NEW NCHRP REPORT

A Matter of Course

Predicting River Change

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Riverbank erosion and channel migration have affected trade routes and transportation corridors for thousands of years. Active river channel migration still poses a significant threat to the stability of bridges and other highway facilities.

A 4-year research effort has developed a practical methodology for predicting the rate and extent of channel migration near transportation facilities. National Cooperative Highway Research Program (NCHRP) Project 24-16, Methodology for Predicting Channel Migration, was completed in July 2003.

The research produced not only a formal report describing the predictive methodology *(1)*, but also a stand-alone handbook with aerial photographs and map comparisons *(2)* that provides a complete applications supplement. The comparison techniques in the handbook range from simple overlays to computer programs, including geographic information system (GIS) measurement and extrapolation routines for assessing historical meander migration and predicting future migration.

Matter of Course

In bridges that span rivers and floodplains, often only the piers and pilings within the channelized section have deep foundations, and those on the floodplain or marginal to the channel may have shallow foundations. When channel migration removes a significant amount of bankline underneath a bridge, floodplain piers and pilings with shallow foundations may be exposed and undermined and may fail.

In some cases, the failure of only one pier may cause a significant portion of a bridge to collapse, as happened with a major highway bridge over the Hatchie River in Tennessee in 1989 (Figure 1). In addition, significant bankline loss associated with incremental channel migration (Figure 2) can undermine or flank bridge abutments that rest on floodplain soils or that have shallow foundations.

Typical meander bend on the San Joaquin River in California.

FIGURE 1 Failure of a bridge pier as a result of channel migration led to collapse of bridge over the Hatchie River, Tennessee, in 1989.

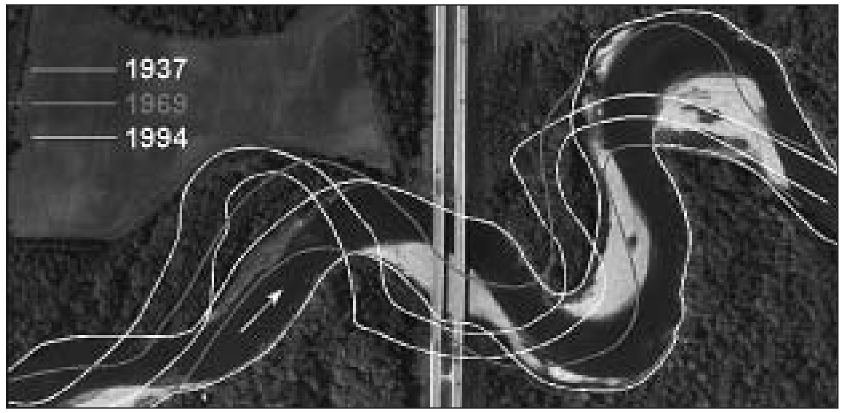


FIGURE 2 Channel migration can have wide-ranging effects on bridge abutments that rest on floodplain soils. Aboe, Wapsipinicon River near DeWitt, Iowa.

Most of the streams that present a hazard through lateral migration at road crossings are alluvial. The channel of alluvial streams is formed by the action of flowing water on boundary materials deposited by the stream. The boundary materials can be eroded and transported.

The banks of alluvial streams migrate through erosion and accretion; floodplains, islands, and side channels undergo modification with time. Actively meandering streams continually change position and shape as a consequence of fluvial processes and hydraulic forces on streambeds and banks. The changes may be incremental or episodic, gradual or rapid, and systemwide or local.

Meanders grow and move naturally, but human activities may accelerate the rate of change or may trigger new changes as a result of morphological response in the stream system. The migrating bends of actively meandering alluvial streams can cause serious impacts on highway infrastructure.

Evaluating the Options

An extensive literature review reveals that the only complete model of a river is the river itself. The past behavior of a meandering reach does not necessarily indicate future behavior; nonetheless, the historical record integrates the effects of all the variables in that location.

An evaluation of empirical (observation-based) and deterministic (process-based) approaches to predicting meander migration supports the conclusions of the literature review. Other investigators had concluded that limitations in data availability and model capabilities made it difficult to model in detail the variation of stream movement over time. An analysis of channel history, however, can reveal trends in stream alignment and in average rates of migration *(3, 4)*.

Empirical approaches are more likely than deterministic approaches to yield a practical methodology. The research therefore emphasized enhancing and using empirical databases to develop techniques of photogrammetric comparison for predicting meander migration.

NCHRP Report 533, *Handbook for Predicting Stream Meander Migration Using Aerial Photographs and Maps*, a stand-alone guide for predicting stream meander migration, is the principal product of NCHRP Project 24-16. The handbook deals with incremental channel shift and provides a methodology for predicting the rate and extent of lateral channel shifting and the down-valley migration of meanders.

The methodology is based primarily on an analysis of bend movement from map and aerial photograph comparisons. As a result, practicing engineers can evaluate the potential for adverse impacts from incremental meander migration during the design life of a bridge or highway river crossing and can ascertain the need for countermeasures to protect the bridge from any hazards.

Classifying the Reach

An essential first step in applying the methodology is screening and classifying the river reach or reaches under consideration. Using a database of more than 1,500 meander bends on 89 rivers in the United States, the research team verified and extended the results of earlier research *(5, 6)*. The investigation confirmed that meandering channels that do not vary significantly in width are relatively stable, but channels that are wider at bends are generally more active.

This simple stratification of meanders is valuable to the bridge engineer as a screening procedure, to identify meanders that are stable. The class of "equiwidth" meandering streams does not require additional analysis. The more actively meandering streams can be analyzed with the photogrammetric comparison techniques presented in the handbook.

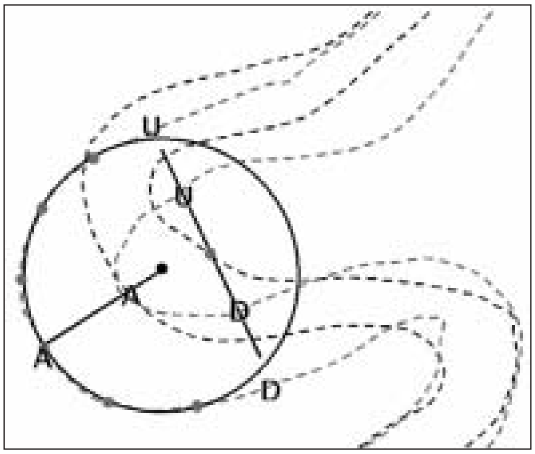


FIGURE 3 Measuring the change in radius and movement of the centroid of best-fit circles on the banklines yields a quantitative estimate of migration distance, rate, and direction.

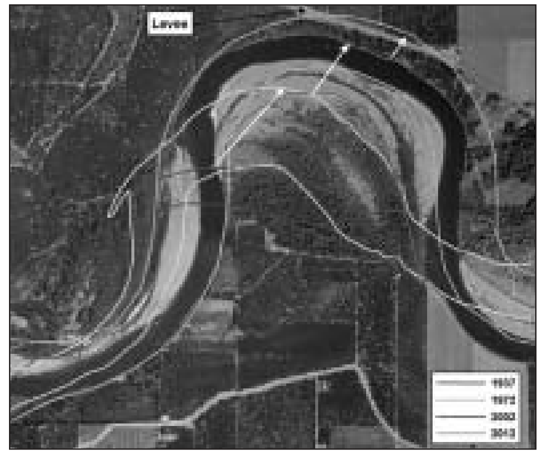


FIGURE 4 Historic and predicted channel migration of Sacramento River, 1937–2012.

Aerial Photo Comparisons

The methodologies require time-sequential aerial photographs or maps of the meander site. Historical and contemporary aerial photos and maps are available at low cost from several federal, state, and local agencies. The Internet also provides sites with links to data resources and searchable databases for maps and aerial photographs.

The availability of aerial photographs makes the methodologies presented in the handbook powerful and practical tools for predicting meander migration. A sampling of websites that provide historic aerial photograph resources appears at the end of this article.

The comparison of sequential historic aerial photographs, maps, and surveys provides an easy and relatively accurate method for determining stream migration rates and directions. The amount of detail available for analysis increases as the length of time between successive maps or photos decreases. Nonetheless, a longer period of record in a comparison will average-out any anomalies and will provide a better basis for predicting meander migration by extrapolation.

Abrupt changes in migration rate and major shifts of position often can be accounted for by analyzing

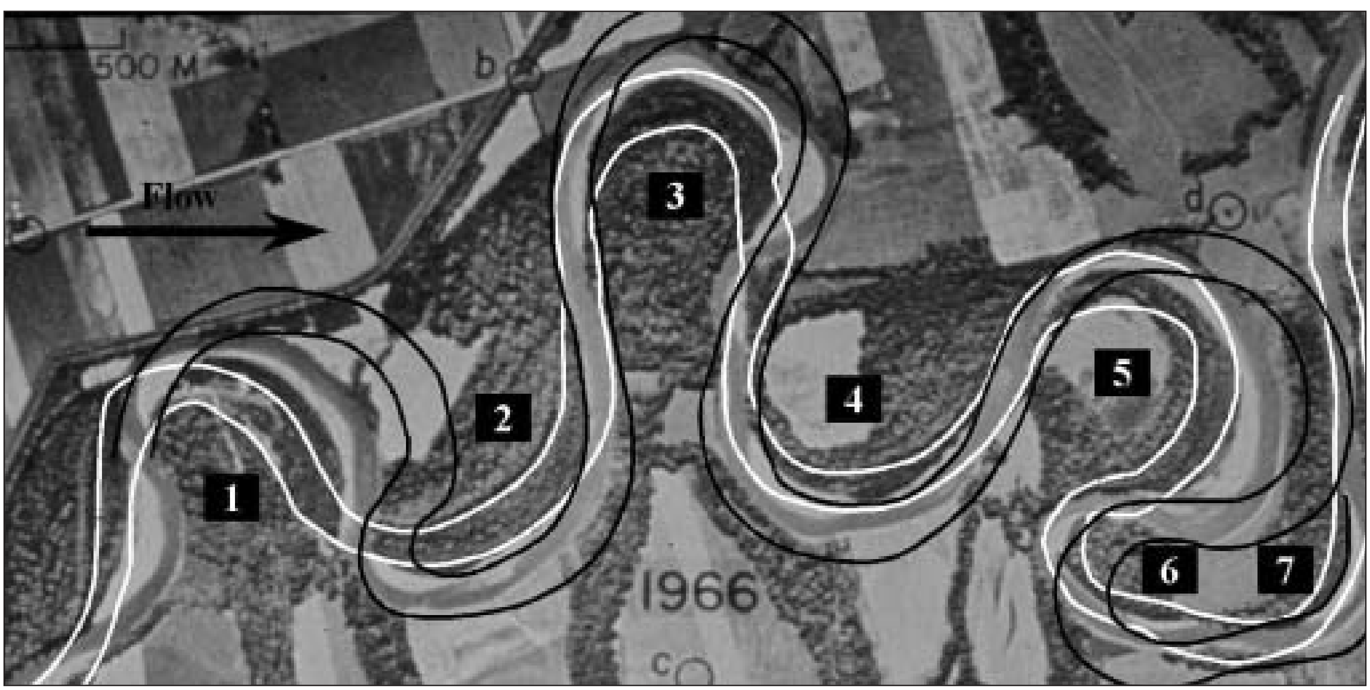


FIGURE 5 Aerial photograph of White River in 1966 superimposed with 1937 bankline position (in white) and bankline prediction for 1995 (in black).

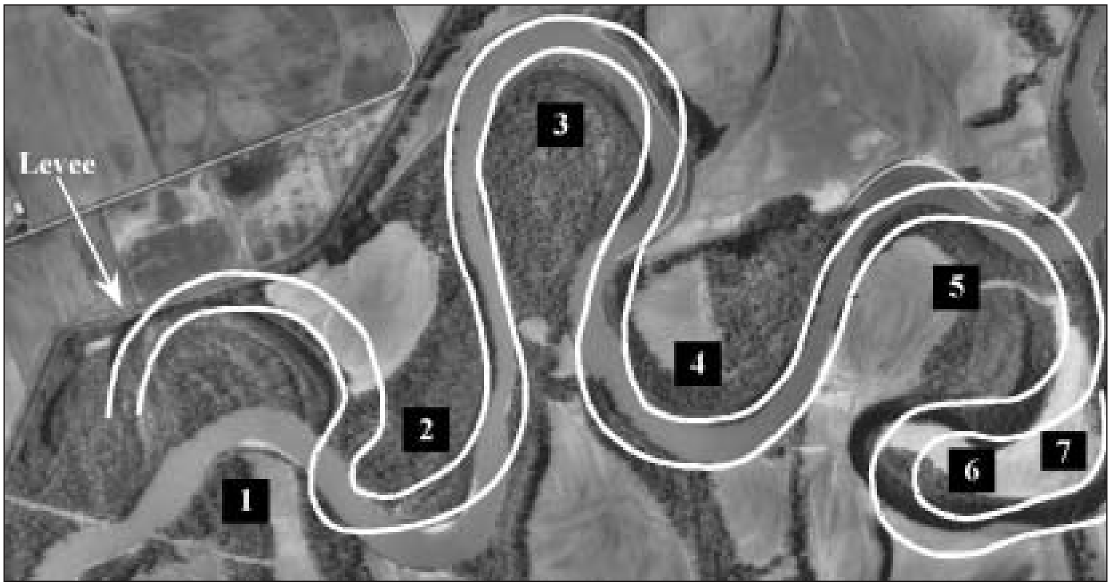


FIGURE 6 Predicted 1995 bankline position (in white) superimposed onto a 1995 photograph of White River. Anomalies are attributable to man-made and natural cutoffs and bank protection.

maps and photos for changes in land use; in addition, gage records of nearby streams can reveal extreme flow events. Predicting migration for channels that have been modified extensively, or that have undergone major adjustments because of land use changes, will be less reliable than those made for channels in relatively stable watersheds.

Overlay Comparisons

An overlay comparison coordinates channel banklines or centerlines traced from successive historic maps or photos, enlarged or reduced to a common scale. Common reference points are identified, and the banklines of the meander bend are delineated on successive photos. The banklines are overlaid or superimposed by matching the common reference points.

The superimposed bankline positions can be evaluated by measuring the change in radius and movement of the centroid of best-fit circles on the banklines (Figure 3), to provide a quantitative estimate of migration distance, rate, and direction over time. The information and data obtained from this analysis inform predictions about the future position of the river (Figure 4).

The process can be completed manually by tracing the stream bends and the inscribed circles on clear mylar overlays. Importing the bends and circles into a GIS, however, presents the comparisons with greater precision and accuracy.

The Data Logger, a menu-driven template for inscribing the circles, was developed to streamline the measurement and analysis of bend migration data and to aid in predicting channel migration. The Data Logger provides a quick way to gather and archive data on the river planform—that is, the river's contour seen from above.

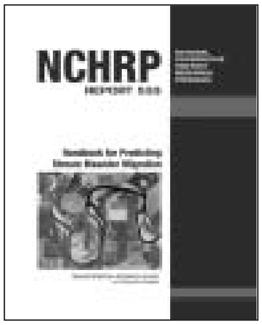
Using the data archived by the Data Logger, the Channel Migration Predictor forecasts the magnitude and direction of bend migration at a specified time in the future. The Channel Migration Predictor examines a table of data for several bends, as well as two or three historical records per bend, and then predicts rates of change in bend radius and bend center position.

Testing the Techniques

Aerial photograph comparisons and the GIS prediction tool were used to predict meander migration by the White River in Indiana. Aerial photographs from 1937 and 1966 were obtained for a reach of the river; the banklines were delineated on each set of photographs; and the banklines were registered for comparison. The GIS meander migration prediction tool was used to estimate the bankline position for 1995.

Figure 5 shows the 1937 bankline position of seven meander bends and the 1995 bankline positions of the same bends as predicted by the GIS meander migration prediction tool, superimposed on the 1966 aerial photograph. The 1995 bankline positions of the bends predicted by the GIS meander migration prediction tool were then superimposed onto a 1995 photograph of the river (Figure 6).

A comparison of the actual bankline locations with the predicted bankline positions reveals that the GIS tool can predict meander migration accurately for unconstrained bends—that is, for streams without revetment (banks with stone or concrete facing) or hard points. Figure 6 shows the accuracy of the pre-



dictions for the 1995 bankline positions of Bends 3 and 4 and for the cutoff at Bend 5.

The unexpected and anomalous bankline positions are attributable to a man-made cutoff (Bends 1 and 2), a natural cutoff (Bends 5, 6, and 7), and, possibly, bank protection (Bends 3 and 4) before 1995. The man-made cutoff of Bend 1, probably a response to the major threat posed by meander migration to a nearby levee, also has caused the distortion of Bend 2 in comparison with the predicted shape.

The cutoff of Bend 5 has caused the distortion of Bend 5 and the abandonment of Bends 6 and 7. The migration of the outer bank along the downstream limb of Bend 3 and at the apex of Bend 5 appears to have been halted in part by a protective bank revetment. The bankline positions of Bends 1 and 2, as well as the revetted portions of Bends 3 and 4, probably would have matched the predicted positions if not for human interference.

Reality Check

Much work remains before statistical or deterministic methods can predict the impacts of meander migration on transportation infrastructure with certainty and ease. The methodology developed in this research, employing a comparative analysis of maps and aerial photographs, may be viewed as an interim approach; nonetheless, the methodology will not be replaced by more sophisticated analytical techniques soon. The techniques presented in the handbook will always be useful for reconnaissance or for a "reality check" on other approaches to predicting meander migration.

The handbook contains guidance on the applications of the analytical products of NCHRP Project 24-16, along with examples; describes map and aerial photograph comparison techniques; and offers guidelines for predicting channel migration near transportation facilities. The methodology will be useful in the reconnaissance, design, maintenance, and inspection of highway facilities and will help reduce the cost of construction, repair, rehabilitation, and countermeasures for lateral channel instability.

The screening procedure to identify the stable reaches of meandering streams will prevent the unnecessary allocation of resources for engineering and inspection. The result will be a more efficient use of highway resources and a reduction in the costs associated with the impacts of channel migration on highway facilities.

Practical Products from Channel Migration Research

◆ *NCHRP Report 533: Handbook for Predicting Stream Meander Migration* describes the application of the stream prediction methodology with illustrated examples. An accompanying CD-ROM contains an ArcView–based data logger and channel migration predictor.

◆ *NCHRP Web Document 67: Methodology for Predicting Channel Migration* contains the final report and is accessible online.

◆ *CRP-CD-49: Archived River Meander Bend Database,* a four-CD set, is a companion product to the web document and contains a database of 141 meander sites with 1,503 bends on 89 U.S. rivers.

To purchase the handbook or CD set, or to view the handbook or web document online, go to www4.trb.org/trb/ onlinepubs.nsf.

Acknowledgments

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Websites

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www.terraserver-usa.com

U.S. Geological Survey: PhotoFinder
edcwww.cr.usgs.gov

U.S. Department of Agriculture: Aerial Photo Field Office
www.apfo.usda.gov/filmcatalog.html