ASFPM RIVERINE EROSION HAZARDS WHITE PAPER

by

ASFPM Riverine Erosion Hazards Working Group

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Despite billions of dollars being spent on flood control strategies and mitigation, and continuing efforts to educate the public about flood hazards, flood losses continue to increase. One reason is well known—continued development in and around floodplains. Another reason is that most of the effort to curb flood loss has been directed at inundation, leaving initiatives to mitigate the significant damage to infrastructure from riverine erosion on the sidelines.

Erosion and deposition are among the natural processes of a river. However, the direction, rate and scale of these processes have been altered by human activity within channels, floodplains and upland watersheds. Structural controls and channelization measures historically applied to protect near-stream development have exacerbated riverine erosion over time, increasing the vulnerability of the infrastructure, homes and businesses they were meant to protect.

The nation must begin to break the costly cycle of encroachment, erosion-related damage, structural controls, further encroachment and so on. While some state and local jurisdictions have implemented programs to restrict new development or redevelopment in erosion-prone areas and mitigate hazards by working in concert with natural river processes, their numbers have been limited. The problem or challenge is how best to follow through and support the state and local needs for technical, legal and financial assistance necessary to create riverine erosion hazard programs.

The main purpose of this White Paper is to encourage state and local governments to begin mapping riverine erosion hazard areas in their communities. The mapping should be carried out using methodologies that they feel are appropriate for their specific conditions and at a level of detail that meets their specific requirements. This White Paper looks into the successes and challenges of this approach, and offers 11 recommendations.

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ACKNOWLEDGEMENTS

This White Paper was a collaborative effort among members of several ASFPM entities, including the Arid Regions Committee, Technical Pod and Natural and Beneficial Functions Committee and other ASFPM members. This paper is intended to provide discussion and context for the variety of approaches and programs that have been or are being developed around the United States.

While we have taken every effort to ensure this paper is free of errors, omissions and typos, any found are our own.

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On the cover: *Dodge Road Bridge over the Rillito Creek in Tucson, AZ, in October 1983. Photo courtesy of Peter Kresan, Pima County Regional Flood Control District.*

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ACRONYMS & ABBREVIATIONS

Acronym or Abbreviation	Explanation
ASFPM	Association of State Floodplain Managers
ARS	Agricultural Research Service (USDA)
BCA	Benefit Cost Analysis
BW-12	Biggert-Waters Flood Insurance Reform Act of 2012
CFR	Code of Federal Regulations
CMZ	Channel Migration Zone
CRS	Community Rating System
EHA	Erosion Hazard Area
EHZ	Erosion Hazard Zone
EO	Executive Order
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management Standard
FHWA	Federal Highway Administration
FIFMTF	Federal Interagency Floodplain Management Task Force
FIRM	Flood Insurance Rate Map
GIS	Geographic Information System
GPS	Global Positioning System
HUD	Department of Housing and Urban Development
IECA	International Erosion Control Association
IPCC	Intergovernmental Panel on Climate Change
LIDAR	A remote-sensing technology similar to radar. (The term is of disputed origin.)
NFIA	National Flood Insurance Act
NFIP	National Flood Insurance Program
NFIRA	National Flood Insurance Reform Act
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	National Research Council
NRCS	Natural Resources Conservation Service (formerly Soil Conservation Service, SCS)
REHA	Riverine Erosion Hazard Area
Risk MAP	Risk Mapping, Assessment, and Planning Program
RL	Repetitive Loss
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service; now the Natural Resources Conservation Service (NRCS)
SFHA	Special Flood Hazard Area
SRL	Severe Repetitive Loss
USC	United States Code
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

SECTION 1 – INTRODUCTION

Riverine erosion is significant in many areas of the world. However, it has not been integrated into community natural hazard planning to the extent that other natural hazards, such as flood inundation and earthquakes, have been. In a 1999 report, the Federal Emergency Management Agency (FEMA) reported that in the U.S., "approximately one-third of the nation's streams experience severe erosion problems" (FEMA 1999). Total annual damage in stream reaches with severe erosion problems was estimated to be $450 million (in 1998 dollars), with total annual treatment costs estimated to be in excess of $1 billion. Treatment costs may include, among others, costs for cleaning debris and sediment deposits from the channel after a flood; repairing or replacing bank armoring or other treatments designed to stabilize the channel; and damage to other superstructure elements intersecting with the channel, such as bridges, storm drain outlets or buried utility lines.

Riverine erosion damages can be more serious than flood inundation damages in several ways. First, riverine erosion can affect structures located outside, as well as inside the regulatory floodplain, and elevating structures above the 100-year base flood elevation may not provide adequate protection from erosion damages. In addition, erosion can not only damage a structure, it can completely remove the land underneath the structure, making it impossible to rebuild on the site. Finally, riverine erosion damage can occur not only during a single large flood event, but may also occur during smaller long-duration floods, or from the cumulative impacts of a series of small floods over a long time period.

Photo caption: Galloway Wash, Cave Creek, Arizona. Blue area is the FEMA floodplain, yellow line is the Erosion Hazard Zone boundary from the Cave Creek Drainage Master Plan. Note the houses on the south bank in the center left of the photo that are outside the floodplain, but inside the Erosion Hazard Zone.

Photo credit: JE Fuller

As a result of human activity, many streams have been significantly altered. This is especially true for streams located in or near urban areas, streams in areas of intensive agricultural activity, and streams located along major transportation corridors. Such altered streams may be more vulnerable to damage from erosional and depositional processes.

The focus of this paper is riverine erosion, including depositional and erosional processes, occurring along watercourses, whether perennial, ephemeral or intermittent. Although erosion does occur in rock channels, the discussion in this paper will be limited to erosion of channels in alluvial materials. These channels are also referred to as movable bed channels, because the location and geometry of the channel can be changed over time through the operation of erosional and depositional processes.

Photo caption: Caliente, Nevada. Train derailment caused by lateral erosion at the interface between a stream and adjacent transportation infrastructure.

Photo credit: Clark County Regional Flood Control District

Federal legislation authorizing riverine erosion mapping and integration of erosion hazards into the NFIP has been enacted, but not implemented. Given the fact that riverine erosion processes can cause serious damage and injuries, communities have found it necessary to take action to reduce their impact. In the absence of comprehensive action by FEMA and other federal government agencies, it appears likely that self-directed local action will remain the most effective means of addressing riverine erosion hazard problems for the foreseeable future.

States and municipalities have become the important incubators for the development of riverine erosion hazard area mitigation programs. Local people have the most in-depth and up-to-date information about local conditions, and can utilize this knowledge to develop site-specific solutions for the community's problems. Empirical techniques have been developed by states, counties, flood control districts and municipalities to provide an assessment of riverine erosion risk for purposes of land-use planning and regulation of construction in vulnerable areas.

FEMA could nonetheless play an important role in helping to make information about local programs around the country more readily accessible to others addressing the same problems. FEMA could provide leadership and resources in such areas as research, incentives for the NFIP Community Rating System program, training for state and local personnel, and support for peer-to-peer mentoring and information sharing. The experience gained through these partnerships could provide a basis for future inclusion of the assessment and management of riverine erosion hazard areas in the NFIP, should that be desired.

Presidential Executive Orders 11988 and 13690 provide important opportunities to build the types of federal-state-local partnerships mentioned above. The stated reason for issuing EO 13690 is "...to improve the Nation's resilience to current and future flood risk..." (Obama 2015). Certainly, the risk of erosion should be considered in this context as a common consequence of flooding. EO 13690 specifically requires consultation among federal agencies in issues related to flood risk, and also requires agencies to actively seek stakeholder input.

This White Paper articulates current challenges in applying river science to the creation of sound policies and programs to mitigate riverine erosion hazards, and includes a list of recommendations to capitalize on opportunities identified by practitioners. A preliminary compilation of current state, county and local programs that address riverine erosion hazards is included in Appendix C. Contact information is provided to encourage communication among interested parties. This compilation is necessarily incomplete, and we encourage you to add to the list and join the discussion.

Section 1 References

Hazards Study Branch, Federal Emergency Management Agency. 1999. Riverine Erosion Hazard Areas, Mapping Feasibility Study [Internet]. Washington, DC: FEMA (US); [accessed 2015 Oct 1]. Available *http://www.fema.gov/media-library-data/20130726-1545-20490-3748/ft_rivfl.pdf*

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SECTION 2 – BACKGROUND

Humans have been aware of, and concerned about, hazards associated with erosion and deposition of sediment throughout recorded history. In the fourth century BC, Aristotle made observations and formulated theories about how landforms evolve. In the 10th century AD, Persian philosopher Avicenna and Chinese scientist Shen Kuo separately proposed theories of landform change that took into account sedimentary uplift and soil erosion.

However, modern scientific approaches to understanding the processes of erosion and deposition did not begin to emerge until the 19th and early 20th centuries. James Hutton, a Scottish physician and naturalist, developed the new science of geology in the late 18th century, based on observation and careful scientific reasoning. Hutton elaborated the principle of uniformitarianism, which holds that the same natural laws and processes that operate in the world now have always operated in the past, and apply everywhere. This and other advances by Hutton and others set the stage for a much better understanding of the processes at work in shaping the Earth's surface. Broad-scale landscape evolution models were developed by *William Morris Davis*, an American geographer, geologist, geomorphologist and meteorologist, in the late 19th century.

Modern quantitative geomorphology developed in the early 20th century through the efforts of a large and multidisciplinary group of scientists and engineers. At roughly the same time, a scientific approach to geotechnical engineering began through the work of *Karl Terzaghi*, starting in about 1925. The principles of geotechnical engineering are applied to predict the behavior of hillslopes and stream banks under the influence of flowing water—an important component of the evaluation of erosion hazards.

Since the middle of the 20th century, the study of riverine erosion has become increasingly multidisciplinary, with important contributions by hydraulic engineers, hydrologists, physical geographers, geotechnical engineers, soil scientists, geomorphologists (especially fluvial geomorphologists), sedimentary petrologists, quaternary geologists, cartographers (now including specialists in Geographic Information Systems and remote sensing), computer modelers and mathematicians specializing in statistics and probability.

The multidisciplinary nature of the study of riverine erosion and deposition processes makes available to us insights of a large and varied group of scientists and engineers. But at the same time, this makes it very difficult for any one person to know about all of it, or stay current with new advances in these fields.

Advances in fluvial geomorphology have provided a better understanding of how a river evolves and adjusts to environmental changes, whether caused by natural processes or human actions. In fluvial geomorphic terms, a stream or river is described as a system, consisting of the stream itself, and the water that flows in it, and the sediment that is eroded from it, deposited in it, or transported through it; along with the watershed around the stream, from which water and sediment are conveyed to the stream. If climatic conditions and land use on the watershed stay about the same, a stream tends to reach a more or less stable state, known as dynamic equilibrium, when large and abrupt changes in the characteristics of the stream do not occur under normal conditions. If the material (sediment) and energy (from flowing water) inputs to the stream change, however, then the system has to adjust to the changed conditions, until a new state of dynamic equilibrium is reached.

As the stream system rebalances in response to changed conditions, the hazard from flooding or erosion may also change. For example, if the amount of sediment being transported into the stream system increases, in excess of the capacity of the stream to transport that sediment, more sediment than previously may be deposited, resulting in a braided channel pattern, which could cause inundation in areas previously thought to be outside of the flood hazard area. Another example would be of a stream with erosion protection, such as riprap or gabions, along its banks. Over time, or in an unexpectedly large flood event, the bank protection may fail, resulting in erosion and flooding in areas not previously thought vulnerable.

This condition occurs more frequently in modified or altered streams, including urbanized rivers and stream channels, rivers and streams in agricultural areas, streams confined by transportation corridors or levees, and rivers impacted by dams or other impoundments. While the flood hazard associated with these conditions has been recognized, unanticipated flooding due to erosion or deposition is a problem that has not been adequately addressed by any level of government.

Previous Studies of Riverine Erosion Hazards

In 1974, Congress enacted the Streambank Erosion Control Evaluation and Demonstration Act of 1974 (Section 32, Public Law 93-251), which authorized $50 million for a national demonstration project. USACE carried out the project, an important component of which was an evaluation of the extent of streambank erosion in the country (USACE 1981). This report is important because it is one of the very few attempts to get a sense of the condition of streams in the U.S. However, the proposed solution for the country's riverine erosion problem was bank protection methods, rather than nonstructural solutions.

The report, *Riverine Erosion Hazard Areas Mapping Feasibility Study* (FEMA 1999), addressed requirements in the national Flood Insurance Reform Act enacted in September 1994. The purpose of the study was "…to determine whether it is technologically feasible to map riverine erosion hazard areas." The report concluded that: "The case studies indicate that there are scientifically sound procedures for delineating riverine erosion hazard areas…Given a suitable time frame, future erosion could be estimated either extrapolating from historic data or through the use of mathematical models."

Taking note of FEMA's Mapping Feasibility Study, the Vermont Agency of Natural Resources prepared a report to the Vermont General Assembly on the "Options for State Flood Control Policies and a Flood Control Program" (1999), which identified riverine erosion as the predominant form of flood damage in the state and the need to establish a river and riparian corridor management program. This report explores policy and program options for transportation, utility, agricultural and private sector development, as well as river, watershed and debris management concerns. The legislative report and other resources that explain how Vermont went on to implement a comprehensive riverine erosion assessment and mitigation program are at *http://www.watershedmanagement.vt.gov/rivers.htm*.

There have been other reports on riverine erosion hazards by state, local and research entities (see Appendices A and C), but by and large, they tend to offer guidelines or methodologies for assessing risk and delineating vulnerable areas. There have been very few comprehensive studies of riverine erosion and of methodologies for risk assessment.

Riverine Erosion Hazard Management at the Federal Level

The National Flood Insurance Act of 1968 was enacted by Title XIII of the Housing and Urban Development Act to provide previously unavailable flood insurance protection to property owners in flood prone areas. Mudslide protection was added to the program by the Housing and Urban Development Act of 1969, and flood-related erosion protection was added by the Flood Disaster Protection Act of 1973.

The Upton-Jones Amendment (1988) modified the NFIP to provide relocation and acquisition coverage for structures in imminent danger from an encroaching shoreline. While the Amendment focused on coastal erosion, consideration of riverine erosion hazards is not excluded. A prerequisite for insurance coverage under this Act is that the insured structures must be declared uninhabitable by the local permitting authority and they must be subject to erosion, or be within the geographical boundaries of an erosion zone that has been included in a state-approved program.

Riverine erosion is well integrated into NFIP regulations. Provisions concerning riverine erosion are included in various sections of 44 CFR, Parts 59 and 60. Definitions of “Area of special flood-related erosion hazard” and “Flood-related erosion area management” are included in Part 59.1 “Definitions.” Part 60.5 deals with “Floodplain management criteria for flood-related erosion-prone areas,” and Part 60.24 covers “Planning considerations for flood-related erosion-prone areas.” Accordingly, NFIP regulations require local communities with flood-related erosion-prone areas to recognize: (1) The importance of directing future developments to areas not exposed to flood-related erosion; and (2) The possibility of reserving flood-related erosion-prone areas for open space purposes (44 CFR Chapter 1, Part 60.24). Local communities are also required to manage development in “flood-related erosion prone areas” by (1) Requiring the issuance of a permit for all proposed construction, or other development in the area of flood-related erosion hazard, as it is known to the community; (2) Requiring review of each permit application 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 flood-related erosion hazard; and (3) If a proposed improvement is found to be in the path of flood-related erosion or to increase the erosion hazard, require the improvement to be relocated or adequate protective measures to be taken that will not aggravate the existing erosion hazard (44 CFR Chapter 1, Part 60.5(a)).

Although protection against damage from flood-related erosion has been part of the NFIP since at least 1973, a set of specific programs and procedures for the evaluation and mitigation of riverine erosion hazards has not been implemented as part of the NFIP. There is a provision in the NFIP for designating Zone E, “Area of special flood-related erosion hazard,” on Flood Hazard Boundary Maps, but this appears not to have been carried through to inclusion on FIRM panels.

The NFIRA of 1994 included a requirement in Section 577 that FEMA submit a report to Congress evaluating the technological feasibility of mapping REHAs and assessing the economic impact of erosion and erosion mapping on the NFIP. The report, titled “Riverine Erosion Hazard Areas: Mapping Feasibility Study” (FEMA 1999), concluded that it is technologically feasible to map riverine erosion hazard areas. The report’s conclusions also included preliminary discussion of some methodological details, and rough estimates of the costs for a program of REHA mapping. No progress on implementation of the REHA recommendations has been made since its publication in 1999. The report provided a rough cost estimate of $200 million-$300 million in 1998 dollars to implement the studies as part of the NFIP. Two options for implementation of a nationwide REHA delineation program were also discussed: federally run, and/or locally run. However, no recommendation was made as to whether the program should be implemented.

Riverine Erosion Hazard Management at the State, County and Local Levels

Erosion hazards are an important issue in many parts of the U.S. In some states, for example Vermont, the damage resulting from riverine erosion exceed those caused by inundation during flood events. In the absence of action on the part of FEMA to evaluate riverine erosion hazards or incorporate erosion hazards into the NFIP and FIRM programs, numerous state, county and local agencies have developed programs of their own. Some have adopted or developed methods for the delineation of erosion hazard areas or corridors. In some cases, the governing agency has funded studies and promulgated the results in the form of maps, or map overlays for existing FIRM panels, showing erosion hazard zones along local watercourses. Where a methodology is prescribed for local use, developers may be required to have engineering studies performed to assess the level of erosion hazards at a specific site.

State, local and county programs for the evaluation of riverine erosion hazards and the regulation of development in erosion hazard areas will be discussed in detail in Section 4 of this report. Sample documents illustrating the approaches adopted in these local programs are presented in Appendix C.

Section 2 References

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SECTION 3 – PROBLEM STATEMENT

Rivers are not static in the landscape. They are dynamic and move by erosion, deposition and avulsion process. The direction, rate and scale of these natural processes have been altered significantly, however, by human activity within channels, floodplains and upland watersheds (Kline and Cahoon 2010; Schiff et. al 2014). Structural controls and channelization measures historically applied to protect near-stream development have exacerbated riverine erosion over time, increasing the vulnerability of the infrastructure, homes and businesses they were meant to protect (EPA 2007). The nation must begin to break the costly cycle of encroachment, erosion-related damage, structural controls, further encroachment, and so on. While a few state and local jurisdictions have implemented programs to restrict new development or redevelopment in erosion-prone areas and mitigate hazards by working in concert with natural river processes, their numbers have been limited (see Appendix C). The problem or challenge is how best to encourage and support the state and local need for the technical and legal assistance and the funding necessary to create riverine erosion hazard programs.

Photo caption: Costly cycle of encroachment, erosion damage and structural controls continues after Tropical Storm Irene (2011) in Vermont.

Photo credit: Lars Grange, Mansfield Heliflight

Federal regulations recognize erosion hazards, but they are non-binding, providing little more than encouragement. The bottom line is that FEMA lacks the funds to accurately map inundation-based risk across the country, much less map riverine erosion areas. If funding were not the issue, the NFIP would still be challenged to address (a) the implication that erosion-prone properties (outside the mapped 100-year floodplain) would need insurance if located within a federally-mapped erosion hazard area; (b) the need for E-zone-based insurance rates; (c) the need for a unified federal standard for defining erosion-related risk (analogous to the base flood); and (d) the challenge of developing a general mapping standard that addresses the variability of geo-fluvial processes and anthropogenic impacts across the nation. Without a national-level program, the delineation of riverine erosion areas and the regulation of practices that cause or aggravate flood-related erosion hazards falls to state and local jurisdictions.

The lack of a national level consensus on how to map or quantify the risk associated with REHs is not necessarily problematic, but the issue then becomes supplanted by the challenge of creating different regional frameworks given the inherent variability in river response to floods across the nation and even within certain states.

There are technical issues as well. As a nation, we have not conceived of methods to manage erosion and inundation at the same time and in a watershed context. What are the important distinctions, scales and synergies that should factor into flood and geo-fluvial hazard mapping and our pre- and post-disaster recovery programs?

We know that the dredging, channelization, levees and dams built in the name of flood control have changed river sediment regimes, often exacerbating channel erosion and deposition processes (Thorne et al. 1997). We know that natural geo-fluvial processes and river channel evolution are not only beneficial to ecosystem recovery and health (Schiff et al. 2008), but if strategically promoted upstream may enhance natural floodplain function and reduce inundation damages downstream. We also understand that riverine erosion can:

- occur on lands outside the mapped 100-year floodplain limits;
- occur during flows that are much less than the 100-year peak; and
- result in loss of not only a structure, but the land under it, ergo there is no chance to rebuild.

However, we have not assembled this knowledge of hydrologic and fluvial geomorphic processes into a cogent, science-based policy that would guide the comprehensive flood hazard mitigation planning desperately needed in erosion- and sedimentation-prone regions of the country.

In addition to the need for a science-based policy, climate change science is increasing the sense of urgency felt in many regions of the country. Chaotic weather patterns resulting from accelerating changes in climate may dramatically change the peak discharge and frequency of large storm events (Karl et al. 2009; Galford et al. 2014) and thereby have the potential to affect the degree and rate of riverine erosion. Changes in flood and erosion hazards can and should be anticipated.

Many state, regional and local agencies and jurisdictions are attempting to tackle these technical, policy and programmatic issues and build riverine erosion hazard programs, but many impediments remain. Specifically, we note the following:

The application of clear-water hydraulics has been a technical pillar in our water-related engineering, with multiple benefits including the development of a national inundation-based flood hazard mapping standard. However, the traditional use of this science does not serve our need to explain flood inundation and fluvial erosion over space and time.

There are many watershed, floodplain and in-stream activities that increase the nature and rate of riverine erosion and sedimentation. For instance, in Vermont many historic attempts to contain flooding increased channel slope, depth and incision, thereby exacerbating fluvial erosion (Kline and Cahoon, 2010). As a country, we have yet to translate this data into new policies recognizing the importance of natural stability and the role of floodplains in minimizing erosion into a coherent set of best practices and regulation to minimize human influences on erosion and sedimentation rates.

Federal guidelines for flood hazard mapping and model floodplain ordinances do not address riverine erosion hazards. An all or nothing approach to federal involvement in developing an erosion hazard program may have historically contributed to the problem. States, counties and municipalities are trying to move forward and the rate of their success could be enhanced with peer-to-peer exchanges and a greater partnership with the federal government, even where it may be limited to technical guidelines, grants and the sharing of legal information.

Additionally, federal funding programs are not tooled specifically to support the mitigation of riverine erosion-related risks. If they were, it might be an incentive for state, regional and local initiatives to move forward in creating a program. For instance, if buyouts were to qualify for funding under the FEMA hazard mitigation grant program when located in a state-mapped riverine erosion hazard area, the states would have the incentive to develop a mapping program. At present, if a house is built at the top of the river bank because the FIRM showed the property to be up and out of the SFHA, and then the house is swept away by erosion during a flood, the property would likely not be able to meet the required Benefit-Cost ratio associated with a FEMA buyout grant because the properties outside SFHA are not eligible for the substantial damage waiver or the pre-calculated benefits, even if the state had mapped the area within an erosion hazard zone. This scenario played out in Vermont after Tropical Storm Irene where, ironically, the properties were not in the mapped SFHA because of historic river dredging and berming conducted before the FIRMs were made to avoid inundation flooding.

Photo caption: Properties damaged or destroyed in a flood may not be eligible for a buyout if they are not in a FEMA Special Flood Hazard Area. While this Vermont property was built above the BFE, it is in a state-mapped River Corridor.

Photo credit: Steve Mackay, homeowner

Our greatest challenge is shifting from reactive to proactive policies, but to do so would be our most cost effective course. The underlying problem in many of the above listed issues is the deficient and ever decreasing public funds being allocated to the science and pre-disaster mitigation programs that will help us develop the land and river management principles and practices to address riverine erosion.

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SECTION 4 – CURRENT PRACTICES

States, counties, municipalities and universities in nearly every region of the country are beginning to collaborate in the development of riverine erosion hazard area mapping procedures, erosion hazard mitigation practices, and an array of public and private efforts to implement regulatory, technical assistance, funding and outreach programs (see Appendix C).

Over the past 15-30 years, distinct but overlapping methodologies have emerged to identify and map riverine erosion hazard areas, including:

- Hydrologic-based setback computations;
- Fluvial geomorphic-based delineations to accommodate natural stream processes; and
- Engineering-based setbacks to avoid geotechnical bank failure and bank retreat.

Jurisdictions have established mapping procedures based on site-specific setbacks, geomorphically-defined zones, or a combination of the two methods. The primary objectives are to restrict new development in hazardous areas, protect against the increase of on- and off-site erosion-related damages, and to manage river systems recognizing that unhindered fluvial processes will lead to least erosive conditions (Leopold 1994, Thorne et al. 1997, Piegay 2005). Current mapping methods are being used on the one hand to explore the costs and benefits of predicting and managing risk at a particular site, and on the other hand, mapping and developing land-use plans to accommodate current and future fluvial geomorphic process. That is, to:

- Minimize site-specific risks by calculating or modeling the probability and extent of channel movement and the rate of bank migration under certain flood flow conditions, over a given time period, to create a setback distance; and/or
- Minimize systemic risks by establishing a “no-build” riverine erosion hazard corridor along the valley floor necessary to accommodate the historic and existing sediment regimes (and commensurate “stable” geometry maintained by dynamic processes).

Site-specific hydrologic and geotechnical evaluations are relatively inexpensive to use on a project-by-project basis, but have limitations if larger-scale geomorphic processes are not considered or if the applicant uses channel armoring to lower risk without regard to off-site impacts. The mapping of historic migration zones or meander belt-based river corridors may also be inexpensive, if conducted at the project or site scale, but may underestimate the lateral bank retreat caused by geotechnical failures that may occur beyond the historic migration zone or meander belt. Some methodologies combine these approaches by accommodating natural stream processes and geotechnical bank erosion zones (Rapp and Abbe, 2003).

Unlike inundation zones, riverine erosion hazards are not necessarily proportional to the peak flood discharge. Catastrophic losses may result from larger flood events; smaller, more frequent events; or from the cumulative effects of a series of smaller storms. Accordingly, jurisdictions are mapping and regulating riverine erosion hazard areas based on their acceptance of risk and the benefit cost analysis of complete avoidance or “no-build” zones within:

- A portion of the valley floor to accommodate erosional and depositional processes within more moderate spatial and temporal scales, but with the acknowledgement that channel management (i.e., stream bank revetments) may become feasible upon reaching quasi-equilibrium conditions for the protection of investments outside the zone in the future, or

- The entire valley floor (or nearly so), maximizing the protection of channel migration, avulsion and natural stream processes over larger spatial and temporal scales, with little to no channel management anticipated or permitted.

Programs are recognizing the difference between mitigating inundation risks and mitigating erosion risks. For instance, we acknowledge that if an avulsion channel suddenly forms next to a house during a flood, there is no reasonable equivalent of a freeboard requirement that would reduce the vulnerability of the structure to erosion. More commonly, erosion hazard zones are mapped to accommodate channel movement rather than rely on the efficacy of human structures to control natural processes. Experience has shown that bank armoring used to arrest erosion at the site-scale (i.e., particularly in high bed-load systems) are likely to fail and/or cause erosion elsewhere, and therefore should not be used to compensate for encroaching closer to the river. Even more so, piecemeal bank armoring and channelization within a stream network may cumulatively translate into much more dramatic occurrences of erosion, deposition and avulsion.

Avulsion on North St. Vrain Creek near Lyons, Colorado, through a residence during the September 2013 floods. Photo Credit: Michael Blazewicz (2013)

Another trend in current geomorphic-based practice is the development of a so-called planning-level exercise to delineate riverine erosion hazard areas based on valley geometry and the existing and/or calculated channel planform associated with natural sediment erosional and depositional processes. These methods benefit greatly from the use of LiDAR data, which is very costly, but still have a lower cost per mile than the design-level geomorphic practices, and make it possible to rapidly create maps for an entire jurisdiction adopting development guidelines, overlays and zoning. Backing up these rapid methods are more rigorous, field-based studies, modeling and engineering to verify delineations and further guide development siting and land use regulation.

Conceptual models are being implemented on a qualitative level to first identify the type of system response to floods (widening, bed incision, avulsion, etc.) based on the hydrology of the river, the stability status of the channel (e.g., channel evolution stage, land use change in watershed), its sediment load and caliber, and the relative strength of the banks (vegetation). Tools to predict river movement well and across many different types of rivers to draw defensible REH lines and quantify risk have not been fully vetted from a scientific standpoint, but there are well established tools for identifying riskier or more sensitive areas within a corridor at the reach scale (Brierley and Fryirs, 2005). Metrics that are quantifiable using remote sensing data such as valley confinement, channel slope, riparian zone condition, and flow variability are all useful information in characterizing river sensitivity to floods (Jagt et al. 2015).

Looking across the range of existing objectives, methods, costs and degree of risk management, the following “consensus” approach for the development of local riverine erosion hazard programs may be emerging:

- Start at a larger mapping scale with less expensive setback and geomorphological approaches, using remote sensing techniques;
- Refine maps as modelling and detailed field studies are completed at finer scales; and
- Allow for more detailed site-specific engineering or geotechnical analysis to be performed to refine maps and avoid site-specific hazards.

Current practice is evolving to meet the differing needs and physical realities across the continent, and therefore we must be skeptical of a prescriptive national standard. For instance, flood inundation models based on clear water hydraulics and floods with specified return frequencies have been universally applied with positive outcomes across the country (albeit consistently missing the effects of channel evolution), but imagine the outcome if the 100-year flood were applied universally to assess riverine erosion. Fluvial geomorphology is the interplay of water and land and requires the inclusion of factors based on climate, runoff characteristics, soils, surficial geology, vegetation and land uses as they may differ from region to region and often from one year to the next. Regional programs are also grappling with factors associated with river system response to:

- Extensive historic channel straightening, land drainage and channel incision;
- Changes in watershed hydrology and sediment regimes over historic periods, e.g., excessive tillage and grazing, forest disease and wildfire, loss of glaciated areas, or landscapes that have gone from forested to deforested and back to forested (over a span of 100 years), climate change impacts to overall precipitation trends and impacts from watershed urbanization;
- The existence and then loss, modification or relocation of beaver dams and mill dams, and;
- Extensive floodplain encroachment and channel confinement (i.e., how much structural riverine controls are engendered in the degree of avoidance selected by a jurisdiction in their land use regulations).

Local efforts have gone beyond mapping programs and have gained experience with establishing public policies and implementing land use controls to avoid riverine erosion hazards. A handful of states have also established programs, laws and regulations to address riverine erosion hazards. The avoidance and mitigation of riverine erosion hazards is being borne out in an array of public and private programs under the categories of land use regulation, technical assistance, funding assistance or incentives, and education and outreach

While river erosion hazards are not, as yet, folded into the NFIP, numerous federal agencies, including FEMA, are beginning to assist local and state jurisdictions in the development of programs to mitigate and manage riverine erosion hazards. This partnership is desperately needed. The issuance of EO 13690, including the directives that federal actions minimize harm, utilize climate-informed science, and restore and preserve natural and beneficial values of floodplains, is a new call to action that could greatly advance opportunities for cost-effective avoidance-based solutions.

Section 4 References

Brierley GJ, Fryirs KA. 2005. Geomorphology and River Management: Applications of the River Styles Framework. Oxford (UK): Blackwell Publishing. 398pp.

Jagt KF, Blazewicz M, Sholtes JS. 2015. Fluvial hazard zone delineation: A framework for mapping channel migration and erosion hazard areas in Colorado. Technical Report for Colorado Water Conservation Board, Floodplain Management Program. Denver (CO): Colorado Water Conservation Board. Available from *http://coloradohazardmapping.com/hazardMapping/phaseOneErosionMapping/Documents*

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SECTION 5 – OPPORTUNITIES

Several opportunities exist to improve the management of riverine erosion hazards in the U.S. These opportunities exist at all levels of government.

At the federal level, integrating riverine erosion hazard areas into the NFIP will require the development of detailed procedures for each of the traditional three components of the program: mapping, insurance and management. As part of the process of modifying existing NFIP regulations to accommodate management of riverine erosion hazards, clarification of other aspects of the NFIP regulations not directly related to riverine erosion can also be considered. The new provisions for riverine erosion could be harmonized with the existing coastal erosion policies. Development of the riverine erosion guidelines will require close coordination with programs at the state, county, district and local levels, some of which have been in place for some time. Finally, clarification of NFIP riverine erosion policies also provides an opportunity to contribute to the evolving FEMA RiskMAP program. The development of coordinated multi-hazard delineations in the RiskMAP program will permit a more comprehensive depiction of flood risk, from each contributing cause, and also as an overall assessment.

At the state level, delineation of riverine erosion hazard areas as an additional map layer with statewide coverage has already been completed, or is currently underway, by a few states, such as Vermont, New Hampshire, Washington and Indiana. Sharing success stories and encouraging stakeholders in other states to study and utilize them as models, as appropriate, can help other states to initiate similar programs in their jurisdictions. Important and useful information about the process of securing funding and the details of preparing such map data layers can be gained from studying successful programs in other states. Examples of state-led efforts can be found in Appendix C.

Even without a clear federal policy and mandate, many local communities throughout the nation have already adopted riverine erosion data layers developed at the state or local level as an overlay to the regulatory zoning layer. This makes the information about the delineated erosion hazard areas publicly available, and may also be accompanied by changes in the regulations for new development and redevelopment in these areas. This trend should be highlighted and shared with other local governments to encourage them to develop similar programs. Examples of local policies with regard to riverine erosion risk management can be found along with the examples from state programs in Appendix C.

SECTION 6 – RECOMMENDATIONS

Based on current technology and precedents set by federal National Floodplain Insurance Program policies and state and local Riverine Erosion Hazard Area (REHA) mapping initiatives, the following actions are recommended for REHA mapping and management programs:

Recommendation 1: Federal, state and local agencies should recognize the following foundational principles for riverine erosion hazard management:

- Not all rivers are the same. Different tools and approaches may be required for different rivers.
- Erosion hazard delineation techniques should account for local hydrologic, soil and climatic conditions; consider site-specific hydraulic data; and should reflect local topography, channel morphology, and stream processes operating over reasonable engineering time scales, rather than relying on single event channel response.
- Methodologies for delineating riverine erosion hazard areas must be reproducible and defensible, while recognizing the non-stationary nature of fluvial systems and erosion hazards.
- Past practices to control inundation may have caused some of the nation's erosion hazard vulnerability. The science to clarify the problems associated with using clear water hydraulics to support watershed management should be further developed and communicated.

Recommendation 2: Every state should have a riverine erosion hazard program that is supported by outreach, education, mapping protocols and monitoring.

- Early outreach to all potential stakeholders on the need for developing REHAs has been demonstrated to be important in several states that have started such a program, as is continuing education on identifying, monitoring, and mitigating riverine erosion hazards. These programs appear to work best when integrated into a broader discussion of flood hazards along with inundation.
- FEMA (1999) suggested that developing REHAs at the local level would allow for floodplain management to be adapted to local needs. The variety of programs and mapping protocols undertaken by sample communities presented in Appendix C indicates that this effort is well underway.
- Regional hydrogeomorphic variation dictates that locally-developed programs will be more adaptable to the specific environment. In many cases, variations in REHA mapping methodology may be required for major physiographic regions within a state or a county.
- States should continue to develop standards and methodologies for documenting riverine erosion. and document (with assistance from communities) actual riverine erosion using ground and aerial surveys, pre- and post-flood videos and photographic documentation, develop and maintain numerical models and establish GIS datasets. A central repository for historical flood documentation should be established and maintained for future reference and scientific evaluation.

Recommendation 3: States should promote a watershed approach to delineation and management of flood-related hazards.

- This is essential to ensure activities within river corridors outside the communities (agriculture areas, as an example) do not exacerbate existing issues or create new problems within the watershed.
- Watershed-wide activities outside of the river corridor often contribute to erosion within the corridor. These types of activities should be identified and impacts quantified locally.
- The implementation of local watershed-wide Best Management Practices (BMPs) for reducing erosion impacts should be encouraged through state and federal financial and regulatory incentives. See the principles promoted in The Nature Conservancy's "*Floodplains by Design*".
- Identify erosion hazards as a natural function and identify floodplain and channel development impacts that have public and private adverse economic impacts. Promote *The Active River Area* concept.

Recommendation 4: States, with the support of FEMA and other collaborating federal agencies, should conduct regular training to increase awareness of riverine erosion hazards and keep abreast of advances in technology.

- This training should be targeted at FEMA, state and local community floodplain reviewers, floodplain management agencies, permitting agencies, private-sector planners, engineers and other professionals involved in analyzing riverine erosion hazards.
- The target audience should be taught to recognize and delineate potential riverine erosion hazard areas.
- Training should be developed for risk-assessment and insurance professionals responsible for developing and administering damage coverage.

Recommendation 5: Federal agencies should establish preferential policies and embrace technical and financial incentives in support of state and local riverine erosion hazard programs.

- The impact of flooding crosses agency boundaries. Groups like the Silver Jackets, that foster multiagency federal, state and local collaboration are critical to responding effectively to flood hazards. Their important role needs continued recognition at the legislative level.
- For state and local riverine erosion hazard programs to be successful, multiple federal agencies, including USACE, USGS, USEPA, NRCS, FHWA and HUD, will need to recognize the value and need for such programs, support such programs through preferential policies and financial means, and refrain from supporting projects (including post-disaster activities) that may inadvertently undermine such programs in the long run.
- Erosion hazards should be required to be addressed in all state mitigation plans. The adoption of a FEMA-approved state hazard mitigation plan that include consideration of erosion hazards and annual reporting could provide the necessary assurance that federal and state policies are being achieved and trigger a higher federal cost-share for planning and project grants by various federal agencies.
- Similar to other federal agencies, FEMA could institute an annual state performance partnership grant that would give states with erosion-related damage the steady or secured resources necessary to develop their own mitigation and mapping program.

Recommendation 6: FEMA, in collaboration with other federal agencies, should assist and encourage local and state agencies to take the initiative to develop a riverine erosion hazard area data layer.

- Develop an inventory and a guidebook of best management practices for funding and developing a statewide riverine erosion hazard area data layer.
- Develop educational materials and outreach modules targeted at states, to clarify the necessity and benefits of state-led development of a riverine erosion hazard data layer.
- Develop a procedure to actively collect and store the best available riverine erosion hazard area data layers produced by state and local communities into the Risk MAP database as a non-regulatory product.

Recommendation 7: FEMA, in collaboration with other federal and state agencies, should assist and encourage local communities to adopt the best available riverine erosion hazard area data layer, or if such data is not yet available, adopt a minimum channel setback as an overlay zone, along with regulations for development/redevelopment in these areas.

- Local communities should be encouraged to adopt riverine erosion hazard area regulations as higher standards.
- Develop fact sheets, case studies and resource materials for local communities to use when they adopt higher standards for riverine erosion hazard area zones.

Recommendation 8: FEMA should explore linkages between delineation of riverine erosion hazard areas, and insurance and management concerns.

- Better understanding of the nature and type of riverine erosion hazards will result in better assignment of risk for insurance purposes and better public and private management of the actual hazards. For example, FEMA should revise its BCA to place a higher value on the buyout of structures and relocation of utilities in riverine erosion hazard areas (whether in regulatory floodplain or not) for the purpose of restoring floodplain function and reducing the need for stream channelization, both of which would reduce risks of flood and fluvial erosion to downstream communities.

Recommendation 9: FEMA and collaborating federal and state agencies should commit more resources to promote the application of fluvial geomorphic science

- Fluvial geomorphology can help explain local sediment and debris regimes, incised channel evolution and the changing nature of flooding and fluvial erosion in different landscapes.
- Fluvial geomorphology can also help demonstrate how stressors on stream systems can change over time.
- All federal and state agencies should participate in this effort, since the benefits will cut across many sectors of the economy, from public infrastructure to recreation and other ecosystem services.

Recommendation 10: Executive Order 13690 and the Federal Flood Risk Management Standard (FFRMS) should be implemented to restore or enhance processes associated with natural hydrologic, sediment and debris regimes.

- In so doing, federal, state, regional and local agencies would be minimizing and reducing erosion-related damage in the spirit of 44 CFR Chapter 1, Part 60.5(a), as discussed in Section 2 of this report.
- Deadlines should be established for federal agency compliance with the EO 13690 and FFRMS, and such individual federal agency compliance should be structured to use the best available riverine erosion data from state- and locally-adopted erosion hazard maps.
- State and federal agencies should collaborate in the development of appropriate techniques for the inclusion of climate change forecasts into the development of future erosion hazard zones, recognizing the non-stationary nature of fluvial systems.

Recommendation 11: ASFPM, with assistance from FEMA or other federal agencies, should initiate a project to develop a toolbox for analyzing and mapping erosion hazard areas. This should include guidelines for recognizing differences between erosion hazards created by local conditions and systemic hazards.

- Currently used riverine erosion hazard area delineation methods should be evaluated as part of this effort and a system of categorizing these methods based on the level of detail should be established (similar to the topographic mapping quality level system). Also needed are recommended protocols for modification of each level of erosion hazard mapping based on better data, methods, etc.
- This toolbox would include resource references, a model REHA ordinance, recommendations and guidelines for briefing local elected and non-elected decision makers, and recommendations for public education.
- This White Paper has focused on systemic erosion hazards resulting from watershed-wide or river-system drivers. A distinction should be made between these large-scale erosion hazards that can be mapped, and localized erosion hazards resulting from the improper design or construction of structures in the floodplain, or improper siting of floodplain or channel encroachments.

Section 6 References

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APPENDIX A: ADDITIONAL READING

1. Federal Emergency Management Agency (FEMA). 2015. Reducing Losses through Higher Regulatory Standards. FEMA-DR-4145-CO [Internet]. Washington, DC (US): FEMA. [accessed 2015 October 12]. Available from *http://www.fema.gov/media-library-data/1429759760513-f96124536d2c3ccc07b3db4a4f8c35b5/FEMA_CO_RegulatoryLAS.pdf*

   In March, 2015, FEMA published a manual titled, *Reducing Losses through Higher Regulatory Standards: 2013 Colorado Floods Case Study* (FEMA-DR-4145-CO). The manual discusses erosion hazards and highlights the City of Fort Collins, among other Colorado communities. The city has identified erosion buffer zones on several of its drainage ways. A focus of the report is erosion setbacks.

2. Flood Control District of Maricopa County (FCDMC). 2003. Draft Erosion Hazard Zone Delineation and Development Guidelines [Internet]. Phoenix (AZ): prepared by J.E. Fuller/Hydrology & Geomorphology, Inc. [accessed 2015 Oct 15]. Available from *http://floods.org/ace-files/documentlibrary/committees/Arid/Draft_EHZ_Guidelines-52203.pdf*

   In 2003, the Flood Control District of Maricopa County, Arizona, developed a set of draft guidelines for the evaluation of erosion hazards. Many of the recurrent issues in the evaluation and mitigation of erosion hazards are addressed. In the end, the proposed guidelines were not implemented in Maricopa County, but the report may be considered as an early example of local efforts to address the issue of erosion hazards in a comprehensive way. The methodologies recommended in the report have been applied in other jurisdictions outside of Maricopa County, including Arizona, Nevada, Utah, California and New Mexico.

3. The University of Massachusetts (Amherst) is researching mapping methods to delineate riverine erosion hazards. In June 2015, the *Fluvial Geomorphology Task Force* of the *UMass RiverSmart Communities* project held a technical workshop to assist the Commonwealth of Massachusetts in defining “river corridors.” During the workshop, subgroups critiqued the following eight papers to inform a mapping methodology development for a Massachusetts REH Program.

   3.1. Biron PM, Buffin-Bélanger T, Larocque M, Choné G, Cloutier CA, Ouellet MA, Demers S, Olsen T, Desjarlais C, Eyquem, J. 2014. Freedom Space for Rivers: A Sustainable Management Approach to Enhance River Resilience [Internet]. Environmental Management, 54(5): 1056–1073. [accessed 2015 Oct 1] Available from *http://doi.org/10.1007/s00267-014-0366-z*

   This method maps levels of risk of flooding and stream mobility. Overlaying these two graded maps creates a "Freedom Space" map with three levels of risk. Building from the work of Piegay, Baptist, Ollero, Kline and Cahoon, this protocol aims to combine inundation and erosion mapping on a reach or watershed scale. "Mobility Space" is calculated using migration rates determined from historical maps and photos, vegetation and soil data to estimate bank and floodplain erodibility, and topography to determine valley edges. "Flood Space" is mapped based on field assessment of morphologic evidence and desktop assessment of topographic evidence of flood susceptibility, as well as through assessment of wetland maps. Two levels of mobility (50 years and "floodplain") and three levels of flooding (high, medium and low) are determined and joined to create a three-tiered map of "Freedom Space" (minimum, functional and rare).

3.2. City of Austin. 2013. Guidance on Establishing an Erosion Hazard Zone [Internet]. Austin (TX): City of Austin, Watershed Protection Department. [accessed 2015 Oct 5]. Available from *https://www.austintexas.gov/faq/erosion-hazard-zone-criteria*

This method estimates basic erosion hazard zones adjacent to arroyos based on channel width and depth and meander belt width. The method was designed by the city of Austin to prevent development or improvement of property within erosion hazard zones. The protocol contains two levels of assessment: a simple and conservative Level 1 assessment, and a more detailed Level 2 assessment when the Level 1 results are determined to be too conservative. The delineated Erosion Hazard Zone covers the surface and subsurface, and it is based on potential future channel incision and accounts for channel migration within the active meander belt. Future vertical incision and lateral migration extents are estimated through a basic equation relating those distances to bankfull width and depth and the width of the channel meander belt.

3.3. Kline M, Alexander C, Pomeroy S, Jaquith S, Springston G, Cahoon B, Becker L. 2009. Vermont Stream Geomorphic Assessment Appendix E: River Corridor Delineation Process [Internet]. Waterbury (VT): Agency of Natural Resources. [accessed 2015 Oct 1]. Available from *http://www.vtwaterquality.org/rivers/docs/assessmenthandbooks/rv_apxecorridordef.pdf*

This method was developed as part of the Vermont geomorphic assessment protocol. Using this method, river corridor lines are drawn at multiples of the bankfull width around a drawn "meander centerline." Any part of these corridors that is cut off by a valley edge is extended on the other side of the river so that the full corridor is preserved where possible. The key parameters of the method are erodibility of channel banks, sediment and flow regime characteristics, confinement and degree of departure from reference conditions. This method, has three phases: Phase I is based on remote-sensing and windshield surveys, Phase II includes qualitative field measurements, while Phase III requires quantitative surveying to inform modeling.

3.4. Larsen EW. 2007. Sacramento River Ecological Flows Study: Meander Migration Modeling Final Report [Internet]. Chico (CA): The Nature Conservancy. [accessed 2015 Oct 5]. Available from *https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=92446*

This method uses stream power and shear stress relationships and basic physical parameters to predict future channel locations under specific discharge scenarios. Developed as part of the Sacramento River Ecological Flows Study, this model was designed to predict how a river will migrate over time under different management scenarios. The model maps the effective stream power—that which is above a minimum threshold value to produce erosion but below a maximum threshold value at which point the channel overtops its bank and no longer increases its bank-shear-stress. Basic land cover and geology are used to determine bank and floodplain erodibility. Stream power, erodibility and historical flow rates are used to predict site-specific migration rates.

3.5. Mussetter Engineering Inc. 2008. Sediment and Erosion Design Guide [Internet]. Rio Rancho (NM): Southern Sandoval County Arroyo Flood Control Authority. [accessed 2015 Oct 5]. Available from *http://sscafca.org/sediment-and-erosion-design-guide/*

This is a methodology for delineating a Lateral Erosion Envelope around arroyos using empirically-derived bank retreat equations based on bank material and incision depths. This resource provides a wide range of information about geomorphology, hydrology, and sediment dynamics. One key aspect is a description of a methodology for delineating a LEE around intermittent degraded streams (arroyos). This method focuses on empirically-derived bank retreat equations based on bank material and incision depths to create erosion hazard zones. Various methods for defining geomorphic parameters are suggested. The LEE product only includes surface areas. Bankfull discharge, bankfull width, and bank materials and soils information are used to calculate the longitudinal length and lateral distance of the erosion hazard zone. A safety setback is added to that distance to create the LEE.

3.6. Pasquale N, Perona P, Schneider P, Shrestha J, Wombacher A, Burlando P. 2011. Modern comprehensive approach to monitor the morphodynamic evolution of a restored river corridor [Internet]. Hydrology and Earth System Sciences, 15(4): 1197–1212. [accessed on 2015 Oct 1] Available from *http://doi.org/10.5194/hess-15-1197-2011*

Reconstruction of historical paths is used to determine channel migration rates and predict future channel locations. These predictions are tempered by natural and human confinements. The Morphodynamic Corridor is assumed to experience erosion in all cases while the Event Morphodynamic Corridor is only at risk during extreme floods. This method is part of the larger Italian framework for hydromorphological assessment, analysis and monitoring (IDRAIM). Other components include the "Morphological Quality Index," "Morphological Dynamics Index" and "Event Dynamics Classification." The results of these tools can be incorporated in the corridor delineation tool. These tools uses historical channel locations to determine migration rates and predict future locations. These predictions are tempered by natural and human confinements, determined from topographic maps.

3.7. Rapp CF, Abbe TB. 2003. A Framework for Delineating Channel Migration Zones. Ecology Final Draft Publication #03-06-027 [Internet]. Olympia (WA): Shorelands and Environmental Assistance Program, Washington State Department of Ecology. [accessed 2015 Oct 1]. Available from *http://www.ecy.wa.gov/pubs/0306027.pdf*

This method delineates the Channel Migration Zone based on a summation of other delineated zones. These other zones are the Historical Migration Zone, Avulsion Hazard Zone, Erosion Hazard Area, and Disconnected Migration Area. The CMZ = HMZ + AHZ + EHA – DMA. The AHZ, EHA and DMA are delineated through field mapping and the assessment of surficial geology, fluvial landforms, geotechnical characteristics and current physical conditions of the given area. When combined with historical data analysis, field observations provide the means for predicting future channel change and delineating the boundaries of the CMZ.

3.8. Smith MP, Schiff R, Olivero A, MacBroom J. 2008. The Active River Area: A Conservation Framework for Protecting Rivers and Streams [Internet]. Boston (MA): The Nature Conservancy. [accessed 2015

Oct 1]. Available from http://www.floods.org/PDF/ASFPM_TNC_Active_River_%20Area.pdf

This GIS-based tool is designed to map all of the areas important to the sediment and water processes in a river at a large scale. Analysis is very basic but incorporates fluvial processes, groundwater processes and sediment processes. Each process is modeled using a separate set of GIS steps and the resulting maps are combined. The region of the active river migration and movement of materials into the river is mapped using three basic GIS-based analyses.

4. The Washington Department of Ecology has created several supporting technical documents that are mentioned in Appendix C below. These technical documents were created to support the State Shoreline Management Act through the Act's Shoreline Master Program guidelines.

4.1. Legg NT, Olson PL. 2014. Channel Migration Processes and Patterns in Western Washington: A Synthesis for Floodplain Management and Restoration. Ecology Publication #14-06-028 [Internet]. Olympia (WA): Shorelands and Environmental Assistance Program, Washington State Department of Ecology. [accessed 2015 Oct 21]. Available from https://fortress.wa.gov/ecy/publications/SummaryPages/1406028.html

4.2. Legg NT, Heimburg C, Collins BD, Olson PL. 2014. The Channel Migration Toolbox: ArcGIS® Tools for Measuring Stream Channel Migration. Ecology Publication# 14-06-032 [Internet]. Olympia (WA): Shorelands and Environmental Assistance Program, Washington State Department of Ecology. [accessed 2015 Oct 21]. Available from https://fortress.wa.gov/ecy/publications/SummaryPages/1406032.html

4.3. Olson PL, Legg NT, Abbe T, Reinhart MA, Radloff J. 2014. A Methodology for Delineating Planning-Level Channel Migration Zones. Ecology Publication #14-06-025 [Internet]. Olympia (WA): Shorelands and Environmental Assistance Program, Washington State Department of Ecology. [accessed 2015 Oct 21]. Available from https://fortress.wa.gov/ecy/publications/SummaryPages/1406025.html

5. Jagt KF, Blazewicz M, Sholtes JS. 2015. Fluvial hazard zone delineation: A framework for mapping channel migration and erosion hazard areas in Colorado. Technical Report for Colorado Water Conservation Board, Floodplain Management Program [Internet forthcoming]. Denver (CO): Colorado Water Conservation Board.

The State of Colorado Water Conservation Board is in the process of developing, reviewing, and testing a protocol for mapping fluvial hazard zones for identifying and communicating riverine hazards throughout the state. As defined for this process, 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. This guidance outlines a hierarchical and geomorphic context-based framework for mapping the FHZ in Colorado. Factors including drainage area, channel slope, and valley confinement influence the type of channel response to floods as well as the method for mapping the FHZ. This protocol contains a two-level approach to mapping the FHZ. The first level (Level 1) relies primarily on remotely-sensed geomorphic data with field verification and is intended to be efficient in both time and cost for implementation across whole watersheds. The second level (Level 2), provides guidance for refining Level 1 FHZs for specific reaches or where complexities in land use and channel alteration make a Level 1 delineation challenging. Level 2 involves a greater level of effort and may include field and modeling components. The work has been informed by on-going fluvial hazard mapping efforts in Vermont, Washington, Indiana and the Arid Southwest.

APPENDIX B: GLOSSARY

100-year flood: See Base Flood.

A-zone: Area subject to inundation by 100-year flooding where wave action does not occur or where waves are less than 3 feet high; designated Zone A, AE, A1-A30, A0, AH or AR on a Flood Insurance Rate Map.

Armor: To protect slopes from erosion and scour by flood waters. Techniques of armoring include the use of woody vegetation, riprap, gabions or concrete.

Base flood: The flood flow that has a 1 percent probability of being equaled or exceeded in any given year. Also known as the 1 percent annual exceedance flood or 100-year flood.

Base Flood Elevation (BFE): Elevation of the base flood in relation to a specified datum, such as the National Geodetic Vertical Datum. The Base Flood Elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program.

Basin: A basin is a geographic area that contains and drains to a stream named and noted on common maps or a geographic area that drains to a non-flowing water body, such as a lake or marine area, named and noted on common maps.

Benefit-Cost Analysis: (BCA): BCA is the method by which the future benefits of a mitigation project are estimated and compared to its cost. The end result is a benefit-cost ratio (BCR), which is derived from a project’s total net benefits divided by its total project cost. To evaluate proposed hazard mitigation projects prior to funding FEMA requires a BCA to validate cost effectiveness.

Channel Migration Zone (CMZ): Although some variation is found among different geographic locations and regulatory agencies, a channel migration zone usually includes those areas within the lateral extent of likely stream channel movement that are subject to risk due to stream bank destabilization, rapid stream incision, stream bank erosion and shifts in the location of stream channels.

Clear Water Flow: A largely hypothetical flow condition free of any sediment and debris. Clear water flow can occur downstream of sediment traps such as dams and detention basins. A clear water flow is often erosive due to sediment transport imbalance.

Community Rating System (CRS): The CRS is a voluntary program under the NFIP that rewards participating communities, by providing flood insurance premium discounts, for exceeding the minimum requirements of the NFIP and completing activities that reduce flood hazard risk.

Depth of Flooding (DOF): The DOF is difference between the Base Flood Elevation and the elevation of the lowest grade adjacent to a structure.

Disaster Mitigation Act of 2000 (DMA 2000): The DMA 2000 is Public Law 106-390 and is the latest federal legislation enacted to encourage and promote proactive, pre-disaster planning as a condition of receiving financial assistance under the Robert T. Stafford Act. The DMA 2000 emphasizes planning for disasters before they occur. Under the DMA 2000, a pre-disaster hazard mitigation program and new requirements for the national post-disaster hazard mitigation grant program (HMGP) were established.

Disconnected Migration Area (DMA): The portion of the Channel Migration Zone (CMZ) where the channel has been physically disconnected from its CMZ by human constraints (as defined in *A Framework for Delineating Channel Migration Zones*, prepared by the Washington State Department of Ecology. Cited in Appendix A, above).

Drainage Basin: The catchment area that drains to a river, lake or other body of water.

Dynamic Equilibrium: Fluvial equilibrium is the relationship of sediment load and size to stream slope and discharge. Equilibrium is achieved when these elements are in balance. Dynamic equilibrium is achieved when a perturbation to one element of the four results in adjustments of one or more of the other three.

Erosion: The wearing away of the land surface by detachment and movement of soil and rock fragments, during a flood or storm, or over a period of years, through the action of wind, water or other geologic processes.

Erosion Hazard Area (EHA): The area of the Channel Migration Zone (CMZ) unaccounted for in the AHZ or the HMZ that delineates channel susceptibility to bank erosion from stream flow or mass wasting. The EHA is defined by the erosion setback (ES) and geotechnical setback (GS) (as defined in *A Framework for Delineating Channel Migration Zones*, prepared by the Washington State Department of Ecology. Cited in Appendix A, above).

Erosion Hazard Zone (EHZ): An area where stream channel erosion is likely to result in damage to or loss of property, buildings, infrastructure, utilities or other valued resources (as defined in City of Austin. 2013. *Guidance on Establishing an Erosion Hazard Zone*. Cited in Appendix A, above).

Erosion Setback (ES): As part of the Erosion Hazard Area (EHA), the ES encompasses the area outside the HMZ and AHZ that is susceptible to channel erosion; it includes those areas that are not at risk of avulsions, but are susceptible to stream or river erosion (as defined in A Framework for *Delineating Channel Migration Zones*, prepared by the Washington State Department of Ecology. Cited in Appendix A, above).

Federal Emergency Management Agency (FEMA): FEMA is an agency within the Department of Homeland Security created in 1978 to provide a single point of accountability for all federal activities related to disaster mitigation and emergency preparedness, response and recovery.

FEMA Floodway: The FEMA floodway is the channel of the stream and that portion of the adjoining floodplain that is necessary to contain and discharge the base flood flow without increasing the base flood elevation more than 1 foot.

Flood: Under the National Flood Insurance Program, a general and temporary condition or partial or complete inundation of normally dry land areas from (1) the overflow of inland or tidal waters, (2) the unusual and rapid accumulation or runoff of surface waters from any source, or (3) mudflows or the sudden collapse of shoreline land.

Flood Depth: Height of the flood water surface above the ground surface.

Flood Elevation: Height of the water surface above an established elevation datum, e.g., National Geodetic Vertical Datum, North American Vertical Datum, Mean Sea Level.

Flood Fringe, Zero-Rise: The zero rise flood fringe is that portion of the floodplain outside of the zero-rise floodway. The zero-rise flood fringe is generally a flood storage zone associated with standing water rather than flowing water.

Flood Hazard Area: Any area subject to inundation by the base flood or risk from channel migration including, but not limited to, an aquatic area, wetland or closed depression.

Flood Hazard Boundary Maps (FHBM): Map of a community issued by FEMA, where the boundaries of the flood, mudflow and related erosion areas having special hazards have been designated.

Flood Insurance Rate Map (FIRM): Map of a community, prepared by the Federal Emergency Management Agency that identifies special hazard areas and risk premium zones applicable to the community. The latest FIRM issued for a community is referred to as the "effective" FIRM.

Flood Insurance Study (FIS): Examination, evaluation, and determination of flood hazards and, if appropriate, corresponding water surface elevations in a community or communities, or examination, evaluation, and determination of mudslide (i.e., mudflow) and/or flood-related erosion hazards in a community or communities.

Flood Risk Reduction: An action taken to decrease exposure of people and property to flood or channel migration hazards.

Floodplain: The floodplain is the total area subject to inundation by the base flood.

Fluvial Geomorphology: The science that studies river landform history to understand formative processes and predict changes using a combination of field observation, experimental studies and numerical models.

Freeboard: A factor of safety usually expressed in feet above a flood level for purposes of floodplain management.

Future Conditions Hydrology: Future conditions hydrology is the flood discharges associated with projected land-use conditions based on a community's zoning maps and/or comprehensive land-use plans and without consideration of projected future construction of flood detention structures or projected future hydraulic modifications within a stream or other waterway, such as bridge and culvert construction, fill and excavation. Traditionally, this approach has not been considered or included any impacts due to climate change.

Geomorphology: The interdisciplinary and systematic study of landforms and their landscapes as well as the earth surface processes that create and change them.

Geotechnical Engineering: Geotechnical engineering deals with earth materials, including soil, rock, and groundwater. In addition to participating in the design, construction, and operation of most civil engineering projects, geotechnical engineers also deal with various geologic hazards impacting our society, such as landslides, soil erosion and earthquakes.

Geotechnical Setback (GS): As part of the Erosion Hazard Area (EHA), the GS extends from the outer boundary of the Erosion Setback (ES) for the purpose of establishing a stable slope configuration following mass wasting. GS delineation accounts for the natural adjustment process that an embankment over-steepened by channel erosion will go through (as defined in *A Framework for Delineating Channel Migration Zones*, prepared by the Washington State Department of Ecology. Cited in Appendix A, above).

Hazard: An event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business and other types of loss or harm.

Hazard Mitigation: Hazard mitigation refers to reduction or alleviation of the loss of life, personal injury, and property damage that could result from a disaster through long- and short-term strategies. Hazard mitigation can be structural or non-structural involves strategies such as planning, policy changes, programs, projects and other activities that could mitigate the impacts of hazards.

Historical Migration Zone (HMZ): The portion of the Channel Migration Zone (CMZ) study area that the channel occupied in the historical record (as defined in *A Framework for Delineating Channel Migration Zones*, prepared by the Washington State Department of Ecology. Cited in Appendix A, above).

Hydraulics: The branch of science or engineering that addresses fluids (especially water) in motion in rivers or canals, works, and machinery for conducting or raising water, the use of water as a prime mover, and other fluid-related areas.

Hydrology: The scientific study of the movement, distribution, and quality of water on Earth and other planets. Hydrology includes *hydrometeorology*, *surface hydrology*, groundwater hydrology (*hydrogeology*), *drainage basin* management and *water quality*.

Large Woody Debris (LWD): Large pieces of wood in or partially in stream channels, including logs, pieces of logs, root wads of trees and other large chunks of wood. LWD provides streambed and bank stability and habitat complexity. LWD may occur naturally, or can be placed to provide habitat and/or channel.

Lateral Erosion Envelope (LEE): is the expected lateral erosion limit that can be expected by a series of typical runoff events over a 30-year period, but not including a 100-year storm event (as defined in the *Sediment and Erosion Design Guide*, prepared for Southern Sandoval County Arroyo Flood Control Authority. Rio Rancho, New Mexico. Cited in Appendix A, above).

Levee: A manmade structure, usually a reinforced earthen embankment, designed and constructed to contain, control, or divert the flow of water so as to provide protection from temporary flooding. Similar to a berm, a levee also has the connotation of being certified to provide protection to otherwise flood prone areas.

Levee, Training: A partial levee system that does not tie off to high ground at one or both ends and functions as a raised revetment to redirect the main flow of the river. A training levee is designed to prevent bank erosion and channel migration or avulsion. A training levee does not contain the base flood, but may provide limited protection against low level flooding.

National Flood Insurance Program (NFIP): The federal program under which flood-prone areas are identified and flood insurance is made available to the owners of the property in participating communities.

National Flood Insurance Reform Act of 1994 (NFIRA): The National Flood Insurance Reform Act of 1994 resulted in major changes to the National Flood Insurance Program (NFIP). The Act, which amended the Flood Disaster Protection Act of 1973, provides tools to make the NFIP more effective in achieving its goals of reducing the risk of flood damage to properties and reducing federal expenditures for uninsured properties that are damaged by floods.

Native Vegetation: Native vegetation refers to plant species indigenous to a region that reasonably could be expected to naturally occur on a specific site.

No Adverse Impact Floodplain Management (NAI): A concept where the action of one property owner does not adversely impact the rights of other adjacent, upstream or downstream property owners, as measured by increased flood peaks, flood stage, flood velocity and erosion and sedimentation.

Planform: The alignment and width of a river or stream channel as seen from above.

Nonstructural Solutions: Nonstructural solutions are methods of reducing flood risks through institutional controls such as floodplain development regulations, rather than structurally altering the river or stream itself. Another nonstructural floodplain solution includes preservation of the natural channel and floodplain through establishment of a flood right-of-way or easement.

Regulatory Floodplain: This term refers to an area managed and administered as floodplain through land-use regulations. It includes, but is not limited to, areas designated by FEMA and published on FIRMs, and additional areas identified by other government agencies as being susceptible to flooding using the best available flood information.

Repetitive Loss Property: A repetitive loss property is any NFIP-insured property that, since 1978 and regardless of any change(s) of ownership during that period, has experienced any of the following:

- Four or more paid flood losses exceeding $1,000 each,
- Two paid flood losses exceeding $1,000 each within any 10-year period since 1978, or
- Three or more paid losses that equal or exceed the current value of the insured property.

Repetitive Loss Area: A defined area that includes identified repetitive loss properties and other properties not listed as repetitive loss that are subject to the same flooding conditions.

Revetment: A facing of stone, broken rock or other material placed on a stream bank or slope to minimize erosion by moving water.

Riparian Area: The area adjacent to flowing water, for example, rivers, perennial or intermittent streams, seeps or springs, that contains elements of both aquatic and terrestrial ecosystems, which mutually influence each other.

Risk: Risk is the estimated impact that a hazard would have on habitat, people, services, facilities and structures in a community. Risk measures the likelihood of a hazard occurring and resulting in an adverse condition that causes injury or damage. Risk is often expressed in relative terms such as a high, moderate, or low likelihood of sustaining damage above a particular threshold due to occurrence of a specific type of hazard. Risk also can be expressed in terms of potential monetary losses associated with the intensity of the hazard.

Risk Assessment: Risk assessment is the process of measuring potential loss of life, personal injury, economic injury and property damage resulting from hazards. This process assesses the vulnerability of people, buildings and infrastructure to hazards and focuses on (1) hazard identification, (2) impacts of hazards on physical, social and economic assets, (3) vulnerability identification, and (4) estimates of the cost of damage or costs that could be avoided through mitigation.

Risk Mapping, Assessment and Planning (Risk MAP): is the Federal Emergency Management Agency (FEMA) Program that provides communities with flood information and tools they can use to enhance their mitigation plans, such as more precise flood mapping products, risk assessment tools and planning and outreach support.

Riverine: Of or produced by a river or stream. Riverine floodplains have readily identifiable channels.

Riverine Erosion Hazard Area (REHA): An area where erosion or avulsion is likely to result in damage to or loss of buildings and infrastructure.

Scour: Removal of soil or fill material by the flow of flood waters. The term is frequently used to describe storm-induced, localized conical erosion around pilings and other foundation supports where the obstruction of flow increases turbulence. See Erosion.

Special Flood Hazard Area (SFHA): An area within a floodplain having a 1 percent or greater chance of flood occurrence in any given year (100-year floodplain); represented on Flood Insurance Rate Maps by darkly shaded areas with zone designations that include the letter A or V.

Structural Solution: Reducing flood hazard through physical means, such as dams, levees, revetments or channelization of rivers and streams.

Structure: A structure is anything permanently constructed in or on the ground, or over the water; excluding fences 6 feet or less in height, decks less than 18 inches above grade, paved areas and structural or non-structural fill.

Undermining: Process whereby the vertical component or erosion or scour exceeds the depth of the base of a building foundation or the level below which the bearing strength of at the foundation is compromised.

Vulnerability: The extent of exposure or susceptibility of an asset to damage. Vulnerability depends on an asset's construction, contents, and the economic value of its functions. Like indirect damages, the vulnerability of one element of the community is often related to the vulnerability of others. For example, many businesses depend on uninterrupted electrical power. Flooding of an electric substation would affect not only the substation itself but businesses as well. Often, indirect effects can be much more widespread and damaging than direct effects.

Watershed: An area of land that drains into a single outlet and is separated from other drainage basins by a topographic divide.

Water Surface Elevation: Height of the water surface above an established elevation datum, e.g., National Geodetic Vertical Datum, North American Vertical Datum, Mean Sea Level, reached by floods of various magnitudes and frequencies in the floodplains of coastal, lacustrine and riverine areas.

X-zone: A flood hazard zone outside the 100-year floodplain, in which flood risk is moderate to minimal. Older maps differentiate the X Zone into Zones B and C, which represent moderate and minimal flood risks, respectively.

Zone: A geographical area shown on a Flood Insurance Rate Map (FIRM) that reflects the severity or type of flooding in the area.

APPENDIX C: STATE, COUNTY AND LOCAL PROGRAMS

State, county and local riverine erosion hazard programs have provided the following short program descriptions. Any and all jurisdictions that have a program now or are in the process of beginning a program are encouraged to send a program description to *editor@floods.org* for inclusion in future versions of this paper.

Please name the jurisdiction, provide a brief description that will help others understand the types of information that you may be willing and able to share, including one or more key URLs where people may access more information about your program, and provide a key program staff person willing to answer questions. Here's a template:

City, County, State of _______________: Brief description (i.e., one to three short paragraphs)

Program URLs:

Contact Information:

STATE PROGRAMS

State of Arizona Dept. of Water Resources State Standards Work Group has developed guidelines for determining erosion hazard setbacks for new development. State Standard 5 "Watercourse Bank Stabilization" describes the setback requirements.
http://www.azwater.gov/AzDWR/SurfaceWater/FloodManagement/StateStandards.htm

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State of Colorado enacted legislation in 2015 to establish a statewide erosion hazard mapping program. This program will establish an interagency technical panel to develop erosion zone mapping methodologies, update stormwater criteria manual, develop model land use codes and develop new maps in prioritized areas in partnership with local communities. The legislation will also seek to establish standards for debris flow mapping. The new law may be found here:
http://www.leg.state.co.us/clics/clics2015a/csl.nsf/fsbillcont/ABF9F124C63B39CE87257E0400702AD1?Open&file=245_enr.pdf

To date, Colorado has made efforts to map erosion hazards through its watershed master planning effort in several watersheds. Additional information regarding the erosion mapping program will be found at the Colorado Water Conservation Board Agency's website:
http://www.coloradohazardmapping.com/Documents

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State of Indiana, through the Indiana Silver Jackets, has supported the development of the Indiana Fluvial Erosion Hazard Mitigation Program to address continuing losses to erosion. Flood losses have continued to increase in Indiana, and one area of flood loss that had not been historically addressed was fluvial erosion hazards. In the early 1990s it was recognized that fluvial erosion could account for as much as 60 percent of the loss and damage from some floods. Despite that recognition, most Indiana flood hazard mitigation programs were still focused on the inundation portion of the flood hazard. To help address erosion hazards, the Indiana FEH Program has developed regional curves for Indiana, refined FEH mapping methods for Indiana streams, quantified erosion rates for selected Indiana streams, added predicted bankfull channel geometry to U.S. Geological Survey Indiana StreamStats, prepared and started disseminating advisory fluvial erosion hazard corridor maps, and identified and mapped infrastructure with potential for FEH damage in over 16 watersheds. The program is funded by the Indiana Office of Community and Rural Affairs.

For more information about the Indiana FEH Program please visit our website: *http://feh.iupui.edu/*, or contact:

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Commonwealth of Massachusetts is developing guidelines and procedures to incorporate fluvial geomorphic principles into management of river corridors. A fluvial geomorphology and river management consortium including representatives from UMass Extension, the UMass Center for Agriculture, Food and the Environment, UMass Department of Geosciences and Massachusetts Geological Survey implemented a participatory approach to fluvial risk management design. Beginning in 2012, we have engaged expert stakeholders from across Massachusetts and New England to develop and meet Massachusetts-specific fluvial risk management goals. In multiple, structured participatory workshops, we crafted fluvial risk management goals and a definition of the Massachusetts river corridor, and we analyzed current corridor delineation methods in the context of our definition to develop a Massachusetts river corridor delineation methodology. We crafted action items to move the fluvial risk management design from planning to application.

Results of this effort, including our corridor definition, methodology, and implementation strategy may be found here: *https://extension.umass.edu/riversmart/*

More information about research in Massachusetts rivers can be found at:
http://extension.umass.edu/riversmart/

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State of Montana has initiated the development of an erosion hazard mapping program.
http://geoinfo.msl.mt.gov/Home/data/montana_channel_migration_zones

Yellowstone River Channel Migration Zone Mapping

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State of New Hampshire has protocols in place to conduct geomorphic assessments and identify fluvial erosion hazards, and provides information and technical assistance to communities relative to channel erosion and migration issues. A fact sheet may be found here:

http://des.nh.gov/organization/commissioner/pip/factsheets/geo/documents/geo-10.pdf

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State of Oregon has been working to complete a Statewide Channel Migration Assessment with funding from the Oregon Department of Land Conservation and Development. The assessment will help prioritize areas where detailed channel migration studies should be performed. A summary page for the program where project links may be accessed is at:

http://www.oregongeology.org/flood/channelmigration.htm

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State of Vermont has enacted laws requiring the state to reduce fluvial erosion hazards by creating and distributing river corridor maps; establishing procedures and rules governing state regulatory decisions; and creating incentives for the municipal adoption of bylaws protecting river corridors and floodplains (10 V.S.A. Chapter 49).

River corridor designs are based on the existing, historic and calculated river meander belts. A majority of Vermont streams and rivers have been channelized historically and are now incised within narrow, mountainous valleys, disconnected from their floodplains. The protected river corridor keeps new development out of harm's way as the river evolves toward a dynamic equilibrium, as well as minimizing the need for further channelization, which transfers erosion and erosion hazards to properties and infrastructure downstream.

The Vermont Rivers Program consists of river, floodplain, and flow management sections that share habitat, water quality, and hazard mitigations objectives. The technical assistance and regulatory aspects of these sections are integrated through equilibrium, connectivity, hydrologic and river corridor performance standards.

The Vermont Agency of Natural Resources publishes river corridor maps on its web-based Natural Resource Atlas. The ANR Rivers Program provides technical assistance to local communities and regional planning commissions to collect and utilize stream geomorphic data and river corridor plan recommendations for updating local hazard mitigation plans and adopting river corridor and floodplain protection bylaws.

The state has adopted Flood Hazard Area and River Corridor Rules governing all activities that are statutorily exempt from municipal regulation (e.g., utilities, state buildings and roads). Procedures have also been adopted to explain the state's protocols for creating and updating of river corridor maps and establishing a "No Adverse Impact" standard used in administering these rules and the State Land Use Laws (Act 250). Regulatory and technical guidance documents, as well as data links and ANR's assessment and mapping protocols may be found at: *http://www.watershedmanagement.vt.gov/rivers.htm*

For information about Vermont's outreach and support to municipalities, see: *http://floodready.vermont.gov/*

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<u>State of Washington</u> incorporates channel migration and erosion hazards into its State Shoreline Management Act through the Act's administrative codes Shoreline Master Program guidelines. Local communities are responsible for implementing the Shoreline Master Program guidelines. The guidelines require communities to identify and regulate development in channel migration zones. The Washington State Department of Ecology works with local communities to update their Shoreline Master Programs. Ecology provides technical guidance and assistance for mapping channel migration zones and implementing the Shoreline Master Program in relation to channel migration.

The state act and regulations links are at: *http://apps.leg.wa.gov/rcw/default.aspx?cite=90.58*

Shoreline Master Program guidelines at: *http://apps.leg.wa.gov/wac/default.aspx?cite=173-26*; includes citations specific to watershed characterization and inventory; definition of channel migration; flood hazard reduction; critical area requirements; modifications; shoreline stabilization; and conditional use for dredge material disposal and for mining .

Supporting technical guidance (cited above in Appendix A):
Olson PL, Legg NT, *et al.* 2014. A Methodology for Delineating Planning-Level Channel Migration Zones: *https://fortress.wa.gov/ecy/publications/SummaryPages/1406025.html*

Legg, N.T., and Olson, P.L., 2014, Channel Migration Processes and Patterns in Western Washington: A Synthesis for Floodplain Management and Restoration:
https://fortress.wa.gov/ecy/publications/SummaryPages/1406028.html

Legg NT, Heimburg C, Collins BD, Olson PL. 2014. The Channel Migration Toolbox: ArcGIS® Tools for Measuring Stream Channel Migration:
https://fortress.wa.gov/ecy/publications/SummaryPages/1406032.html

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COUNTY PROGRAMS

Clackamas County, Oregon is actively pursuing Channel Migration Zone risk reduction methods for the upper Sandy River. Below is a link to a recent report and supporting mapbook files commissioned from Natural Systems Design, including an innovative "relative elevation mapping" technique the NSD uses. *http://office.naturaldes.com/htcomnet2/Handlers/AnonymousDownload.ashx?folder=7bcda461*

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King County, Washington began regulating land use within mapped Channel Migration Zones in 1999 and the regulations were incorporated into King County Code as part of the Critical Areas Ordinance. King County Channel Migration Zone (CMZ) mapping protocols were revised in 2014 for consistency with the 2012 King County Shoreline Master Plan update, the Washington State Administrative Code (WAC 176-26-221(3)(b)) and Washington State Department of Ecology guidelines.

King County has studied and mapped CMZs along five major rivers, with two other studies in progress to map CMZs along most King County's major river channels. This continued effort to identify channel migration hazards is part of King County's flood hazard management program. Each CMZ study looks at historic channel locations, geology, basin hydrology, riverbank materials, current channel conditions, abandoned channels and potential avulsion sites, channel migration rates, and existing infrastructure to characterize channel migration zones. Study findings are used to map both severe hazard and moderate hazard areas within the channel migration zone. King County's CMZ land use regulations include the restriction of new development within the severe hazard area of the CMZ. New development also may be greatly limited within the moderate hazard area.

In addition to land use regulation, King County CMZ studies and maps are utilized for other floodplain management purposes. King County is preparing river corridor plans along five river areas to develop flood risk reduction actions, such as capital projects. The river corridor plans integrate multiple objectives to identify a desired future condition of the river corridor. The river corridor planning process identifies problems, evaluates alternative solutions, and mitigates impacts on a cumulative scale. Because channel migration hazard is a key component of flood risks affecting these river corridors, CMZ studies and maps are integral to producing informed and comprehensive river corridor plans.

More information on King County's channel migration mapping program can be found here: *http://www.kingcounty.gov/services/environment/water-and-land/flooding/maps/migration.aspx*

More information on King County's River and Floodplain Management Program, including the River Corridor Planning process, can be found here:
http://www.kingcounty.gov/depts/dnrp/wlr/sections-programs/river-floodplain-section.aspx

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Maricopa County, Arizona, Flood Control District develops Watercourse Master Plans (include erosion hazard zones). Drainage manual includes a methodology for determining event-specific erosion hazard setback distances.

Erosion setback methodology at http://fcd.maricopa.gov/downloads/manuals/Hydraulics-Manual.pdf

Erosion policies at http://fcd.maricopa.gov/downloads/manuals/policies-standards-manual.pdf

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Pierce County, Washington identifies areas at severe risk of channel migration as a floodway. Channel Migration Zone floodways are regulated on the three most populated rivers. The floodplain code is found in Pierce County Code Title 18E.70 and a recently revised river hazard management plan describes the program in detail:

http://www.piercecountywa.org/Archive.aspx?AMID=118

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Pima County, Arizona, Regional Flood Control District established erosion hazard setbacks and an erosion hazard management ordinance.

Erosion setback regulations at https://www.municode.com/library/az/pima_county/codes/code_of_ordinances?nodeId=TIT16FLMA_CH16.28ERHAARBUSE (Chapter 16.28)

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<u>Salt Lake County, Utah</u> delineated the Jordan River Meander Migration Corridor

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<u>Washington County, Utah</u>, FEMA sponsored erosion hazard delineations for several river systems – Virgin River, Beaver Dam Wash and Shoal Creek.

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MUNICIPAL PROGRAMS

<u>City of Austin, Texas</u> has code and criteria that regulate development that may be potentially impacted by future erosion. The city has mapped erosion hazard zones for several watersheds within the desired development zone and requires an analysis for new development proposed within 100 feet of any creek centerline with a drainage area greater than 64 acres. Here is a link to the drainage criteria that applies to the erosion hazard zones:
http://www.austintexas.gov/sites/default/files/files/Watershed/erosion/EHZ_Criteria_2013_Q3.pdf

For a general website link to Austin's Erosion Control and Stream Restoration Program, please use the following: *http://www.austintexas.gov/department/erosion-control-stream-restoration*

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<u>City of Fort Collins, Colorado</u> has mapped an erosion buffer zone on several creeks and has specific regulations that apply to these areas. Here is a link to the regulations that apply to the erosion buffer zones: *http://www.colocode.com/ftcollins/municipal/chapter10.htm#sec10d201*

For a general website link, please use the following:
http://www.fcgov.com/utilities/what-we-do/stormwater

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<u>City of Phoenix, Arizona</u> adopted an Erosion Hazard Zone as zoning overlays (e.g., Skunk Creek)

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City of Tucson, Arizona requires new development to be set back from the banks of streams.
http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=60970

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Washington City, Utah delineated Erosion Hazard Zones for Virgin and Santa Clara rivers and the Ft. Pearce and Sand Hollow washes.

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