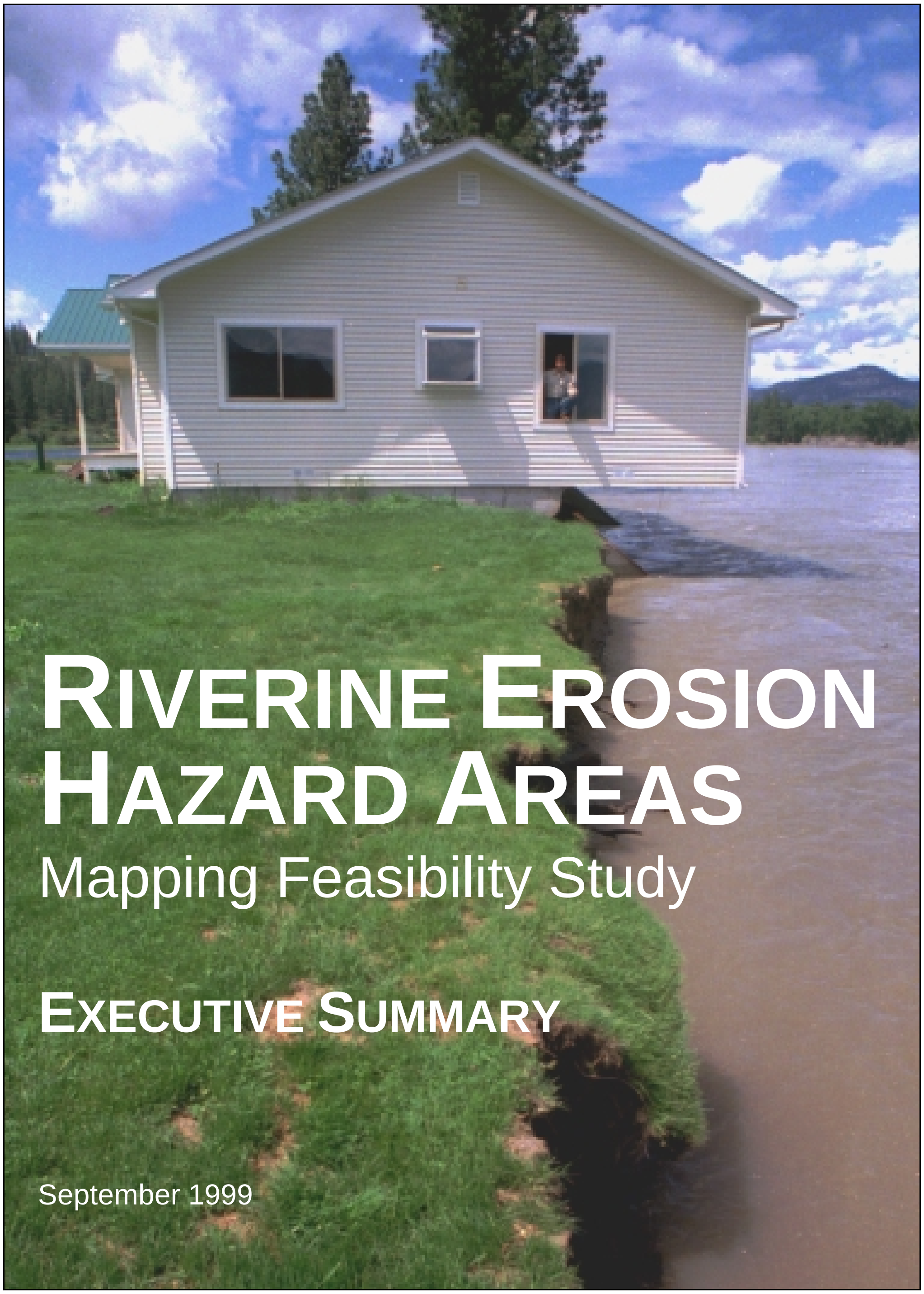
FEDERAL EMERGENCY MANAGEMENT AGENCY

TECHNICAL SERVICES DIVISION
HAZARDS STUDY BRANCH



RIVERINE EROSION HAZARD AREAS

Mapping Feasibility Study

EXECUTIVE SUMMARY

September 1999

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Cover: House hanging 18 feet over the Clark Fork River in Sanders County, Montana, after the river eroded its bank in May 1997. Photograph by Michael Gallacher.

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Report Preparation

In reponse to the National Flood Insurance Reform Act of 1994, Section 577, this report was prepared by the Hazards Study Branch, Technical Services Division, Mitigation Directorate, FEMA.

Acknowledgements

The project team expresses sincere thanks to the following persons who assisted in the review of this report:

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Executive Summary

This Riverine Erosion Hazard Area (REHA) mapping feasibility study addresses requirements in the National Flood Insurance Reform Act (NFIRA) enacted in September 1994. Section 577 of NFIRA requires that FEMA submit a report to Congress that evaluates the technological feasibility of mapping REHAs and assesses the economic impact of erosion and erosion mapping on the National Flood Insurance Program (NFIP). The purpose of this study is to determine whether it is technologically feasible to map riverine erosion hazard areas.

Section 577 of NFIRA has specifically defined an erosion hazard area as follows:

> Erosion hazard area means, based on erosion rate information and other historical data available, an area where erosion or avulsion is likely to result in damage to or loss of buildings and infrastructure within a 60-year period.

In the context of this study, erosion is the removal of a volume of sediment from a stream reach. However, in riverine areas, a stream reach can be stable and still migrate back and forth. Channel instability occurs when natural or man-induced processes lead to excessive erosion or deposition. Therefore, when a stream migrates laterally but maintains its dimensions, pattern, and profile, stability is achieved even though the river is "active" and moves across the floodplain. For this study, a reach experiencing this type of lateral migration is considered to be "eroding," and thus has an associated REHA. This is because stream migration can threaten buildings and infrastructure.

Collapsed house on eroding streambank along the Cimarron River in Logan County, Oklahoma in March 1998. Photograph courtesy of Kathy Schmidt.

Technological feasibility is defined as existence of:

> Methodologies that are scientifically sound and implementable under the NFIP. Scientific soundness means that the methodologies are based on physical or statistical principles and are supported by the scientific community. "Implementable" means that the approaches can be applied by FEMA as part of a nationwide program under the NFIP and for an acceptable cost.

In the present study, the project team conducted a search of existing methodologies used to predict riverine erosion, with emphasis on case studies. In general, case studies were categorized as:

1. *Geomorphic methods* - relying primarily on historic data and geomorphic investigations;
2. *Engineering methods* - relying primarily on predictive equations based on engineering and geomorphic principles; and
3. *Mathematical modeling methods* - relying primarily on computer modeling of fluvial processes.

A Project Working Group (PWG) of experts in the field of riverine erosion was organized. Their functions were to provide guidance to FEMA on technological feasibility of mapping REHAs, to act as an information source to locate and select case studies, and to review and comment on reports prepared during the study. The PWG included a nationwide mix of individuals from academia; Federal, State, regional and local government; and the private sector.

Based on the literature review, case study analysis, and input from the PWG, methodologies for analyzing and mapping REHAs were identified. A determination on technological feasibility was reached.

Using cost data associated with existing case studies, the study team estimated the approximate unit cost (*i.e.*, cost per river mile) of conducting riverine erosion hazard studies and adding the areas to existing Flood Insurance Rate Maps (FIRMs). The study team estimated the approximate overall costs for conducting studies and mapping the riverine erosion hazard areas nationwide.

Riverine Erosion

Fluvial systems respond to perturbations that may be the result of naturally occurring inputs, such as precipitation, or human intervention in the form of urban development, forestry, mining, flow diversions, flood regulation, navigation, and other activities. Complex physical processes whose mathematical characterization is still imperfect govern the response, although there is reasonable qualitative understanding of the nature of this response. The basic premise is that streams are constantly attempting to attain a state of balance involving their geometry (dimensions, pattern, profile), the properties of the bed and bank material, and the external inputs imposed. The process to achieve this state of equilibrium can span long periods and affect large areas.

In the context of riverine erosion hazard areas, engineers are mostly concerned with migration of the channel alignment and various forms of erosion and deposition. These events can potentially occur in any stream environment but are often most dramatic in arid and semi-arid regions where the large sediment yields and the flashy character of floods can cause severe changes in channel configuration.

Numerous factors affect the spatial and temporal response of a stream channel. These factors encompass various aspects of geomorphology and fluid mechanics and include fluid properties, sediment characteristics, discharge, sediment transport, channel geometry, and fluid velocities. The behavior of these variables depends on the time scale under consideration: short term, long term, and very long (geologic) term. For example, channel geometry can be considered relatively constant in the short term of a few weeks but highly variable in the geologic time frame.

For most practical applications, engineers are interested in phenomena that take place in the short and long term; thus, certain variables can be considered independent. For instance, in the geologic time frame, valley slope is a function of geology and climate; however, short- and long-term channel formation processes occur at a much faster rate, and valley slope can be considered independent in many instances. For short and long term analyses, it can be assumed that the discharge regime and sediment supply are the driving variables that act on channel boundaries and vegetation to produce changes in channel cross section, longitudinal profile, and alignment.

Mobile home destroyed after bank collapse in Flamingo Wash during the July 8, 1999 flood in Las Vegas, Nevada. Photograph courtesy of Leslie Sakumoto.

Erosional and depositional processes in alluvial channels are defined as follows:

Degradation:	Lowering of the channel bed on a substantial reach length occurring over a relatively long period of time in response to disturbances that affect general watershed conditions, such as sediment supply, runoff volume, and artificial channel controls.
Aggradation:	Raising of the channel bed as a result of disturbances in watershed conditions that produce the opposite effect to those leading to degradation.
General Scour:	Lowering of the streambed in a general area as a consequence of a short-duration event such as the passage of a flood. Examples are the erosion zones near bridge abutments and those in the vicinity of gravel pits.
Local Scour:	Lowering of the bed due to localized phenomena such as vortex formation around bridge piers.
Deposition:	Raising of the streambed due to a specific episode. An example is the formation of a sand bar after a flood event. Deposition is used in this document as the counterpart to general scour.
Lateral Migration:	Shifting of the streambank alignment due to a combination of the above vertical erosional and depositional processes. The most common example is meander migration in the floodplain. Bank retreat due to mass failure is another example.

Vertical variations in the streambed are additive in that the net change is the result of long- and short-term processes. For instance, a reach that is undergoing aggradation due to increased sediment yield from the watershed can also experience general and local scour as a consequence of flood events.

Streams are constantly progressing towards a state of dynamic equilibrium involving water and sediment. The geometry of the stream undergoes adjustments so that the sediment transport capacity of the water is in balance with the sediment supply. Natural and artificial factors can upset this state of equilibrium. Earthquakes, large floods, climatic changes, urbanization, and construction of civil works in the waterway introduce changes in the sediment supply and amount of runoff reaching the stream. For example, development in the watershed typically increases the impervious area and hence the volume of runoff. Similarly, clear-cutting of forests increases the sediment yield to the stream. Dams trap sediment and have a regulating effect that increases low flows and reduces high flows. Channelization projects reduce channel length and therefore increase slopes. Diversions for irrigation or public water supply reduce the effective flows. Finally, an event such as a large flood can dramatically reshape the floodplain and increase channel width.

Evaluation of Channel Changes

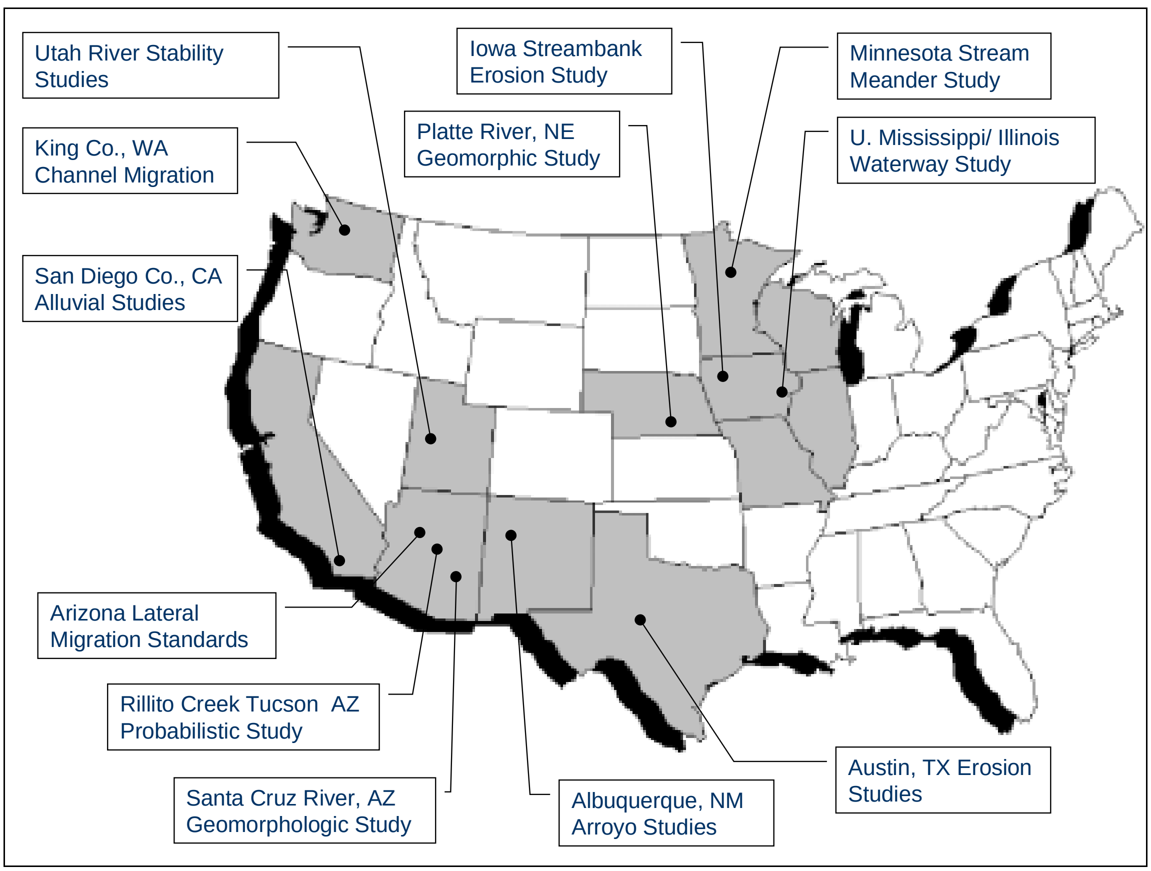
Mathematical representation of fluvial fluid mechanics is difficult due to imperfect knowledge of the complex physical phenomena involved. The many attempts to modeling of fluvial processes have shortcomings largely due to the fact that sediment transport equations commonly overpredict or underpredict sediment loads by orders of magnitude of actual measured sediment transport rates.

Some analysis methods are based on the hypothesis that the stream system tends toward a state of dynamic equilibrium in which the channel adjusts to changes in the water and sediment supply regimes. These methods include simple equations called "regime relationships," techniques based on mechanical stability conditions, and complex computer models. These equilibrium-based approaches have difficulties in accounting for ever-changing land use conditions.

In addition to fluvial processes, numerous climatic, environmental and geotechnical factors are involved. Hydrodynamically induced erosion and deposition and the occurrence of mass failure of the streambanks drive channel cross sectional changes. Induced effects include changes in roughness, bed material composition, vegetation cover, and planform. Prediction of cross sectional adjustments can only be accomplished for site-specific conditions after the most significant geomorphological factors have been identified. Therefore, any prediction of channel geometry should be based on sound field observations.

Literature Review

Of several hundred pieces of literature, 108 articles and reports were evaluated to survey methods currently in use to predict channel changes. Of this set, 12 case studies were selected for detailed review. The map below shows the geographic region covered by all of the case studies combined. The general features of the case studies are summarized in the table on the next page.



Location of case studies.

General features of the case studies.

Case Study Title	Location	Drainage Area (mi^2)	Stream Type	Study Method Category
AMAFCA Sediment and Erosion Design Guide	Albuquerque, New Mexico	1 - 100	Arroyos	Geomorphic and engineering analysis
Inventory and Analysis of Stream Meander Problems in Minnesota	14 streams in Minnesota	Information not available	Perennial	Geomorphic (using historic data)
A Probabilistic Approach to the Special Assessment of River Channel Instability	Rillito Creek, near Tucson, Arizona	920	Ephemeral	Mathematical (using historic data)
Geomorphology and Hydrology of the Santa Cruz River, Southeastern Arizona	Santa Cruz River basin, Arizona	3,640	Ephemeral and perennial	Geomorphic (using historic data)
San Diego County Alluvial Studies	San Diego County, California	40. (Model has been run for 1 – 10^5 mi^2)	Ephemeral and perennial	Mathematical modeling
City of Austin Technical Procedures for Watershed Erosion Assessments	Austin, Texas	1 - 30	Ephemeral and perennial	Engineering and geomorphic analyses
River Stability Study, Virgin River, Santa Clara River and Ft. Pierce Wash, Vicinity of St. George, Utah	Virgin River , Santa Clara River, and Ft. Pierce Wash basins, Utah	550 - 3,800	Ephemeral and perennial	Geomorphic
Hydrologic and Geomorphic Studies of the Platte River Basin, Nebraska	Platte River basin, Nebraska	Information not available	Perennial	Geomorphic
Streambank Erosion Along Two Rivers In Iowa	East Nishnabotna River and the Des Moines River, Iowa	960 - 1,450	Perennial	Engineering analysis with geomorphic analysis using historic data
Channel Migration Studies in King County, Washington	Snoqualmie , Tolt, Raging, and Green Rivers, King County, Washington	30 - 360	Perennial	Geomorphic and engineering analysis (using historic and field data)
Bank Erosion Field Survey Report of the Upper Mississippi River and Illinois Waterway	Upper Mississippi River and Illinois Waterway, Minnesota, Wisconsin, Iowa, Illinois, and Missouri	28,900 mi^2, for Illinois Waterway	Perennial	Geomorphic and engineering analysis (using the field data)
Arizona Standards for Lateral Migration and Channel Degradation	Arizona, statewide	Information not available	Ephemeral and perennial	Geomorphic and engineering analysis

In assessing the technical feasibility of mapping REHAs, each case study was analyzed for applicability, limitations, potential for mapping riverine erosion, cost, and regulatory potential. These documents revealed that numerous techniques are currently in use covering geomorphic methods, basic engineering principles, and mathematical modeling. This diverse collection of techniques is necessary because of the uniqueness of each site and to address the objectives of the specific projects.

Assessment of Technical Feasibility

The case studies indicate that there are scientifically sound procedures for delineating riverine erosion hazard areas. Various geomorphic, engineering, and modeling procedures can be applied, depending on site-specific conditions. Specialized knowledge and experience are needed to draw conclusions that would lead to delineation of a hazard area.

A time frame of 60 years has been specified in Section 577 of NFIRA as the interval of interest for delineation of riverine erosion hazard areas. Although it is feasible to use the specified 60-year time frame, the case studies and the opinions of the PWG indicate that existing techniques may be better suited for shorter time frames, *e.g.*, 30 years with periodic revisions to the particular REHA study and delineation. This limitation arises from data inaccuracies, imperfect knowledge of sediment transport mechanics, and unknowns in future watershed development, hydrologic conditions, and magnitude and sequence of future flooding events. However, most structures have a useful life well over 30 years and predictions should somehow address a longer time span.

Given a suitable time frame, future erosion could be estimated either extrapolating from historic data or through the use of mathematical models. In both cases, an estimate of the reliability of the prediction needs to be provided.

Cost

An approximate analysis was performed to estimate the total cost to the Federal government of mapping riverine erosion hazard areas. The sources of cost data include information provided by the PWG, costs reported in the case studies, FEMA reports and other literature, and cost data from previous studies performed by the project team members. The data are not sufficient to make reliable nationwide cost estimation; however, they can be used to perform an educated guess for total costs.

Average study values are $2,000-$3,000 per mile for geomorphic methods, $6,000-$7,000 for engineering methods, and $10,000-$12,000 for mathematical modeling methods. If this effort were to be implemented as part of the NFIP, the cost to the Federal government would be between 200 and 300 million dollars. Section 577 of NFIRA specifies that, if REHA determination is found to be technically feasible, a cost-benefit study is to be conducted. The current study does not include these cost-benefit analyses.

Implementation

There are at least two potential options for implementation of a nationwide REHA delineation program: a federally run program and a locally run program. The federally run program would be integrated into the NFIP. The fundamental principle of this first option is to expand the current floodplain regulations to encompass riverine erosion. This option emphasizes authority from the Federal government. The existing framework can be modified to accommodate the new responsibilities of regulating erosion-prone areas.

Disadvantages are the additional cost to the Federal government and the challenge of developing appropriate guidelines for REHA delineation in a field that requires flexibility and accessibility to a wide array of analytical options.

The second option shifts the authority for regulating erosion-prone areas to the local jurisdictions. Implementation would be tailored to suit individual floodplain management needs. The Federal government would provide technical assistance, if required, and disseminate information. The main advantage is that the communities would have the flexibility to match their resources and needs with the complexity of the studies.

Conclusions

- It is technologically feasible to map riverine erosion hazard areas. Flexibility in the choice of analysis techniques is needed to address site-specific conditions.
- REHA delineations for a period of 60 years are possible; however, better predictions may be achieved for a shorter time span, such as 30 years, with periodic revisions.
- The analytical methods used should be able to provide an indication of the reliability of REHA delineations.
- Average study values are $2,000-$3,000 per mile for geomorphic methods, $6,000-$7,000 for engineering methods, and $10,000-$12,000 for mathematical modeling methods.
- The cost of mapping REHAs nationwide ranges between approximately 200 and 300 million. This estimate is based on limited information.

Implementation of erosion regulations can be either done as an extension of the NFIP or delegated to local jurisdictions with support from the Federal government.