered and may support a steeper, stable hillslope.

The City of Austin, TX (2013) and Maricopa County, AZ (2013) utilize a similar methodology for urban streams. This method involves delineating stream bank toes, assessing the potential for incision, adding this additional incision depth to the channel bottom elevation if incisional processes are still active, and extending a slope failure angle out from the maximum estimated incision depth along the toe of each bank. These erosion hazard setback slopes range from 3:1

to 6:1 slopes depending on failure angles of bank material, existence of engineered bank and hillslope revetment, and desired level of safety factor. If extensive bank and hillslope engineering or impacts from development exist along an urbanized channel, it may be more appropriate to conduct a Level 2 FHZ analysis.

Level 1 Field Verification

All FHZ mapping efforts should include field verification with the following objectives:

- Verify reach breaks based on slope, adjacent land use, valley type, and channel morphology.
- Characterize terrace, hillslope, and stream bank material resistance to erosion.
- Identify any infrastructure, channel engineering, or other features that may impact the FHZ delineation that may not be discernible using remote sensing data.
- Field verify top of banks, slope toes and bank material in the urban protocol.

This rapid visual survey of existing geomorphic conditions can be conducted as a driving tour of the project streams. This may include short walks to channel access points where possible. Qualitative assessments of the geomorphic conditions for each reach should be recorded at representative locations within each reach.

4.3 Level 2 Methodology

The Level 1 approach is designed as a planning-level boundary that can be used for regulatory purposes. If Level 1 FHZ delineation is determined to be too coarse, the protocol insufficient to accurately delineate the FHZ, or where Level 1 boundaries are contested, a Level 2 approach to FHZ delineation is recommended to obtain detailed analysis and mapping. This more detailed approach to FHZ delineation will also identify other natural and human-induced factors that might either mitigate or exacerbate fluvial hazards.

The Level 2 approach is less prescriptive than the Level 1 approach at this time, as appropriate methodologies will vary greatly depending on the river style and development setting. The following is an outline of important processes to consider and basic approaches and methodologies that may be utilized under a Level 2 analysis.

<u>Full FHZ Protocol:</u> Components of the full FHZ protocol such as the active river corridor, the erosion hazard setback, and avulsion hazard zones can all be refined using additional field verification of geomorphic features as well as more detailed characterization of hillslope resistance to erosion and the potential influence of debris flows using maps produced by the Colorado Geologic Survey. Two-dimensional hydraulic modeling can aid in mapping where avulsion hazards might exist and represent a potential refinement of the mapping method used under Level 1 analysis (e.g., Swan and Aggett, 2011). Stream bed and bank characterization coupled with hydraulic modeling of flood flows can be used to determine bank and bed

resistance to scour. Where extended historic aerial maps are available, mapping channel migration rate and direction may also aid in delineating the FHZ (Lagasse et al. 2004).

Developed and other highly modified river corridors: In river corridors that have substantial development or where modification of the landscape for agriculture may have removed geomorphic indicators of the active river corridor, a Level 2 approach may be necessary. In these situations, field surveys of bank armoring, location and dimensions of artificial levees, modern geomorphic and topographic features, and hillslope stability are all surveyed through field based GPS data collection to evaluate the FHZ. In areas with river bank armoring, evaluation the competence of this armoring is necessary using field measurements and hydraulic modeling.

Meandering streams in low gradient, unconfined valleys: The Level 1 approach for these river types involves a rough characterization of the meander belt width centerline using aerial photography, applying a buffer to this centerline, and also identifying any potential avulsion hazard zones using available aerial photography and a relative elevation model. Level 2 analysis in these river types may require additional acquisition and geo-rectification of historic aerial photographs to delineate historic channel locations and migration rates; identification of high flow or relic channels not identified in the Level 1 analysis; and field verification of geomorphic features. Channel-width multipliers applied to the meander centerline (in order to obtain an estimated meander belt-width) may be better assigned for each reach depending on stream geomorphic classification and the likelihood of adjustment (based in part on the stage of channel evolution and the departure from reference condition) during a flood (see Vermont Phase 2 Field Assessment and mapping procedures). Also, the potential for bridge crossings and other in-channel and in-floodplain structures to mitigate or exacerbate fluvial hazards within the river corridor should be assessed.

Level 2 Alluvial Fans: Level 1 FHZ mapping on alluvial fans simply delineates the outer boundary of a fan and incorporates this into the FHZ in its entirety. Some alluvial fan delineations may be further refined to define active and inactive areas and potential flow paths on the fans. This method is applicable in any piedmont/foothill area with transitional topography and confinements; however, it not applicable to tributary alluvial fans. The greatest hazard concern on alluvial fans is associated with active fans that have developed since the last ice age, which reflect the current watershed sediment and hydrologic processes (French, 2012).

The primary means to characterize alluvial fan activity is to identify the distributary and tributary networks on the fan's surface, which define the bounds of an active (hazardous) fan. Tributary, as opposed to distributary, drainage networks are indications that the depositional processes in those areas has ceased (French, 2012). As one transitions off the fan, the FHZ approach should be implemented on each identified flow path from the fan edge to the next reach break downstream. Many references regarding alluvial fan hazards have been published. Users are referred to the work of French (c.f., French and Miller 2012).

5.0 Map Development, Maintenance and Interpretation

5.1 Recommended Expertise of Map Developers

The Colorado FHZ team recommends that a geologist, hydrologist, or engineer with experience in fluvial geomorphology approve the final Level 1 map. Due to the dependence of this protocol on landform, soils, and vegetation interpretation, the analyst's past experience in fluvial geomorphology is critical for the Level 1 method. The analyst should have extensive experience and proven expertise in applied fluvial geomorphology. In cases where geotechnical questions are encountered during Level 1 delineation, fluvial geomorphologists should consult with licensed geologists and engineers with expertise in slope stability.

5.2 Use of Historical Aerial Photography

Aerial photograph interpretation is very useful in understanding both the historic position of a river channel as well as its historic level of dynamism. Historic photographs and geomorphic evidence in the floodplains of many of the Front Range rivers indicates that they exhibited multi-thread planforms and may have been much more dynamic than they are today given flow regulation and water withdrawals. Nevertheless, these seemingly quiescent rivers returned to their historic dynamism in many areas during the 2013 floods. Incorporation of historic information of river behavior into river hazard planning may better inform land use decisions within river corridors.

For large-scale mapping of the FHZ, acquisition and ortho-rectification of historical aerial photography is cost and time prohibitive. We feel that the FHZ protocol outlined herein is conservative enough to capture the historic range of a river channel. We encourage the use of aerial photography at any level of analysis, but are recommending it only for Level 2 analysis.

5.3 Influence/Input of Local Knowledge on Map Development

Detailed analysis of historic channel location through aerial photography or field surveys is not included in the Level 1 methodology. Therefore the Level 1 analyst should consult with local government organizations for institutional and observational knowledge. The analyst should seek to understand the level of past channel change as well as the significant efforts that have been placed on attempting to keep the channel from moving. All local and institutional knowledge used to map the FHZ should be documented as part of the map development process.

5.4 Field evaluation/QA/QC

Preliminary remote-sensed delineations should be field-checked for accuracy. It is helpful to flag areas of question on these preliminary maps in order to focus field-check evaluations. Senior-level geomorphologists should review delineations in conjunction with metadatatracking sheets (see example Appendix B). Each QA/QC reviewer should evaluate the channel migration maps and data sheets individually and recommend any changes, if necessary. Then the mapping analysts and reviewers should meet as a group and discuss the draft maps and the recommendations changes.

5.5 Map Interpretation and Limitations

While we present the FHZ as a valuable planning tool with hopes of minimizing future flood damage, it is certainly not all-inclusive and should be utilized with other tools such as FEMA-derived inundation maps. The boundaries of the FHZ and FEMA floodplain generally will not coincide, and should be considered independent of one another, although taken collectively could be used to identify a river corridor (or "river freedom zone" as was identified to enhance river resilience by Biron et. al., (2014) in the province of Quebec, Canada).

The Level 1 FHZ boundary line is a conservative approximation of areas reasonably likely to be influenced by channel migration. While channel migration should be considered unlikely outside of the FHZ boundary, extreme events where channel migration occurs outside of FHZ boundaries are nonetheless possible due to major floods, dam failures, debris flows, landslides, earthquakes, etc. In addition to endangering life and property within these landscape disturbance areas, resulting debris, sediment, or fractures may alter the course of the stream, creek or river into areas not identified in the FHZ. Likewise, the possibility of diversion channels capturing the main stem of the river is not given full consideration in the FHZ mapping. Where a perceived threat to critical infrastructure or life is present, a detailed-level assessment should be undertaken to quantify fluvial hazard potential.

In addition to the aforementioned, the following is a list of self-acknowledged limitations of the FHZ mapping methodology proposed by the research team:

- The Level 1 FHZ method relies heavily on the expertise of the geomorphologists delineating the active river corridor.
- The Level 1 method does not analyze historical channel occupation or migration rates, and therefore does not allow for assignment of a FHZ design life (effective time period), associated probabilities for migration or erosion, or migration or erosion rates.
- The Level 1 method does not provide a detailed account of fluvial hazard in small streams (<2 mi^2).
- The approach for mapping the FHZ based on remotely-sensed geomorphic observations is not particularly well adapted to highly modified reaches or stabilized reaches (e.g. urban streams).
- The method is based on the premise that past trends in meander and avulsion activity will remain constant. This assumption does not account for flood frequency shifts that may occur due to climate change or a catastrophic event such as a dam break.
- The methodology is heavily dependent on the availability of high resolution LiDAR datasets which are currently being collected in many areas across Colorado in an effort led by the Water Conservation Board and Colorado Geologic Survey[17]. In absence of this data, the method is either likely to be less accurate or require an extended field

[17] http://coloradogeologicalsurvey.org/geologic-mapping/lidar/

assessment (Level 2) that may or may not be feasible given constraints due to budgets, timeframes, and property access.

5.6 Map Maintenance and Updates[18]

Few studies reviewed herein assign time periods to FHZ maps. A feasibility study commissioned by FEMA (1998) recommends that FHZ map boundaries have a lifespan of approximately 30 years due to limitations of data and predictive capabilities of existing river mechanic science. Others consider both this 30-year time frame for potential river movement as well as the changes that are likely to be associated with a 100-year flood event (e.g., Fuller and Associates, 2005).Until further data is gathered for Colorado, the authors recommend that full map revision occur:

- every 30 years, or
- following a flood with significant fluvial erosion damage, or
- as-needed in stream systems that are adjusting at rates much greater than anticipated when the map was originally developed, or
- when significant land use or watershed changes (e.g. wildfires) occur.

Ongoing map "updates" may be handled at the municipal level on an as-needed basis with state approval. Updates are recommended to fall into the categories of "minor updates" and "major updates." "Major updates" involve a remapping of the river using the Level 1 methodology or collection of field data and analysis (Level 2) to re-evaluate boundaries and special hazard areas. We suggest major updates be considered when significant hydrology/sediment alterations occur (e.g., dam construction, urbanization, wildfire, and landslides) and/or landowner originated investigations are submitted on a case by case basis. "Minor updates" include the correction of mapping errors and adjustments due to new information (e.g., unmapped bedrock outcrop) unavailable when the first Level 1 analysis was developed. Documentation of each map update/edit should be retained as part of the public record and included in the CWCB's FHZ database.

6.0 Map Use for Flood Hazard Planning

Fluvial erosion is a powerful force that does not lend itself well to simple best-management practices. Past efforts to channelize, berm, and armor streams have proven inadequate considering that these solutions often fail leading to extensive damage and costly repairs not to mention the negative impacts to the ecological health of our riparian areas and fisheries. Recent river restoration projects that attempt to control river processes by slowing bank erosion and limiting channel migration have gained popularity but the high cost of designing and installing these restoration projects limits their usefulness as a general approach to flood hazard

[18] We offer a broad recommendation for map updates. Additional technical guidance on map maintenance and updates which may serve as a resource/template for Colorado can be found at: http://www.watershedmanagement.vt.gov/rivers/docs/FHARCP_12.5.14.pdf

mitigation particularly since these projects may be prone to failure during high flow events (Nagle 2007). Another approach, removal or relocation of flood damaged infrastructure, is effective but may be too expensive to be applied at a broad scale. Ultimately the most cost-effective tool we have to mitigate flood hazards from inundation and fluvial erosion is avoidance. By limiting human investments in our active river corridors and floodplains we prevent future floods from damaging infrastructure while limiting constraints on the streams themselves allowing them to adjust and stabilize based on their natural (and possibly shifting) hydrology and sediment balance.

The FHZ maps are presented to support efforts to work with local governments and state agencies to develop programs and codes that limit investment and avoid development within the mapped FHZ hazard areas. Erosion hazards and channel avulsions present extreme risks during high flow events in all watersheds in Colorado, and having a robust data set that assesses multiple hazards is critical to long term planning and community resilience.

7.0 Additional Study Needs

The following list of recommended studies has been compiled during development of this report. The project topics were identified by the authors as seeming "gaps" in research related to FHZ development and map management. Resulting information from further study could lead to improvements in the methodology, accuracy, and effectiveness of FHZ mapping. The list is offered in no particular order.

- *Develop regionally specific guidance and protocol for setting erosion hazard setback widths.*
  This question represents a large knowledge gap in the proposed protocol. Identifying appropriate widths within the hillslope and valley margins vulnerable to erosion and mass wasting represents one of the more subjective aspects of the Washington pCMZ protocol, used as a template for the comprehensive FHZ protocol introduced herein. Look to the Colorado Geologic Survey for assistance with this task. Erosion hazard setback width should be linked to geomorphic (reach and valley) classification.

- *Maximum historic river corridor extent or long-term migration rates* Where we have recommended a meander belt-width buffer approach on our low-gradient, unconfined valleys the lack of data about true avulsion potential may result in less conservative FHZ's under Level 1 than results from the full FHZ protocol implemented on medium to steep-sloped channels. Additional research into the potential for these low-gradient channels to avulse or to migrate outside of the mapped buffer area ahead of the recommended map revision would be useful to accurately identify the full FHZ. FHZ maps created using this buffering protocol have been found to be under-conservative along some streams in Indiana (personal communication Barr, 2015). It would also be useful to determine what an appropriate region-specific buffers for meander belt-width delineations should be for Colorado's diverse streams as well as identify what range of slopes are most appropriate to designate the transition from "medium energy" to "low energy" rivers, and hence, the transition from full FHZ to meander belt-width delineation methods.

- *Drainage area threshold and headwaters setback*
  Further investigations into the drainage area threshold would help to: determine when "significant geomorphic change" begins and when a simple setback protocol should be replaced by a full FHZ active river corridor delineation; determine if this drainage area threshold can be applied statewide or if certain regions/geologies have different thresholds; and determine if the setback provided (50' from top of existing bank) for streams falling under the drainage area threshold is appropriate or if it should be regionally modified.

- *Develop a tool for automating stream and valley classification*
  Develop tools for classifying valley slope and channel confinement and the active river corridor. Also, determine what breaks in slope define higher-medium- and low energy

and whether this should vary among geographic regions. Partnering with the USFS on fully developing the HGVC tool may be a good avenue given its history.

- *Develop regional hydraulic relationship equations to aid in determining reference channel dimensions*
  Reference bankfull widths are used to determine valley confinement. Determination of these bankfull widths in Colorado relies on a variety of unconsolidated data sources. A statewide effort to establish hydraulic relationship equations would assist the component of the FHZ that asks mappers to determine their valley confinement (based on a reference bankfull width).

- *Identify what constitutes "urban" for decision tree*
  Quantify what level of urbanization in a reach defines "urban". Likely we are not going to use total watershed percent for this trigger.

- *Quantitatively link valley type with stream power to develop a predictive model for river response to floods.*
  This is an on-going study being conducted as a cooperative project between Colorado State University and the U.S. Forest Service National Stream and Aquatic Ecology Center.

- *Bridge and culvert flagging protocol*
  Because stream crossings create significant channel instability, identifying undersized structures (and perhaps what modifiers, i.e., size, shape, slope, channel type, cause greater fluvial damage) may help to identify higher risk within the FHZ.

- *Map editing protocol*
  Develop a standardized method for tracking edits to FHZ maps so that the information is available publically.

- *Develop state-wide digital library of historic aerial photographs of river corridors*
  Such a digital library would aid in FHZ development and perhaps allow historical aerial photographs to be used in the Level 1 analysis.

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9.0 Definitions:

Adapted from:
Glossary of Stream Restoration Terms
by Craig Fischenich.. February 2000
USAE Research and Development Center,
Environmental Laboratory, 3909 Halls Ferry
Rd., Vicksburg, MS 39180

TERMS
Active River Corridor: is land adjacent to the river that is alluvially-formed or prone to erosion by fluvial processes.
Adjustment process --a type of change, that is underway due to natural causes or human activity that has, or will, result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes)
Aggradation -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed.
Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.
Alluvial -- Deposited by running water.
Alluvium -- A general term for detrital deposits make by streams on riverbeds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas or lakes.
Aquatic ecosystem -- Any body of water, such as a stream, lake, or estuary, and all organisms and nonliving components within it, functioning as a natural system.
Armoring -- A natural process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth.
Avulsion -- A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.
Bank stability -- The ability of a streambank to counteract erosion or gravity forces.
Bankfull channel depth -- The maximum depth of a channel within a riffle segment when flowing at a bank-full discharge.
Bankfull channel width -- The top surface width of a stream channel when flowing at a bank-full discharge.
Bankfull discharge -- The stream discharge corresponding to the water stage that first overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years.
Bankfull width -- The width of a river or stream channel between the highest banks on either side of a stream.
Bar -- An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.
Bed load -- Sediment moving on or near the streambed and transported by jumping, rolling, or sliding on the bed layer of a stream. See also suspended load.
Bed material -- The sediment mixture that a streambed is composed of.
Bed slope -- The inclination of the channel bottom, measured as the elevation drop per unit length of channel.
Berms -- mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.
Boulder -- A large substrate particle that is larger than cobble, 256 mm in diameter.
Braided channel -- A stream characterized by flow within several channels, which successively meet and divide. Braiding often occurs when sediment loading is too large to be carried by a single channel.
Buffer strip -- A barrier of permanent vegetation, either forest or other vegetation, between waterways and land uses such as agriculture or urban development, designed to intercept and filter out pollution before it reaches the surface water resource.
Channel -- An area that contains continuously or periodically flowing water that is confined by banks and a streambed.
Channelization -- The process of changing (usually straightening) the natural path of a waterway.
Clay -- Substrate particles that are smaller than silt and generally less than 0.003 mm in diameter.
Cobble -- Substrate particles that are smaller than boulders and larger than gravels, and are generally 64-256 mm in diameter. Can be further classified as small and large cobble.
Confluence -- (1) The act of flowing together; the meeting or junction of two or more streams; also, the place where these streams meet. (2) The stream or body of water formed by the junction of two or more streams; a combined flood.
Culvert -- A buried pipe that allows flows to pass under a road.
Degradation -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.
Ditch -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.
Drainage area -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.
Ecology -- The study of the interrelationships of living organisms to one another and to their surroundings.

Ecosystem -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.
Embankment -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.
Embeddedness -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is **not** embedded has loose rocks that are easily removed from the stream bottom, and may even “roll” on one another when you walk on them.
Entrenchment ratio --The width of the floodprone area divided by the bankfull width.
Erosion -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.
Floodplain -- Land built of sediment that is regularly covered with water as a result of the flooding of a nearby stream.
Floodplain Function – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).
Flow -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).
Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to rivers or streams, specifically river processes of flow and sediment movement.
Ford -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.
Geographic information system (GIS) – A computer system capable of storing and manipulating spatial data.
Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.
Gradient -- Vertical drop per unit of horizontal distance.
Gravel -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.
Habitat -- The local environment in which organisms normally live and grow.
Headwater -- Referring to the source of a stream or river.
Hydrology -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.
Incised river -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.
Incision ratio -- The low bank height divided by the bankfull maximum depth.
Islands – mid-channel bars that are above the average water level and have established woody vegetation.
Large woody debris (LWD) -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull channel.
Mainstem -- The principal channel of a drainage system into which other smaller streams or rivers flow.
Meander -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.
Mid-channel Bars – bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars are caused by recent channel instability and are unvegetated.
Outfall -- The mouth or outlet of a river, stream, lake, drain or sewer.
Point bar -- The convex side of a meander bend that is built up due to sediment deposition.
Pool -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.
Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 Assessment.
Restoration -- The return of an ecosystem to a close approximation of its condition prior to disturbance.
Riffle -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.
Riffle/step frequency -- ratio of the distance between riffles to the stream width.
Riparian area -- An area of land and vegetation adjacent to a stream (or any other freshwater aquatic ecosystem) that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains.
Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses.
Riparian habitat -- The aquatic and terrestrial habitat adjacent to streams, lakes, and other freshwater aquatic ecosystems.
Riparian -- Located on the banks of a stream or other body of freshwater.
Riprap -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.
River channels -- Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.

River reach -- Any defined length of a river.
Runoff -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.
Scour -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.
Sediment -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.
Sedimentation -- (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.
Segment: A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.
Sensitivity --of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.
Silt -- Substrate particles smaller than sand and larger than clay (3 to 60 mm).
Sinuosity -- The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.
Slope -- The ratio of the change in elevation over distance.
Stable channel -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.
Straightening -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.
Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.
Stream channel -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.
Stream condition -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.
Stream morphology -- The form and structure of streams.
Stream reach -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.
Stream type -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.
Streambank armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.
Streambank erosion -- The removal of soil from streambanks by flowing water.
Streambank stabilization -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.
Streambed -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.
Substrate -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.
Suspended sediment -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.
Tributary -- A stream that flows into another stream, river, or lake.
Urban runoff -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.
Valley Confinement: The degree to which the valley walls confine a channel, often expressed as the ratio of the valley floor width to the bankfull channel width.
Water quality -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Watershed -- An area of land whose total surface drainage flows to a single point in a stream.
Watershed management -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.
Watershed restoration -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.

Appendix A - Federal, State, County and Municipal Erosion Hazard Regulations, Ordinances, and Guidelines.

STATE and LOCAL PROGRAMS	DESCRIPTION	Voluntary (V) or Mandatory (M)	ADDITIONAL INFO
FEDERAL			
FEMA	Riverine Erosion Hazard Areas Mapping Feasibility Study https://www.fema.gov/media-library/assets/documents/7235	V	*This Riverine Erosion Hazard Area (REHA) mapping feasibility study was prepared by the Federal Emergency Management Agency (FEMA) to address requirements in the National Flood Insurance Reform Act (NFIRA) enacted in September 1994. Section 577 of NFIRA required that FEMA submit a report to Congress that evaluated the technological feasibility of mapping REHAs and assessed the economic impact of erosion and erosion mapping on the National Flood Insurance Program (NFIP). The purpose of this study was to determine whether it was technologically feasible to map REHAs.*
NRCS	National Engineering Handbook Part 654, TS14S - Sizing Stream Setbacks to Help Maintain Stream Stability - This technical supplement also presents an empirically based equation that calculates the streamway width required to allow a stream to self-adjust its meander pattern. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17829.wba	V	*Several guidelines are outlined in this technical supplement. This technical supplement also presents an empirically based equation that calculates the streamway width required to allow a stream to self-adjust its meander pattern.Overprediction is not a major concern since the method does not attempt to account for meander migration or riparian zone protection. However, without modification, the equation fails the setback requirements at least half the time, so the calculated belt widths have been evaluated in increasing increments of 10 percent. A 10 percent increase reduced the number of sites where the belt width was underpredicted from 24 to 17, while a 20 percent increase reduced the number of sites where the belt width was underpredicted from 24 to 12. Additional increases up to 50 percent only reduced the number of underpredicted sites from 24 to 8. However, an increase of this magnitude resulted in a mean overprediction of 74 percent in the belt width size at the 39 sites where the equation overpredicted the belt width. Based on this analysis, the following equation is obtained that increases the estimated beltway obtained from equation TS14S–4 by 20 percent: Streamway = 120* $DA^{0.43}$ *(only applies to the eastern United States.)*
ALASKA			
Anchorage	Stream Protection Setbacks (not related to erosion) - AMC 21.45.210 Stream Protection Setback regulates activities within 25 feet of any stream or watercourse in the Municipality. http://anchorage-ak.elaws.us/code/cid12717/21.45.210/ AMC 21.40.115.F.3 R-10 Residential Alpine/Slope District prohibits "construction or excavation within 100 feet of the mean high-water line of any stream, lake or other permanent body of water" in the R-10 district only.	M	*A. Required. There shall be a stream protection setback conforming to this section along all of the streams and their tributaries located within the municipality, including but not limited to those streams designated on the maps and list accompanying this section.* *B. Width. A stream protection setback shall be a minimum of 25 feet wide on either side of the stream, measured landward from the edge of the bed of the stream, identified by the ordinary high-water mark, provided that all stream protection setbacks along streams less than five feet wide at ordinary high water shall be 25 feet wide, on either side of the thread of the stream.*
Matanuska-Susitna Bourough	Current Code - Chapter 17.55: Setbacks and Screening Easements, 17.55.020 Setbacks for Shorelands http://www.codepublishing.com/AK/matanuskasusitnaborough/html/MatanuskaSusitnaBorough17/MatanuskaSusitnaBorough1755.html	M	*Proposed River Erosion Hazard Ordinance - The ordinance will establish criteria and a process for identifying areas with different degrees of erosion risk. The ordinance will establish a numeric rating system, to reflect values assigned to each of these criteria. A final score, based on these ratings, will determine the Erosion Hazard Area assigned.* *"Shorelands" means that upland within 300 feet of any lake, pond, or watercourse, and within 300 feet from any river or stream, or to the landward side of the floodplain, if that distance is greater.* *17.55.020 SETBACKS FOR SHORELANDS.* *(A) Except as provided in subsection (B) of this section, no structure or footing shall be located closer than 75 feet from the high water mark of a watercourse or body of water. Except as provided otherwise, eaves may project three feet into the required setback area.* *(B) Docks, piers, marinas, aircraft hangars, and boathouses may be located closer than 75 feet and over the water, provided they are not used for habitation and do not contain sanitary or petroleum fuel storage facilities. Structures permitted over water under this subsection shall conform to all applicable state and federal statutes and regulations.* *(C) In the city of Wasilla, this section does not apply to structures where construction was completed prior to November 16, 1982. Elsewhere in the borough, this section does not apply to structures where construction was completed prior to January 1, 1987, if the present owner or owners of the property had no personal knowledge of any violation of the requirements of this section prior to substantial completion of the structures. The director of the planning department shall, upon application by a property owner, determine whether a property qualifies for an exception under this subsection.*
ARIZONA	State Standard for Watercourse System Sediment Imbalance (SS 5-96) http://www.azwater.gov/azdwr/SurfaceWater/FloodManagement/documents/SS5-96SystemSedimentBalance.pdf	V	*Level I analysis based on drainage area and discharge. Level II analysis based on Allowable Velocity, Tractive Stress, and Tractive Power analyses.Level III analysis based on hydraulic and sediment transport modeling.*
Flood Control District of Maricopa County (FCDMC)	FCDMC Draft Lateral Erosion Hazard Zone for Natural Channels in Maricopa County, Arizona	M	*The methodology is developed by adapting the City of Austin's "Guidance on Establishing an Erosion Hazard Zone for Structure and Utility Locations near Stream" (City of Austin, September, 2007). The procedure is presented for several scenarios which are (1) straight channel reach when no historical aerial photos are available; (2) straight channel reach when enough historical aerial photos are available; (3) the study area is located between two upstream and downstream bends; and (4) the study area is located on a straight reach but upstream or downstream of a bend.*
Tucson	City of Tucson Standard Manual For Drainage Design and Floodplain Management In Tucson, Arizona - Chapter VII: Erosion-Hazard/Building Set-Back Criteria https://www.tucsonaz.gov/files/transportation/PlansAndDrawings/COT_DRAINAGE_MANUAL.EXE	M	*Analysis based on Allowable Velocity, Tractive Stress, Tractive Power and bank stability analyses.*
Pima County	Title 16 of the Pima County Code also known as the Floodplain and Erosion Hazard Management Ordinance No. 2005-FC2 at Chapter 16.28 http://rfcd.pima.gov/fpm/permits/pdfs/erosion_analysis122206.pdf	M	*Title 16 of the Pima County Code also known as the Floodplain and Erosion Hazard Management Ordinance No. 2005-FC2 at Chapter 16.28. Requires minimum building setbacks in erosion hazard areas where watercourses are subject to flow related erosion hazard. Erosion hazard reductions along a watercourse of 10,000 cfs or greater, must utilize calculations from erosion hazard setback methodologies appropriate for use within Pima County such as the Erosion/Setback Criteria within the City of Tucson Department of Transportation "Standards manual for Drainage Design and Floodplain Management in Tucson, Arizona" or an alternate methodology approved for use by the Pima County Flood Control District. The analysis should also provide information on the channel stability citing accepted sources such as the U.S. Geological Society, the Soil Conservation Service or thesis work at the University of Arizona on the potential for aggradation or degradation within the channel. An alternate method of proving channel stability is to provide this office with a sediment transport analysis. This additional information is required to provide a level of evaluation commensurate with the magnitude of the hazard.*
Pinal County	Pinal County Area Drainage Master Plan Rules of Development - Sect. 2.3 Riverine Erosion http://www.pinalcountyaz.gov/PublicWorks/Documents/Manuals/Pinal%20County%20ADMP%20Rules%20of%20Development.pdf	M	*Policy EHZ-1: Erosion Hazard Zone Delineation Required. All new development adjacent to watercourses with a 100-year discharge greater than 200 cfs must determine an erosion hazard setback. For individual single lot residential development applications, 100-year discharge rates for many watercourses may be obtained from the ADMP GIS. All habitable structures must be located outside the erosion hazard zone setback or provide for engineered bank protection measures.* *Erosion hazard setbacks will be determined using the following methodologies:* *• Drainage Area < 30 square miles:* *o ADWR State Standard 5-96 methodologies.* *o City of Tucson Erosion Hazard Setback Equations* *• Drainage Area > 30 square miles.* *o ADWR State Standard 5-96 Level III methodology.* *The following notes apply to erosion hazard zone determinations in Pinal County:* *• Minimum Erosion Hazard Setback. In no case shall the erosion hazard setback be less than 15 feet without the approval of the County Engineer.* *• Level 1 Setback. Caution should be used in interpreting and applying the results of a Level I evaluation. Watercourses characterized with wide geologic floodplains, multiple or braided channels, highly erosive banks, poorly vegetated banks, and potential for channel avulsion should be evaluated at Level III.* *• Setback Reduction. A Level 1 erosion hazard setback may be reduced if a Level III analysis demonstrates that a lesser setback is warranted. Any erosion hazard setback may be reduced if engineered erosion protection is constructed. Erosion protection must meet the no adverse impact standard.* *• Level III Analysis. An example scope of services for a Level III erosion hazard analysis is provided in Appendix 5.3.* *• Bank Location. In general, erosion hazard setbacks are to be measured from the top of the main channel bank. Guidelines for identifying the top of bank location are provided in Appendix 5.4.* *• Avulsion Hazards. Potential avulsion hazard areas can be difficult to identify. Some guidelines for identifying avulsion hazard zones are provided in Appendix 5.5.*

STATE and LOCAL PROGRAMS	DESCRIPTION	Voluntary (V) or Mandatory (M)	ADDITIONAL INFO
Santa Cruz County	Ord. No. 2015-XX, Sect. 5.10 (Same method as FCDMC Level 1 EHZ Delineation Analysis) http://www.santacruzcountyaz.gov/DocumentCenter/Home/View/4973	M	*5.10 FLOOD RELATED EROSION-PRONE (EROSION HAZARAD) AREAS AND BUILDING SETBACKS. A. The Floodplain Administrator shall require permits for proposed construction and other development within all flood-related erosion-prone areas as known to the community. B. Permit applications shall be reviewed to determine whether the proposed site alterations and improvements will be reasonably safe from flood-related erosion and will not cause flood-related erosion hazards or otherwise aggravate the existing hazard. C. If a proposed development is found to be in the path of flood-related erosion or would increase the erosion hazard, such improvements shall be relocated or adequate protective measures shall be taken to avoid aggravating the existing erosion hazard. D. Within Zone E on the Flood Insurance Rate Map, a setback is required for all new development from the lake, bay, riverfront or other body of water to create a safety buffer consisting of a natural vegetative or contour strip. This buffer shall be designated according to the flood-related erosion hazard and erosion rate, in relation to the anticipated useful life of structures, and depending upon the geologic, hydrologic, topographic, and climatic characteristics of the land. The buffer may be used for suitable open space purposes, such as for agricultural, forestry, outdoor recreation and wildlife habitat areas, and for other activities using temporary and portable structures only. E. All buildings are required to be set back a minimum distance from the top of bank of any watercourse, where approved bank protection is not provided, as follows: 1. The building setback along any straight channel reaches, or reaches with minor curvature, is to equal the square root of the peak flow of the base flood (setback = (Q100)0.5). 2. The building setback along any channel reach with obvious curvature or channel bend, or areas where the embankment is highly susceptible to erosion, is to equal the two and a half times the square root of the peak flow of the base flood (setback = 2.5(Q100)0.5). 3. The building setback for the Santa Cruz River shall be five hundred (500) feet.*
Mohave County	Drainage Design Manual, Section 8.2.2.3 Erosion Setback http://resources.mohavecounty.us/DrainageDesign/DDM/DDM%20for%20Mohave%20County.pdf Mohave County Flood Control Ordinance - 2014, Article 8 Flood Related Erosion Prone Area http://resources.mohavecounty.us/file/Public%20Works/Engineering/PDF/Development/FC%20Ordinance%202014%20RecordedLinked.pdf	M	*Drainage Design Manual, Section 8.2.2.3 Erosion Setback - In locations where the 100-year discharge in a wash exceeds 500 cfs and is contained within the existing channel banks, erosion setbacks consistent with ADWR State Standard 5-96 (ADWR, 1996b) shall be required for all properties developed where watercourses are to be left in an undisturbed state. Mohave County Flood Control Ordinance - 2014, Article 8 Flood Related Erosion Prone Area (see page 40) - primarily just general guidance with no specific setback distance provided.*
CALIFORNIA			
Sonoma County	Riparian Corridors Zoning Code - Area and Specific Plan Stream Setbacks (Attachment E) The Sonoma County General Plan 2020 called for designation of areas along both sides of riparian corridors, referred to "Streamside Conservation Areas" to protect and enhance riparian corridors and functions along streams. The General Plan specifies which streams require a Streamside Conservation Areas, also called a "stream setback," and identified the width of the setback and allowable uses in the setback. Establishes streamside conservation areas along both sides of designated Riparian Corridors based on a set distance measured from the top of the higher bank on each side of the stream as determined by Permit & Resource Management Department. http://www.sonoma-county.org/prmd/gp2020/osrce.pdf County of Sonoma Zoning Code Update Riparian Corridor Combining Zone http://www.sonoma-county.org/prmd/docs/riparian_corridor/fact_sheet.pdf	M	*The zoning for stream setbacks are being revised to be consistent with policies adopted in the recently updated General Plan and grading and building codes and to make the setbacks easier for the public to find. The County has established stream setbacks to protect water quality, reduce erosion, and protect riparian habitat. The 1989 General Plan identified stream setbacks on 58 important salmonid streams. The County's General Plan in 2008 expanded stream setback policies to apply to all streams shown on U.S. Geological Survey topographic maps (USGS maps). These setbacks have been incorporated into the building and grading ordinances. However, when landowners and the public wants to know what the setbacks are they must contact PRMD or the Agricultural Commissioner for a determination because the setbacks have not been included in zoning. This proposal will consolidate all setbacks into the zoning to make it easier to determine what the setback distance is for each stream, and to easily map stream setbacks on individual parcels. These changes will also make permitting more efficient. Proposed zoning changes: - Riparian Corridor (RC) Combining Zone will replace the current Biotic Resource (BR) Combining Zone. - The RC Combining Zone will be added to all streams where setbacks currently apply as designated by the General Plan and Area/Specific Plans. - The RC Combining Zone will include the applicable stream setback distance for development and agricultural cultivation as shown below. <u>Riparian Corridor Category</u> <u>RC Zoning Setbacks Development/Agriculture</u> Riparian Corridor, 200-ft RC-200/100 Riparian Corridor, 100-ft RC-100/50 Riparian Corridor, 50-ft RC-50/25 UplandAreas RC-50/50 UrbanAreas RC-50/25 Upland Riparian Corridor, 50-ft RC-50/50* Area Plan RC-200/50 or RC-200/25 and RC-100/50 or RC-100/25*
California Water Resources Control Board Division of Water Quality Nonpoint Source Pollution Control Program Stream Setback Ordinance Survey	Stream Setback Ordinance Survey conducted by Molly Munz at California Water Resources Control Board - sent to County Public Works Directors and Directors of City Planning Departments: got 27 responses. http://www.swrcb.ca.gov/water_issues/programs/stormwater/docs/hydromodification/meetings/021110/survey_streamsetback.pdf	V	*The majority (66.7%) respondents have a stream setback ordinance or similar type of regulation or standard that limits development within a certain distance from a stream. Most (75%) respondents that did not have any ordinance or standard to limit development adjacent to streams were not considering developing one; about 25% were considering developing one. The stream setback ordinance were multi-objective, the majority (75-88%) were designed to protect or enhance water quality, and for wildlife and aquatic-life habitat protection. About13% of the stream setbacks were required as part of the 100-year flood protection administered by the Federal Emergency Management Agency (FEMA). Stream setbacks for other flood protection purposes were more than double (31%) that of the FEMA designated stream setbacks. Approximately 56% of the stream setback ordinances apply to all streams and at least 37% apply to only some streams. Most of total widths for the stream setback were based on fixed distances which were dependent on site-specific conditions. The minimum distances were usually between 20 to 30 feet and were measured from mid-stream, mean high water line, top of stream bank or channel, or from riparian vegetation. Most of the maximum widths were around 100 feet. In a few cases a maximum of 150-200 feet was cited, these conditions seemed the most complicated with conditions based on land-use, slope, soil type, type of stream, and vegetation type.*
COLORADO			
Denver Urban Drainage and Flood Control District (UDFCD)	Urban Storm Drainage Criteria Manual http://udfcd.org/downloads/down_critmanual_home.htm	NA	*No guidance.*
Ft. Collins	Fort Collins Municipal Code and Charter - Chapter 10, Division 7 - Erosion Buffer Zones, Sec. 10-201 http://www.colocode.com/ftcollins/municipal/chapter10.htm#artIIdiv7	M	*Sec. 10-201. Designation of erosion buffer zones. In accordance with § 10-19, the erosion buffer zones designated by the Utilities Executive Director for the Fossil Creek basin, Boxelder Creek basin, the Mail Creek basin and McClellands Creek basin, as described therein, shall be considered erosion buffer zones and shall be subject to the requirements of this Division, and all other requirements of this Article applicable to erosion buffer zones. Property within an erosion buffer zone that has also been determined to be a floodway or flood fringe and designated as such in accordance with § 10-19, shall be subject to the requirements and restrictions of this Article applicable to said property by virtue of said separate designation in addition to the requirements and restrictions set forth in this Division. (Ord. No. 37, 2005, 3-15-05; Ord. No. 015, 2007 § 24, 2-20-07; Ord. No. 080, 2011, § 1, 9-6-11) Sec. 10-202. Specific standards for erosion buffer zones. In addition to complying with all other applicable provisions of this Article, all development in an erosion buffer zone shall comply with the following applicable provisions. If there is any conflict between any of the following provisions and any other provision of this Article, the more restrictive provision shall control. (1) Development of structures. a. New construction. Construction of any new structure in an erosion buffer zone, including any accessory structure, is prohibited. b. Addition. Addition to a structure, if the addition is in an erosion buffer zone, is prohibited. c. Remodeling and repair. Remodeling and repair of a structure in an erosion buffer zone is allowed. d. Redevelopment. Redevelopment of any structure in an erosion buffer zone is allowed.*

STATE and LOCAL PROGRAMS	DESCRIPTION	Voluntary (V) or Mandatory (M)	ADDITIONAL INFO
Estes Park	Estes Valley Development Code , Chapter 7 General Development Standards, Section 7.6 Wetlands and Stream Corridor Protection http://www.colocode.com/estesvalleypdf.html	M	*E. Buffer/Setback Areas. 1. Stream or River Corridors. a. Building/Structure Setbacks. (1) Stream Corridors (except in the CD zoning district). All buildings and accessory structures shall be set back at least thirty (30) feet horizontally (plan view) from the annual high-water mark of stream corridors, or if not readily discernible, from the defined bank of the stream. Where defined banks are not readily discernible, the setback shall be measured from the thread of the stream. See Figure 7-10. (Ord. 2-02 #5) (2) River Corridors (except in the CD district). (a) General Rule. All buildings and accessory structures shall be set back at least fifty (50) feet horizontally (plan view) from the annual high-water mark of river corridors or, if not readily discernible, from the defined bank of the river. (b) Exception for Lots Developed Prior to the Adoption of this Code. All buildings and accessory structures shall be set back at least thirty (30) feet horizontally (plan view) from the annual high-water mark of river corridors or, if not readily discernible, from the defined bank of the river. See Figure 7-10. (Ord. 2-02 #5) (3) Stream and River Corridors in the CD Zoning District. In the CD district, all buildings and accessory structures shall be set back at least twenty (20) feet horizontally (plan view) from the annual high-water mark of stream or river corridors or, if not readily discernible, from the defined bank of the stream or river. Where defined banks are not readily discernible, the setback shall be measured from the thread of the stream. Where a principal building in the CD district provides public access, including a primary entrance, on the side of the building facing a stream or river corridor, the setback may be reduced to ten (10) feet with the approval of the Decision-Making Body. (Ord. 2-02 #5) b. Parking Lot Setbacks. Except in the CD zoning district, parking lots shall be set back at least fifty (50) feet horizontally (plan view) from the annual high-water mark of stream or river corridors, or if not readily discernible, from the defined bank of the stream or river. In the CD district, parking lots shall be set back at least twelve (12) feet from the delineated edge of the river or stream corridor.*
Larimer County	http://www.larimer.org/planning/planning/Setback/setback_types.htm	M	*A minimum required setback of 100 feet applies to any stream, creek or river identified on a U.S.G.S. (United States Geological Survey) 7.5' quadrangle map. The setback is measured from the centerline of the water course to the closest point of the building.*
El Paso County	Prudent Line Addendum For Unincorporated El Paso County Only - A setback or erosion risk boundary. http://adm2.elpasoco.com/Transprt/New_engineering_criteria_manual/21.pdf El Paso County Land Development Code, Chapter 8, Section 8.4.5. Drainage Considerations and Standards, (E) Protection of Hazardous Areas Associated with Drainage Facilities, (2) Prudent Line Setback http://adm.elpasoco.com/Development%20Services/Documents/Land%20Development%20Code/(21)%20(FINAL)%20LDCChapter8%20Rev2a.pdf	M	*El Paso County Land Development Code, Chapter 8, Section 8.4.5. Drainage Considerations and Standards, (E) Protection of Hazardous Areas Associated with Drainage Facilities, (2) Prudent Line Setback states that: "where applicable, the Prudent Line Setback, which is a buffer zone on either side of the channel where development is prohibited and the channel is allowed to move lateral, shall be shown as a no build area and shall have a maintenance easement to grant El Paso County maintenance access." The definition of a prudent line must recognize both the short-term impacts of flooding and erosion and the cumulative impacts of erosion over the long term. The physical processes involved with channel migration and the analysis of those processes are inherently complex. The procedure outlined in this addendum is a gross simplification of this process in an attempt to establish a procedure that is easily applied, yet provides reasonable definition of a "prudent line." The procedure was developed specifically for application to rural basins in El Paso County, Colorado, where the land use density is low and the application of the prudent line concept is justified given both engineering and economic considerations. The criteria for defining the prudent line is then defined as the enveloping curve considering the 100-year floodplain boundary, the erosion during a 100-year event, or the long term erosion over a 30-year period.*
GEORGIA	Riparian Buffers and Stream Setbacks https://gaenvlaw.wordpress.com/documents/riparian-buffers-and-stream-setbacks/	M	*There are several laws in Georgia mandating stream riparian buffer protection as outlined in the Official Code of Georgia Annotated (O.C.G.A.), including: the Georgia Erosion and Sedimentation Act, the Georgia Planning Act Minimum Standards, and the Metropolitan River Protection Act. All affected local governments must comply (minimally) with these regulations within local plans and ordinances. <u>Georgia Erosion and Sedimentation Act</u> Requirements: The Georgia Erosion and Sedimentation Act of 1975 (O.C.G.A. 12-7) and its subsequent amendments require that primary and secondary trout streams maintain an undisturbed riparian buffer of 50 ft, and all other streams maintain a minimum buffer of 25 ft (measured from where vegetation is wrested by normal stream flow). <u>Georgia Planning Act Minimum Standards</u> Requirements: The Georgia Planning Act Minimum Standards of 1983 (O.C.G.A. 12-2-8) provide local governments with criteria designed to protect specific waterways. Pursuant to the criteria for river corridor protection, all rivers with average annual flow (as defined by the U.S. Geological Survey) greater than 400 cfs must have a 100 ft as measured from the riverbanks and mean high water.*
Cherokee County	Ordinance No. 2005-Z-003 Stream Buffer Protection Ordinance http://www.cherokeega.com/Stormwater-Management/documents/Stream_Buffer_Ordinance.pdf	M	*An undisturbed natural vegetative buffer shall be maintained for 50 feet, measured horizontally, on both banks (as applicable) of all streams as measured from the top of the stream bank. The first 25 feet of this vegetative buffer is established as a State Waters Buffer by the Georgia Department of Natural Resources, Environmental Protection Division. An additional setback shall be maintained for 25 feet, measured horizontally, beyond the undisturbed natural vegetative buffer, in which all impervious cover shall be prohibited. Grading, filling and earthmoving shall be minimized within the setback. A one hundred and fifty (150) foot undisturbed natural buffer is established along both sides of the Etowah River and the Little River, in accordance with Article 26 of the Zoning Ordinance of Cherokee County.*
Georgia DNR	Rules for Environmental Planning Chapter 391-3-6-.04 Criteria for River Corridor Protection http://www.dca.ga.gov/development/PlanningQualityGrowth/DOCUMENTS/Laws.Rules.Guidelines.Etc/DNRRules.EnvironmentalPlanningCriteria.pdf	M	*Section 12-2-8 (as amended) of Article 1, Chapter 2, Title 12 of the Official Code of Georgia Annotated (O.C.G.A.) authorizes the Department of Natural Resources (DNR) to develop minimum planning standards and procedures for the protection of river corridors in the state, and requires local governments to use these minimum standards in developing and implementing local comprehensive plans.The method mandated in O.C.G.A. 12-2-8 for the protection of river corridors is the establishment of natural vegetative buffer area bordering each protected river. Local governments will develop River Corridor Protection Plans (as part of the comprehensive plans authorized under O.C.G.A. 36-70-3) that will maintain the integrity of this buffer area."River corridor" means all land, inclusive of islands, not regulated under the Metropolitan River Protection Act (O.C.G.A. 12-5-440 through 12-5-457), or the Coastal Marshland Protection Act (O.C.G.A. 12-5-280 through 12-5-293), in areas of a protected river and being within 100 feet horizontally on both sides of the river as measured from the river banks. The 100 foot buffer shall be measured horizontally from the uppermost part of the river bank, usually marked by a break in slope. Although not within the measured 100 foot wide buffer, the area between the top of the bank and the edge of the river shall be treated by local governments in the same manner as the river corridor and shall be included within the River Corridor Protection Plan. Because stream channels move due to natural processes such as meandering, river bank erosion, and jumping of channels, the river corridor may shift with time. For the purposes of these standards, the river corridor shall be considered to be fixed at its position at the beginning of each review period for local comprehensive plans. Any shift in the location of the protected river after the start of the review period will require a revision of the boundaries of the river corridor at the time of the next review by the Department of Community*
INDIANA	Silver Jackets Hazard Mitigation Task Force - Fluvial Erosion Hazard (FEH) Program Indiana's FEH study team has developed a set of assessment tools to aid in the identification and assessment of fluvial erosion hazards. http://feh.iupui.edu/	V	*The Indiana Silver Jackets Hazard Mitigation Task Force has initiated a multi-agency program to identify, study, and provide mitigation planning resources for individuals and communities who would like to adopt FEH avoidance strategies. The FEH effort being undertaken in Indiana is modelled after an FEH program developed by the Vermont Department of Environmental Conservation and will greatly benefit from the well-documented strategies, protocols, and products established within that program. The FEH program is a multi-agency mitigation planning effort to provide shared resources so individuals and communities can better recognize areas prone to natural stream-erosion processes and adopt strategies to avoid FEH related risks.To help with that process, the FEH study team has developed a set of assessment tools to aid in the identification and assessment of fluvial erosion hazards. These tools include a series of descriptive guides outlining the most common channel types found in Indiana, the process of identifying bankfull stage in stream channels, as well as methodologies for bridge screening and the assessment of channel bank stability. This site also links to a USGS report that presents regional channel-dimension curves for non-urban wadeable streams in Indiana. In addition, this site will provide newly developed methodologies appropriate for the mapping of fluvial erosion hazards. General Setback = 4 x Bankfull Channel Width(measured from channel centerline)*
KANSAS			
Manhattan	Post Construction BMP Manual, Appendix E - Draft Article XX Stream Setbacks http://cityofmhk.com/DocumentCenter/Home/View/8141	M	*This Stream Setback Ordinance shall apply to all land or new development within the Stream Corridor, as defined by this Article and applied to designated Stream Segments identified on the most current map. No development shall occur on a parcel of land that is within or partially within the defined Stream Corridor, except in accordance with this Article. Stream Corridor widths have been determined by drainage area to the stream.*
Overland Park	Codes and Ordinances - Chapter 18.365 Stream Corridor Requirements http://www.opkansas.org/wp-content/uploads/downloads/18365-stream-corridor-requirements.pdf	M	*This ordinance is created to establish acceptable minimum requirements to preserve and protect stream corridors and other valuable aquatic riparian resources within the City.18.365.040 Designation of Stream Corridor. The stream corridor shall consist of the stream and all lands adjacent to the stream on both sides for the minimum distance from the ordinary high water mark specified below: <u>Stream tributary area:</u> <u>*Minimum distance from "ordinary high water mark" to the limit of stream corridor on each side:</u> Less than 25 acres — See 18.365.040 B Including 25 acres up to 40 acres — 30 feet (See 18.365.040 C) Including 40 acres up to 160 acres — 60 feet Including 160 acres up to 5000 acres — 100 feet 5000 acres and greater — 120 feet*

STATE and LOCAL PROGRAMS	DESCRIPTION	Voluntary (V) or Mandatory (M)	ADDITIONAL INFO
MISSOURI			
Kansas City	Municipal Code 88-415 Stream Buffers - http://online.encodeplus.com/regs/kansascity-mo/downloads/fullcode%201-march-2011.pdf https://docs.google.com/gview?url=https://data.kcmo.org/api/file_data/oZLCZxMHkedRQ97pSCKpIf-nhPsKvxi18FhSpypPa20?filename=Stream+Setback+Fact+Sheet.pdf	M	*The Kansas City ordinance regulates all streams shown on the Kansas City Natural Resources Protection Map. The Planning and Development Department maintains the map. Setbacks are based on the stream's actual characteristics, including the 100-year floodplain or flood conveyance; adjacent steep slopes (greater than 15 percent grades) and mature, native vegetation (such as woodlands). Three zones are specified, with more restrictions closer to the stream.*
MONTANA	Montana Channel Migration Zones http://geoinfo.msl.mt.gov/Home/data/montana_channel_migration_zones	V	*Based on Washington State Department of Ecology guidelines. The fundamental concept of CMZ mapping is to identify the corridor area that a stream channel or series of stream channels can be expected to occupy over a given timeframe. A 100-year CMZ is a typical timeframe used as a corridor defining a century of anticipated channel movement. This timeframe allows for riparian forest maturation within the dynamic river corridor and provides a practical compromise compared to the entire river valley bottom. Channel migration zone mapping serves as a science-based tool to help the public, landowners, and decision makers develop an understanding of river dynamics, along with the inherent risks and benefits associated with those processes. Montana has no regulatory requirements for the applications of channel migration mapping.*
Various Locations	•Big Hole River •Clark Fork - Bitterroot to Huson •Clark Fork - Plains Area •Flathead River - Old Steel Bridge to Flathead Lake •Prickly Pear and Lower Tenmile Creeks •Lower Ruby River •Yellowstone River	V	*CMZ Mapping*
NEW HAMPSHIRE	Fluvial Erosion Hazards and River Geomorphic Assessment Program - Based on Vermont's guidelines. NHGS staff have made some specific adjustments to customize the protocol for application within NH's borders. Maps that identify those areas at greatest risk of erosion represent a useful product derived from the geomorphic assesments. http://des.nh.gov/organization/commissioner/pip/factsheets/geo/documents/geo-10.pdf	V	*The basic unit of river assessment is the geomorphic "reach", which is a specific length of the river channel and adjacent floodplain that shares characteristics that differ from its upstream and downstream neighbors. Each study reach is defined through analysis of a number of key natural physical attributes of the river and its valley. Earth scientists consult topographic and geologic maps and aerial photographs as part of this effort. By providing a consistent, logical framework for describing streams and rivers, classification of a stream or river into a collection of geomorphic reaches represents a critical first step in the assessment process. In the field, data about features, such as the height and form of banks, lengths of riprap, and the locations of active erosion are collected. Crosssections are collected to measure the width of the river and depth across the channel. This information, together with observations about aquatic habitats, and bridge and culvert data, can be used to classify river constrictions, the potential for scouring and damage to crossings and the potential for debris and ice jams. Towns can then develop actions that will help prevent or reduce the same kinds of flood damage experienced in previous years. The river geomorphic assessment tools allow individual reaches to be scored for erosion sensitivity based on data that has been collected in the field. The scoring allows for the determination of the vulnerability of a particular reach to future erosive events that could lead to bank failures and the subsequent potential for property and infrastructure damage during high flow events. With the right flow and geological conditions, a river could also carve a new path for itself an avulsion. Maps that identify those areas at greatest risk of erosion represent a useful product derived from the geomorphic assesments. Final products include maps and digital datasets that identify river features mapped in the field and those areas that are susceptible to potential future erosion events.*
NEW YORK			
Town of Ithaca	The Town of Ithaca enacted a Stream Setback Law , which establishes restrictions on certain activities within a specified distance of Town streams. The main purpose of the law is to improve stream health and water quality by providing a buffer between streams and human activities (http://www.town.ithaca.ny.us/stream-setback).	M	*Key features of the law:* *• The law applies to those streams with an upstream drainage area of 35 acres or greater;* *• Establishes three different setback widths (35ft, 50ft, 100ft) depending on the size of the upstream area draining into the stream;* *• Establishes two different "zones" of protection (Zone 1 and Zone 2) within a setback width, with Zone 1 being streamside and requiring the most protection;* *• A setback width adjustment when streamside wetlands exist or when slopes of 25 percent or greater exist within Setback Zone 1;* *• A Stream Setback Map referenced in the law identifying streams having a drainage area equal to or greater than 35 acres along with their required setback widths;* *• Exemption for parcels 0.5 acres or less in size (a minimum setback for new construction would still apply);* *• Numerous prohibited activities applicable to one or both zones (Zone 1 and/or Zone 2);* *• Added definitions to the Town Zoning Chapter relevant to the Stream Setback provisions.*
NEW MEXICO			
Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)	AMAFCA Sediment and Erosion Design Guide (RCE 1994) - Prudent Line Analysis	M	*The purpose of this manual is to provide guidance for the analysis of sediment areas and arroyos in the AMAFCA jurisdictional area, including methods for evaluating the potential effect of proposed structures or activities on the vertical and lateral stability of the arroyos and drainageways, and for establishing the Prudent Line. The Prudent Line is a boundary along an arroyo or drainageway that would have a low possibility of being disturbed by erosion, scour, or lateral migration of a natural (unlined) arroyo by storms up to and including the 100-year storm. This Design Guide describes basic concepts related to the physical processes that control arroyo behavior, provides engineering tools that can be used to quantitatively analyze specific processes, and provides guidance on combining these tools to predict short- and long-term arroyo behavior.*
Southern Sandoval County Arroyo Flood Control Authority	Sediment and Erosion Design Guide (MEI 2008) http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf	M	*The purpose of this manual is to provide guidance for the analysis of sediment areas and arroyos in the SSCAFCA jurisdictional area, including methods for evaluating the potential effect of proposed structures or activities on the vertical and lateral stability of the arroyos and drainageways, and for establishing the Lateral Erosion Envelope (LEE) line. The LEE line is a boundary along an arroyo or drainageway that would have a low possibility of being disturbed by erosion, scour, or lateral migration of a natural (unlined) arroyo by storms up to and including the 100-year storm. This Design Guide describes basic concepts related to the physical processes that control arroyo behavior, provides engineering tools that can be used to quantitatively analyze specific processes, and provides guidance on combining these tools to predict short- and long-term arroyo behavior.*
OHIO			
Ohio DNR	Rainwater and Land Development Manual, Chpt. 2.5 Stream Setback Area - This practice establishes the setback area based on the predicted belt width of stream, the lowest http://soilandwater.ohiodnr.gov/portals/soilwater/pdf/stormwater/RLD_11-6-14All.pdf	M	*Calculating the Setback Area Width* *-The setback area width is a total width, which crosses the channel and is calculated according to the drainage area (square miles).* *Size:* *-The setback area shall combination of two overlapping areas, one Streamway based and the other based on a minimum distance from the channel bank, equivalent to 1 channel width* *The Streamway size appropriate to accommodate the meander belt is:* *-Streamway width = 147 (Drainage Area in square miles)0.38 (Approximately 10 channel widths)* *In addition, at no point shall the distance between the setback boundary and the channel be less than:* *-Minimum distance from channel = 14.7 (Drainage Area in square miles)0.38 (Approximately 1 channel width)* *A Streamway is more a feature of a valley than individual bends or the present location of a channel , thus the setback area may not always be exactly centered over the stream, especially as streams meander. It is more aptly visualized as a flood path or roughly the flood way. Thus, setback areas should be fit to the valleys. They shall be positioned so that corresponding left and right boundary elevations match and the setback area incorporates the lowest elevations in the valley.*
Clermont County	Post Construction BMP Manual defers to Ohio DNR Rainwater and Land Development Manual, Chpt. 2.5 for stream setback delineations		

STATE and LOCAL PROGRAMS	DESCRIPTION	Voluntary (V) or Mandatory (M)	ADDITIONAL INFO
City of Cleveland	Ordinance No. 1555-13, To supplement the Codified Ordinances of Cleveland, Ohio, 1976 by enacting new Section 351.01 Riparian Setbacks - this is not an erosion setback.		*Riparian setbacks on designated watercourses are established as follows: (1) A minimum of 300 feet on each side of all watercourses draining an area greater than 300 square miles. (2) A minimum of 120 feet on each side of all watercourses draining an area greater than 20 square miles and up to and including 300 square miles. (3) A minimum of 75 feet on each side of all watercourses draining an area greater than one half square mile and up to and including 20 square miles. (4) A minimum of 25 feet on each side of all watercourses draining an area less than one half square mile and having a defined bed and bank as determined above.*
OREGON DEPT. OF GEOLOGY AND MINERAL INDUSTRIES (DOGAMI)	Channel Migration Hazard (data and maps published as DOGAMI Open-File Report Series) http://www.oregongeology.org/flood/channelmigration.htm	V	*The Oregon Department of Geology and Mineral Industries (DOGAMI) maps historic stream channels to determine future channel migration hazards.Following methods developed by Washington Department of Ecology, DOGAMI brings together historic photos, lidar, and field data to create channel migration zone mapping. These maps can be used to understand a type of hazard that is not typically accounted for in traditional FEMA flood maps. Channel migration hazards can exist outside the 1%-annual-chance flood zone. Current projects include Statewide Channel Migration Assessment – funded by the Oregon Department of Land Conservation and Development, this objective assessment will help prioritize areas where detailed channel migration studies should be performed.*
Multnomah and Clackamas Counties	...for the Sandy River, Multnomah and Clackamas Counties, Oregon http://www.oregongeology.org/pubs/ofr/p-O-13-10.htm	V	
Hood County	...for the Hood River and its main forks, Hood River County, Oregon http://www.oregongeology.org/pubs/ofr/p-O-13-11.htm	V	
Coos County	...for select rivers and streams in Coos County, Oregon http://www.oregongeology.org/pubs/ofr/p-O-11-09.htm	V	
TEXAS			
Austin	Watershed and Development Review Dept. http://www.austintexas.gov/sites/default/files/files/Watershed/erosion/erosion_hazardguidline.pdf	M	*This guidance in this document applies to proposed development or improvements adjacent to waterways within the City of Austin jurisdiction. The owner of real property shall provide an erosion hazard analysis where the proposed development is within 100 feet of the centerline of a waterway with a drainage area greater than 64 acres or greater, located where significant erosion is present. This document serves as guidance for delineation of an Erosion Hazard Zone, defined as: An area where stream channel erosion is likely to result in damage to or loss of property, buildings, infrastructure, utilities or other valued resources. An Erosion Hazard Zone provides a boundary outside of which resources are not expected to be threatened as a result of future stream erosion. This document provides guidance to planners, designers and regulators in evaluating the potential impact from erosion for proposed developments and existing resources near defined waterways. The following guidance provides a 'Level 1', analysis that was designed with a conservative factor of safety to predict an Erosion Hazard Zone that is considered sufficient without a high level of site-specific hydrologic, soil, and geomorphic information. An applicant may opt to perform a 'Level 2' analysis using more robust technical procedures and detailed site-specific information, as approved by the Watershed Protection Department.*
Dallas	Sect. 51A-5.106. Setback From Natural Channel Required http://www.amlegal.com/nxt/gateway.dll/Texas/dallas/volumei/preface?f=templates$fn=default.htm$3.0$vid=amlegal:dallas_tx	M	*(a) For purposes of this section: (1) NATURAL CHANNEL SETBACK LINE means that setback line described below located the farther beyond the crest: (A) That line formed by the intersection of the surface of the land and the vertical plane located a horizontal distance of 20 feet beyond the crest. (B) That line formed by the intersection of the surface of the land beyond the crest and a plane passing through the toe and extending upward and outward from the channel at the designated slope. For purposes of this paragraph, the designated slope is: (i) four to one if the channel contains clay or shale soil; and (ii) three to one in all other cases. (2) CREST means that line at the top of the bank where the slope becomes less than four to one. (3) TOE means that line at the bottom of the bank where the slope becomes less than four to one. (b) Except as otherwise provided in Subsection (c), all structures must be located behind the natural channel setback line. (c) A structurally engineered retention system approved by the director may be substituted for the setback required in Subsection (b). (Ord. Nos. 19786; 24085; 25047; 28073)*
Frisco	City of Frisco Engineering Standards, Chpt. DS-Design Standards, Section 4.11K http://www.friscotexas.gov/departments/engineering/Documents/Engineering%20Standards.pdf	M	*K. An erosion hazard setback shall be included within the Drainage Easement for the channel. The purpose of this setback is to reduce the potential for any damage to a private lot or street right-ofway caused by the erosion of the bank. The erosion hazard setback shall be determined as follows, and is provided in Figure 6: 1. For stream banks composed of material other than rock, locate the toe of the natural stream bank. Project a 4:1 line sloping away from the bank until it intersects finished grade. From this intersection add 15' away from the bank. This shall be the limit of the erosion hazard setback. 2. Figure 6 is intended to illustrate various scenarios under which the erosion hazard setback can be applied and how it interacts with the floodplain access easement. Scenario 1 shows a situation where the setback may be located outside the 100-year floodplain and access easement boundaries. Scenarios 2 and 3 show locations where the erosion hazard setback will be located inside the 100-year floodplain and access easement boundaries. L. Any modifications within the area designated as erosion hazard setback, will require a geotechnical and geomorphological stability analysis, and a grading permit (two separate items).*
McKinney	Streambank Stabilization Manual - Chpt. 3E Erosion Hazard Setback Determination: Setback is a projection of a 4H:1V (3H:1V for rock) line from the toe of the stream bank to an intersection with the natural ground plus an additional 15 feet horizontal distance. http://mckinneytexas.org/DocumentCenter/View/416 https://www.plano.gov/DocumentCenter/View/257	M	*ORDINANCE NUMBER 99-04-39: Section E.3.H Erosion Hazard Setbacks - Erosion hazard setback determinations will be made for every stream in which natural channels are to be preserved. Natural channel banks will be protected by use of the determined setbacks unless a plan to stabilize and protect stream banks is approved by the Director of Engineering. Where setbacks are used for erosion protection, no building, fence, wall, deck, swimming pool or other structure shall be located, constructed or maintained within the area encompassing the setback. Section E.4.E Stream Bank Erosion - Erosion control methods identified in the Stream Bank Stabilization Manual will be utilized for erosion control along streams and drainage channels. On-site, upstream and downstream erosion control impacts will be evaluated during design. Erosion hazard setbacks will be required to protect structures and lot improvements from erosion hazards.*
Plano		V	
Garland		V	
Allen		V	
Temple	Design & Development Standards Manual, Design Criteria, Exhibit A: Erosion Hazard Zone Criteria http://www.ci.temple.tx.us/DocumentCenter/Home/View/2090	M	*A. If property is located outside of FEMA mapped flood plain. No erosion hazard zone criteria required; unless property is near or encompasses a crest of slope steeper than 3:1, then Condition E. - If property is subtended by or adjacent to creek (waterway, stream, channel) that meets conditions A, B, C, D or is not mapped by FEMA: If bank is steeper than 3:1, then setback point is either equal to height (x = h = height) as measured from crest of slope of outside waterway bank or 3:1 projection line on inside waterway bank or another distance (longer or shorter) as determined by the engineer of record.*
New Braunfels	Drainage and Erosion Control Design Manual - Ch. 2.9 Erosion Hazard Setback Regulation http://nbtexas.org/DocumentCenter/Home/View/482	M	*NO SPECIFIC GUIDELINES! Erosion hazard setback zone determination is necessary for the banks of streams in which the natural channel is to be preserved. The purpose of the setbacks is to reduce the amount of structural damage caused by the erosion of the bank. With the application of streambank erosion hazard setbacks, an easement is dedicated to the city such that no structure can be located, constructed, or maintained in the area encompassing the erosion hazard setback. The City of New Braunfels allows for streambank stabilization as an alternative to dedicating the erosion hazard setback zone. Streambank erosion hazard setbacks may extend beyond the limits of the regulatory floodplain. Recommendations by a qualified geotechnical engineer or geologist should be presented to the City Engineer for review.*
UTAH			
St. George	City Ordinance found in Chapter 23 Construction Subject to Geologic, Flood or Other Natural Hazards, 10-23-7: Provisions for Flood Hazard Reduction, E. New Development, Section 1.c. http://sterlingcodifiers.com/codebook/index.php?book_id=399&chapter_id=14009#s118362 Map of Erosion Hazard Zones - http://files.geology.utah.gov/online/ss/ss-127/ss-127pl3.pdf	V	*City ordinance states that: "All new development proposals, including subdivisions, located within an erosion hazard area shall be consistent with the need to minimize flood damage. Proposals within these areas shall comply with the following requirements: Provide an engineering study, prepared by a professional civil engineer licensed to practice in the state, which includes an hydraulic analysis, an historical and geological evaluation of potential erosion hazards, and an analysis of long term channel degradation, movement and bank erosion." Erosion-hazard zones are independent of FIRMs 100-year flood zones, and are intended to prevent damage from erosion during flooding, "whether or not the property is located in a FIRMs 100-year flood zone" (CH2MHILL, 1997). Erosion-hazard zones were delineated by JE Fuller/Hydrology & Geomorphology, Inc in 1997 and are based chiefly on a geomorphic analysis of river behavior over time, and are determined through a combination of air photo interpretation, field observations, geology and soils mapping, and consideration of the location and design of structures in active stream channels including bridges, water diversion dams, and channel stabilization structures. Alternating yellow and black bar indicates the erosion-hazard zone study limit.*
Salt Lake County	Codes and Ordinance - Chapter 17.10 - Jordan River Flood Channel Management https://www.municode.com/library/ut/salt_lake_county/codes/code_of_ordinances?nodeId=TIT17FLCOWAQU_CH17.10JORIFLCHMA	M	*The boundaries of the Jordan River flood channel are established and designated to be those coinciding with the "meander corridor" as shown on the channel meander/bend migration corridor maps on file with the county engineering division. The location and dimensions of these boundaries are identified in a scientific and engineering report entitled "Jordan River Stability Study," December 18, 1992, submitted to Salt Lake County by CH2M Hill, with accompanying maps and appendix, and any revisions thereto. The "Jordan River Stability Study" is adopted by reference and declared to be part of this chapter as if fully described and set forth herein.*

STATE and LOCAL PROGRAMS	DESCRIPTION	Voluntary (V) or Mandatory (M)	ADDITIONAL INFO
Washington County	River Stability Study for Santa Clara & Virgin Rivers (JE Fuller 2005) http://www.wcwcd.org/downloads/studies/FINAL_river_stability_report.pdf	V	*Washington County, the City of Santa Clara, and the City of St. George initiated a Master Plan to document what occurred during the 2005 floods, to establish guidelines to manage development within the river corridors, and to prevent future flood damage. In addition to recommending specific protocols for reestablishing stream channel, floodplain and terrace features, the Master Plan evaluates potential future erosion hazards and defines a corridor within which special development practices are required.*
Saratoga Springs	Jordan River erosion hazard zone mapping http://www.saratogaspringscity.com/vertical/sites/%7B78CE255C-3864-45FC-AA11-6125792DB3E4%7D/uploads/Zoning_D_size_reduced.pdf	V	
VERMONT	Vermont Watershed Management Division - Rivers Program http://www.vtwaterquality.org/rivers.htm Fluvial Erosion Hazard (FEH) Area delineations, Vermont Guide to River Corridor Protection http://www.vtwaterquality.org/rivers/docs/FHARCP_12.5.14.pdf Vermont Flood Hazard Area and River Corridor Rule, Chapter 39, Subchapter 3, §29-301(b)(2) River Corridors states: "River corridors shall be delineated by ANR's River Corridor and Floodplain Protection Program pursuant to 10 V.S.A. § 1427." http://www.vtwaterquality.org/rivers/docs/FHA&RC_Rule_Adopted_10.24.2014.pdf	M	*The Vermont General Assembly (1997-1998) directed the Agency of Natural Resources (ANR) to identify options for state flood control policy and a state flood control program. The resulting policy is centered on the goal of managing rivers and their corridors to maintain or reestablish the equilibrium condition. To implement this policy, the River Management Program of ANR has developed tools to understand dynamic river systems and identify appropriate management activities. A major component of this effort is the Fluvial Erosion Hazard (FEH) risk assessment and mapping process. FEH maps identify the location and intensity of fluvial erosion hazards, as well as the area needed by a river to maintain equilibrium. Fluvial Erosion Hazard overlay districts are one of the best avoidance strategies for fluvial erosion hazard mitigation. An overlay district is an additional zoning requirement placed on a specific geographic area (in this case the FEH zone) without changing the underlying zoning. The degree of protection afforded by a FEH overlay district depends upon the exact wording, but could include limits on structures, land use activities, or even vegetative condition. Limiting development within an overlay district based on the boundaries of a FEH map has two major functions. First, it will prevent development in hazardous areas, reducing costly flood losses and increasing public safety. Second, it will prevent river corridor encroachment which would increase overall fluvial erosion hazards and impede a river's natural tendency to adjust toward a more stable, equilibrium condition. Because overlay district boundaries do not shift as a river channel changes position, this approach can provide a consistent, easy-to-administer tool for mitigating fluvial erosion hazards over a wide geographic area. In the long term, this option will do the best job of minimizing human/river conflicts and limiting losses caused by fluvial erosion.*
WASHINGTON	Channel Migration Zone (CMZ) http://www.ecy.wa.gov/programs/sea/sma/cma/index.html Shoreline Master Program (SMP) Guidelines (Chapter 173-26 WAC, Part III) http://www.ecy.wa.gov/programs/sea/sma/guidelines/index.html	M	*The Shoreline Master Program (SMP) Guidelines are state standards which local governments must follow in drafting their shoreline master programs. The Guidelines translate the broad policies of the Shoreline Management Act (RCW 90.58.020) into standards for regulation of shoreline uses. "The Washington State administrative codes that implement the Shoreline Management Act (SMA) require communities to identify the general location of channel migration zones (CMZs), and regulate development within these areas on shoreline streams. Shoreline streams are defined as those with a mean annual flow equal to or greater than 20 cfs. While many channel migration studies and CMZ delineations have been done in Washington State, nearly all have been detailed assessments. These CMZ delineations are more rigorous then required by the state SMA administrative codes, which emphasize planning-level assessments. The rigorous studies are cost-prohibitive to implement for all regulated shoreline streams in the state. The SMA and its administrative codes provide no guidance on planning-level CMZ delineation methods. The Washington Department of Ecology (Ecology) developed a planning-level CMZ delineation (pCMZ) method to support local communities' updates and implementation of the SMA requirements. The pCMZ method uses the nature and extent of valley bottom features to assess past and potential future channel migration, and then define CMZ boundaries. This document describes the pCMZ approach in context of Washington State regulations." (A Methodology for Delineating Planning-Level Channel Migration Zones - http://ntl.bts.gov/lib/52000/52600/52631/1406025.pdf)* *Channel Migration Assessment Steps:* *Step 1 provides some general indicators of channel migration and can be readily done with topographic maps, air photographs or orthophotos.* *Step 2 provides information on appropriate approaches and underlying methods for specific channel patterns, environmental and infrastructure value, and management objectives.* *Steps 3-5 outline tasks for conducting a channel migration analysis portion of an assessment.*
King County	King County's Shoreline Master Program (http://www.kingcounty.gov/environment/water-and-land/shorelines.aspx) - The majority of the new regulations have been incorporated into King County Code Chapter 21A.24 Critical Areas: Designation, Classification and Mapping of Channel Migration Zones (21A.24.274 and 21A.24.275)	M	*2012 King County Comprehensive Plan (updated November 4, 2013), Chapter 5: Shorelines - King County adopted its first Shoreline Master Program (SMP) in 1977. In November, 2010, King County approved an update to the SMP. This update incorporated the shoreline policies in the Comprehensive Plan for the first time. Under the Shoreline Management Act, the SMP must be approved by the Washington Department of Ecology before it takes effect. King County is in the final process of obtaining that approval. Environment designations: shorelines are classified into specific "environment designations" based on their physical, biological and development characteristics. Historically, SMPs have used primarily four basic environment designations ("natural", "conservancy", "rural" and "urban"). New state guidelines recommend six designations: "natural," "rural-conservancy," "urban conservancy," "high-intensity," "shoreline residential," and "aquatic." Local governments may modify state recommended classifications to better accommodate shoreline areas with unique characteristics. Policies and regulations are developed for each designation, reflecting the specific purpose and intent of each environment and responding to its specific conditions.*
Pierce County	Pierce County Rivers Flood Hazard Management Plan http://www.piercecountywa.org/floodplan	M	*The Pierce County Rivers Flood Hazard Management Plan (the "Flood Plan" or "Plan") outlines how Pierce County will address and manage flooding and channel migration hazards on the major rivers, large tributaries and associated floodplains within Pierce County for the next 20 years. Channel migration zone (CMZ) studies and maps provide critical baseline information necessary to understand the effects of potential river migration hazards in river valleys.The CMZ maps identify severe, moderate, and low Migration Potential Areas (MPAs) within the channel migration zone. In preparing these studies and maps, Pierce County used information on historical channel locations (primarily aerial photography), geology, basin hydrology, current channel conditions, sediment transport, composition of bank and bed material, potential avulsion sites, and channel migration rates to characterize the channel migration zones. Because of the risks to public safety and the high cost associated with construction and maintenance of flood risk reduction facilities, the County's approach in severe channel migration hazard areas is to restrict development. To address concerns about channel migration, geomorphic evaluations, channel migration zone analyses, and CMZ mapping have been carried out on sections of five of the major river systems. Of the three classifications of CMZ, Pierce County regulates only the severe CMZ areas, which have the highest risk of being occupied by a river. These areas are deemed high hazard and high-risk for life, safety and damage to buildings and other property improvements.*
Clallam County	Draft Channel Migration Assessment for Clallam County http://www.clallam.net/LandUse/documents/CMZ_study_WRIA_20.pdf	M	*The Washington Department of Ecology (Ecology), Shorelines and Environmental Assistance Program (SEA) is responsible for managing Shoreline Master Program (SMP) updates and providing technical and policy assistance to local communities. A draft Channel Migration Assessment report, dated December 2011, was prepared by SEA for Clallam County streams that fall under the jurisdiction of SMA. Channel Migration Zone maps were delineated for all designated streams, which total approximately 140 miles, and are presented with the December 2011 draft report.* *This report, also prepared by the SEA, provides information, methods, and maps for an additional 170 miles of streams in Clallam County to augment work on the county's Shoreline Master Program already in progress. These general CMZs are intended to provide preliminary maps that comply with SMP guidelines, assist with planning, and indicate areas where additional data and analysis should be conducted to complete a more detailed delineation.*
Kitsap County	Kitsap County Shoreline Master Program, Chapter 22 http://www.ecy.wa.gov/programs/sea/shorelines/smp/pdf/KitsapSMP.pdf	M	*The purpose of the Master Program is to guide the future development of the shorelines in Kitsap County in a manner consistent with the Shoreline Management Act of 1971, hereinafter the "Act." The Act and this Program comprise the basic state and county law regulating use of shorelines in the county. This Master Program is adopted pursuant to the authority granted under the Shoreline Management Act of 1971, Chapter 90.58 Revised Code of Washington (RCW) and Chapter 173-26 of the Washington Administrative Code (WAC). Chapter 22.400.115 Critical Area, E. Geologically Hazardous Areas: Channel migration zones shall be classified as landslide hazard areas, and may be either high geologic hazard or low geologic hazard depending on the site characteristics outlined in KCC 19.400.410.A. Channel migration zone maps can be found in Appendix D of this Program.*

Appendix B. Washington pCMZ reach metadata sheet

Planning-Level CMZ - Reach Datasheet

1 - Reach Characteristics

Reach ID		Date		Assessed by	
Stream Name				Reviewed by	
County				Average Channel Slope	
Reach Breaks	*Rivermile	Upstream		Downstream	
Channel Planform	*Type				
*Description					
Reach Break Reasoning:					

2 - Map the Modern Valley Bottom (MVB)

Soil and Geology Units of MVB:			
Features Observed (Y/N)		*Meander Scrolls	
*Active Meander Cutoffs		*Variable Vegetation Age	
*Oxbow Lakes/Cutoffs		*Variable Channel Width	
*Abandoned Channels		*Active Side Channels	
Active Migration in recent aerials?			
Indication of aggradation/incision			
Other Fluvial Landforms			
*Low-lying areas		*Terraces	
*Valley Margin Scallops		*Other	
MVB Boundary			
*Landform Type			
*Landform Geologic Composition			
*General Notes/Reasoning			
Avulsion Hazard Areas (AHAs)		*Mapped?	
*Diagnostic Landscape Features			
*Expected Avulsion Type(s)			
*General Notes/Reasoning			

3 - Map the Erosion Hazard Area (EHA), Geotechnical Flags and Geotechnical Setback (opt.)

EHA-width criteria and reasoning			
Geotechnical Hazards		*Mapped?	
*Geotech Flags added?			
*Geotech Criteria			

4 - Other Map Units DMA?		PIZ?	
Types of erosion barriers			
Erosion Barrier Criteria			