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16. Abstract

Meander migration and vertical degradation of river bed are processes that have been studied for years. Different methods have been proposed to make predictions of the behavior of rivers with respect to these processes. These two erosion controlled processes consist of the gradual change of the geometry of the river due to the flow of water eroding the soil. This erosion may cause a shift that could be a threat to existing bridges, highways and useful lands. Therefore, there is need for a method that can accurately predict the amount of erosion that may occur in rivers.

Six different sites in Texas were selected for this project. Four of the selected rivers have meander migration problems and two have vertical degradation problems. Each river has shown erosion problems that have been a threat to the bridges, roads or farm lands. Aerial photos and maps from different years were obtained from different sources to study the change of the geometry of the rivers. River hydrographs were obtained from the U.S. Geological Survey to estimate the river velocity. Soil samples from each site were obtained for laboratory testing, using the Erosion Function Apparatus.

A method to predict meander migration and vertical degradation was developed by using the three main factors: geometry, water flow and soil erodibility. A code was written in MATLAB and Excel to predict the future movement of the meander or the vertical degradation by using a model based on the erosion function obtained from the erosion tests of the soil at each site and the average daily velocity of each river. Because this method is based on observed data, it was called the Observation Method.

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OBSERVATION METHOD TO PREDICT MEANDER MIGRATION AND VERTICAL DEGRADATION OF RIVERS

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT), the Federal Highway Administration (FHWA), University of Texas at San Antonio and University of Houston. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The engineer in charge of this part of the project was Dr. Jean-Louis Briaud, P.E., (Texas, #48690).

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CHAPTER 1: INTRODUCTION AND RESEARCH OBJECTIVES

1. 1 INTRODUCTION

Meander migration and vertical degradation are two erosion related processes that occur due to the continuous flow of water in rivers. Both can be slow enough to not cause any problems, but can also be a hazard when floods occur. Bridges, roads, and farm lands that are within the flood zone may all suffer damages. To avoid these types of damages, certain measures can be taken to control problems with erosion, such as improving the location and design of bridges. This in turn prevents costs associated with mitigation and countermeasures taken during the operational life of a bridge or highway. Therefore, it is necessary to know when and if a bridge or highway may be in danger of structural damage during its operational life because of erosion problems. This way, during the design and construction process, preventative measures may be taken and proper solutions may be developed in advance. Two examples of bridges that were in danger of structural damage due to excessive erosion are presented herein.

The Burr's Ferry Bridge on the Sabine River, shown in Figure 1, was built over 80 years ago and is on the state line between Texas and Louisiana. This bridge is above a meander and floods that occurred during the 1990s eroded the bank on both the east and west side of the river. Concrete blocks were used as countermeasures to reduce the erosion along the bank of Louisiana. However, along the bank of Texas, the erosion on the bank of Texas has been a major concern to the Texas Department of Transportation. How close will this meander be to the bridge in 5 or 10 years? If a big flood occurs, how many meters will the river "move" south and get closer to the bridge?

Figure 1: SH 63 at Sabine River (Google Earth)

Another case is the North Sulfur River at SH 34 in Ladonia, TX, shown in Figure 2. This river used to have meanders but was straightened in the 1920s to avoid floods in the farm lands. The problem at this bridge location was of vertical degradation. A new bridge was built in the early 2000s when it was found that the columns of the old bridge were being exposed due to short length, which could have caused a collapse during a flood because of the erosion at the bottom of the river. Although a collapse was avoided, it was obvious that a method needed to be developed to predict the progression of erosion with time. With such a method, similar problems may be avoided in other rivers.

Figure 2: SH 34 at North Sulfur River (Google Earth)

The situations of erosion problems discussed above are very common at different locations in Texas. Some bridges were either not designed to account for these problems or erosion could not be controlled with countermeasures or remedies. The most important aspect of this research project is to develop a simple method that can be used to make a representation of the behavior of the river by using an erosion model. This way, predictions of the movement of a point of interest of the river (in reference to time and distance) can be made based on that model.

There are many factors that have an effect on meander migration and vertical degradation. They can be summarized in three general aspects: soil, geometry, and flow. Many methods have been developed to make predictions, but sometimes one of the three aspects has been ignored. For the method developed in this project, each one of these factors has been taken into consideration to develop a simple solution to these problems.

This research project was sponsored by the Texas Department of Transportation (TxDOT) and was conducted by the Texas Transportation Institute at Texas A&M University (College Station, TX). This research is part of the program “Assessment of the Effects of Regional Channel Stability and Sediment Transport on Roadway Hydraulics Structures”. This program is a collaboration between Texas A&M University, University of Texas at San Antonio, and University of Houston. Each university has a team with different tasks and approaches to provide guidelines for the TxDOT, which will be used for the existing bridges and for rivers with similar problems.

1.2 RESEARCH OBJECTIVES

The objectives of this research project are the following:

- Study sites selected by the TxDOT that have problems related to (1) meander migration and/or (2) vertical degradation. Each river is located in the state of Texas and is affected by erosion.
- Perform site and laboratory tests (full scale experimental study).
- Develop a model that relates the soil erodibility, river flow, and past observations with the meander migration and vertical degradation.
- Develop a method (called Observation Method) using computer programming that uses the model to study the movement of a point of interest or critical point in the river.
- Use the Observation Method to be able to make a prediction of the movement of a selected point of interest or critical point for each river.
- Provide the TxDOT with general guidelines to use the Observation Method for the study of other rivers.

1.3 GENERAL APPROACHES

The Observation Method is based on observed data or the history of the river. The following approaches were implemented for this research and used to develop the Observation Method to predict meander migration and vertical degradation. The Observation Method incorporates the three most important components: soil, flow and, geometry.

1.3.1 Selected Rivers

Six different rivers in Texas were selected to be studied for this project. Four had meander migration problems and two had vertical degradation problems. The rivers are:

- SH 105 at Brazos River (Navasota, TX) – Meander migration
- FM 787 at Trinity River (Cleveland, TX) – Meander migration
- SH 63 at Sabine River (Texas-Louisiana border) – Meander migration
- SH 34 at North Sulfur River (Ladonia, TX) – Vertical degradation
- US 90 at Nueces River (Uvalde, TX) – Meander migration
- FM 973 at Colorado River (Austin, TX) – Vertical degradation

1.3.2 Research Approach

After the selection of the rivers, the research was divided in two important steps: the experimental study and the analytical study.

- Full scale experimental study – Involved the site investigation and tests conducted at site, laboratory testing, and the study of the movement of the river by observation of maps, aerial photos, or cross-sections of rivers.
- Analytical study – Involved the application of the data collected on the experimental study and used in conjunction with a mathematical model to develop a program that is used to establish the behavior of the river and make predictions. The final product of this part of the project is the "Observation Method".

1.3.3 Observation Method

The final product of the analytical study of the project is the Observation Method. This method uses:

- observations from aerial photos or maps for meander migration
- cross-sections for vertical degradation
- flow hydrograph converted to velocity from the river under study

- erosion function, which relates erosion rate to velocity, obtained from the erosion tests using the Erosion Function Apparatus (EFA)

The model used to determine the erosion of a river is determined by the following equation:

$$\frac{\dot{z}}{v_c} = \alpha' \left(\frac{v}{v_c} \right)^{\beta}$$

Where:

$\dot{z}$: erosion rate

v: velocity

v_c: critical velocity

α’ and β: parameters obtained from the erosion function

This model is dimensionless and is used to determine the erosion per day when an average daily velocity from a river is obtained. The critical velocity, minimum velocity for erosion, is site specific and is found by an iterating process. A simple computer program is used to obtain the critical velocity and to view the movement or position of a point of interest or critical point of a river through time. The Observation Method is used for each river selected and the results are incorporated in this report.

CHAPTER 2: RESEARCH APPROACH

2.1 INTRODUCTION

The approach to solve the issues involving meander migration and vertical degradation of rivers can be separated in two main areas: full scale experimental study and analytical study. The first one involves the site visit and both field and laboratory testing, and the second one involves the methodology and the step by step procedure to solve the problem by using a mathematical solution.

2.2 FULL SCALE EXPERIMENTAL STUDY

The steps involving the experimental study were:

- Selection of the different sites.
- A thorough study of the site before visiting (history, maps, photos, prior issues, etc.). The meander migration or vertical degradation problems were studied.
- Site visit and investigation of the problems and the surroundings
- Perform in-situ testing such as pocket penetrometer or vane tests.
- Obtain soil samples for erosion and classification tests.

The experimental study gives a better idea of the expectations and the results of the research. The information that is obtained from this step is used in the analytical study, and a relationship must be established between the observed data and the predicted data.

2.3 ANALYTICAL STUDY

The steps involving the analytical study are:

- Obtain the maps or aerial photos of the sites.
- Obtain the flow hydrograph of each river and convert the flow to velocity using the characteristics of the river.
- Use the erosion results to obtain the parameters that define the erodibility of the soil.

- Use the observed river movement, velocity and erosion function to develop a model and a program. These will be used to obtain the general behavior of the river and be able to obtain the predicted movement of the river.

The main objective of the analytical study is to obtain a model that can be used to study the behavior of the river with time and make a prediction based on that behavior. Using data from the past (observed data) and a model, the movement of the river could be studied through time in both meander and vertical degradation problems. The most important parameter to find in the analytical study is the critical velocity. This velocity is the minimum velocity that is needed for erosion to occur. The critical velocity can be found in the experimental study when erosion tests are performed using the EFA. This velocity may not necessarily be the same as the critical velocity found in the field. The critical velocity is found for each case selected by using a program that iterates and finds the best results based on a comparison between the calculated data and the observed data. Results are obtained and conclusions are made based on the comparisons between the calculated data and the expected behavior.

CHAPTER 3: FULL SCALE EXPERIMENTAL STUDY

3.1 SITE LOCATIONS

The sites of concern for this project are located at six different rivers in Texas, shown in Figure 3. Each one has had erosion problems and different remedies have been implemented for control purposes in some of them. Meander migration and degradation at the bottom of the rivers are some of the issues of these rivers. In general, for those with meander migration problems, aerial photos of these rivers can be used to compare the river movement due to the erosion and deposition of the soil and sediments. In the following sections, an aerial photo is presented for each site, and the red arrow in each of these figures represents the direction of flow.

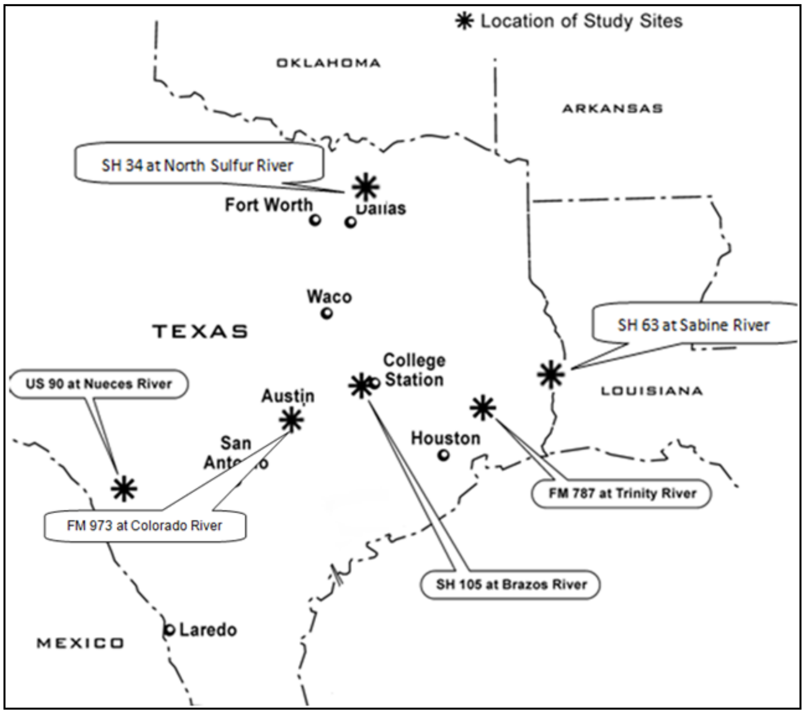


Figure 3: Site locations in Texas

3.2 MOVEMENT OF RIVERS

3.2.1 SH 105 at Brazos River (Navasota, TX)

Figure 4 shows the evolution of the meander migration of the Brazos River towards SH 105. This is between 1989 and 2010. Also, there has been channel movement at the bridge. Figure 5 shows a sketch of the movement at the bridge. A flow hydrograph and velocity hydrograph of this river are shown in Figure 6 and Figure 7, respectively.

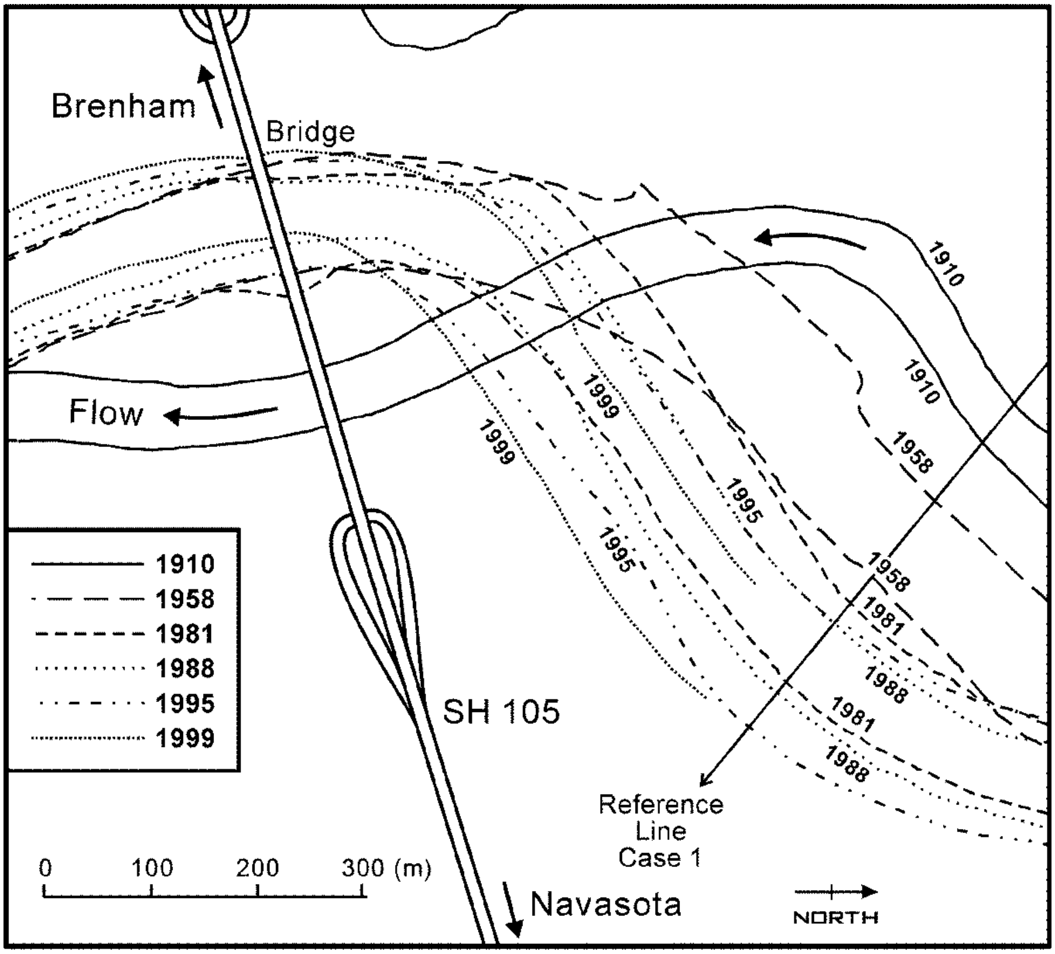
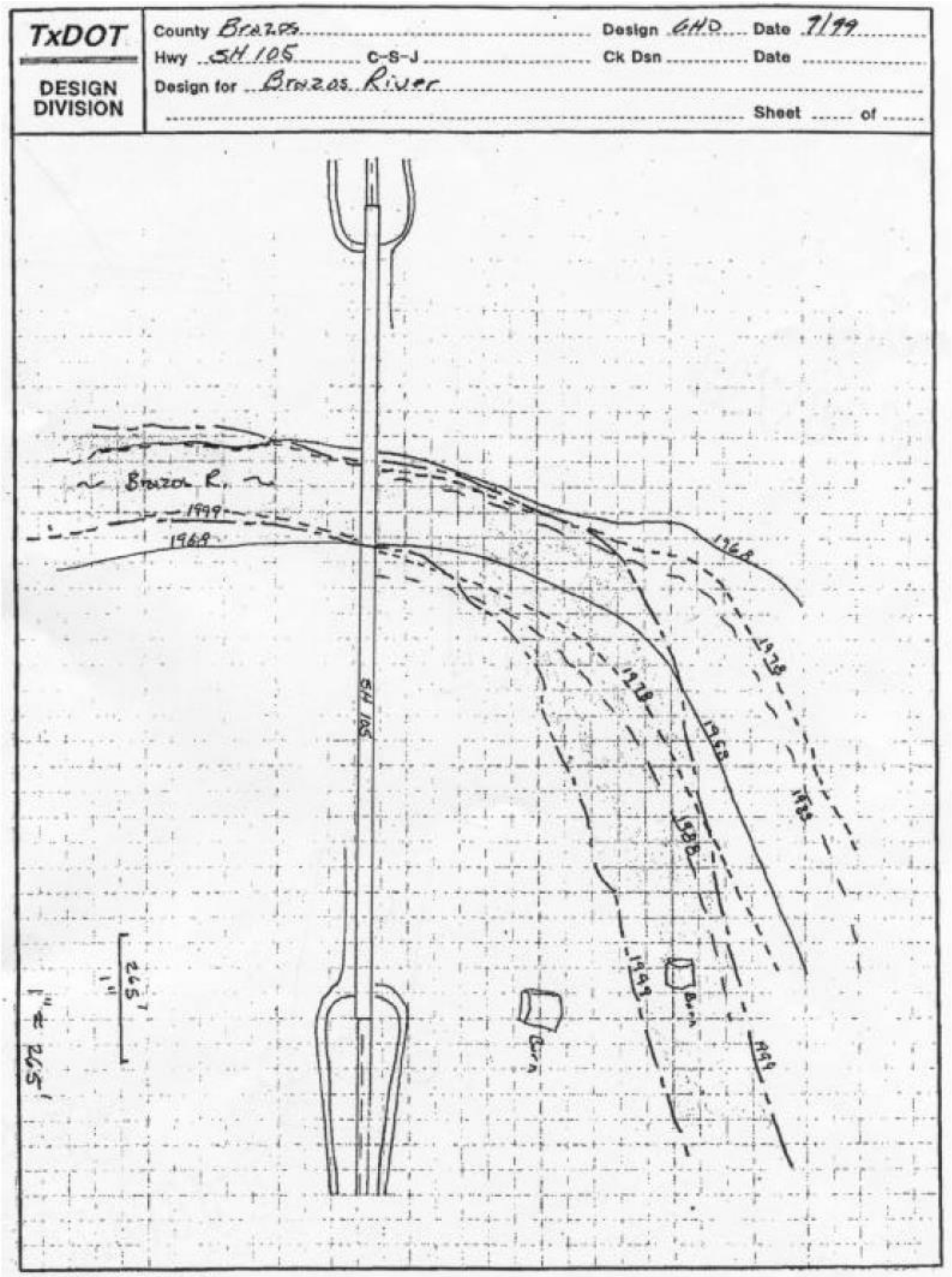


Figure 4: Meander movement of Brazos River between 1910 and 1999 (Briaud et al., 2001)



TxDOT

DESIGN DIVISION

County Brazos Design GHD Date 7/99

Hwy SH 105 C-S-J Ck Dsn Date

Design for Brazos River

Sheet of

Figure 5: Sketch of channel movement

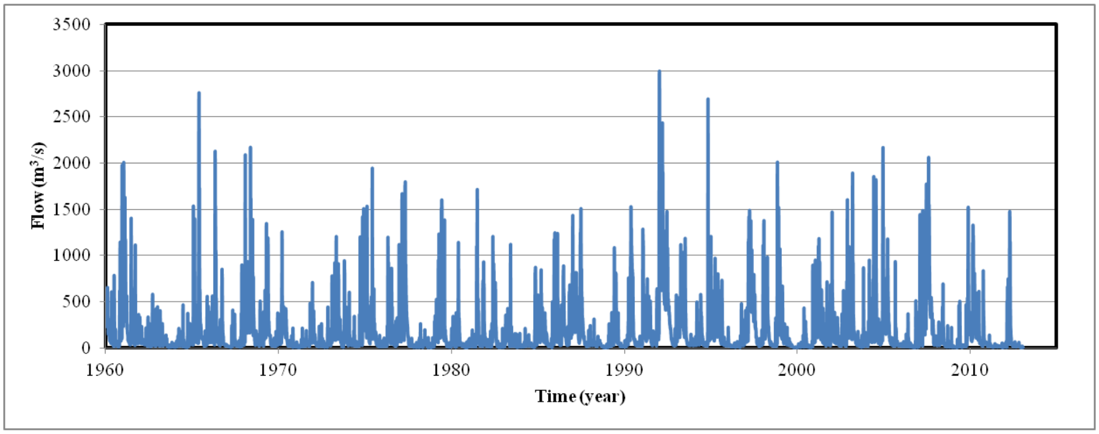


Figure 6: Flow hydrograph of Brazos River

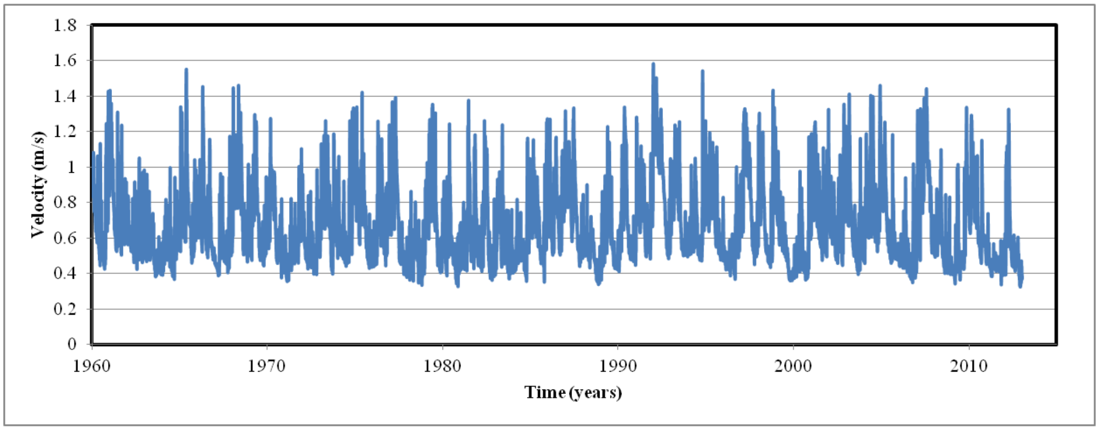


Figure 7: Velocity hydrograph of Brazos River

3.2.2 FM 787 at Trinity River (Cleveland, TX)

Erosion here occurs parallel to the FM 787 and next to the bridge. Figure 8 shows the movement of the river. This drawing was generated by surveying in this area. The surveying in this area was done between 1991and 1995, before the extension of the bridge at the site. Aerial photos of this river do not show the erosion at the site as well as this figure. Figure 9 and Figure 10 show flow and velocity hydrographs, respectively, of this river between 1960 and 2013.

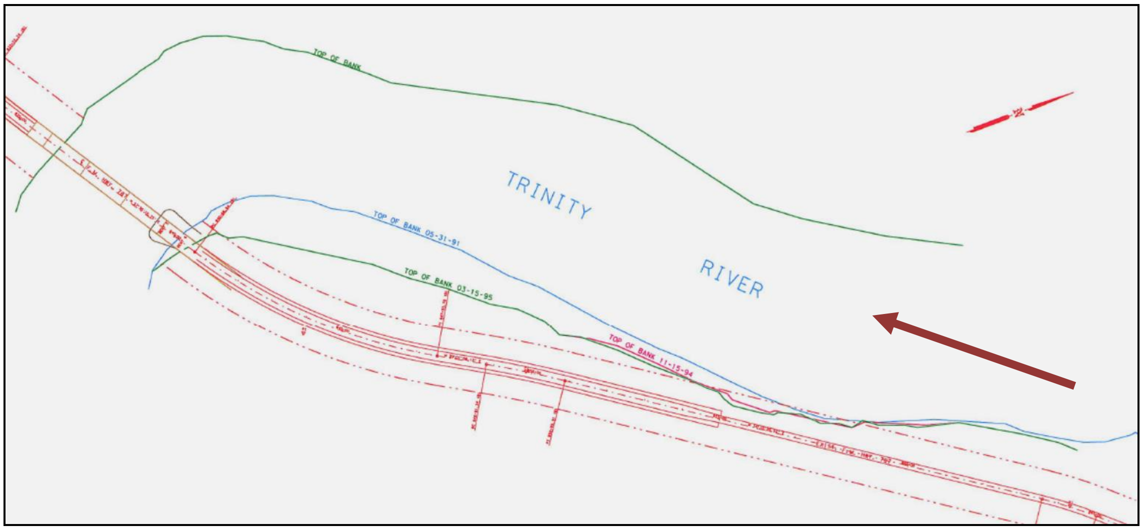


Figure 8: Surveying map of Trinity River

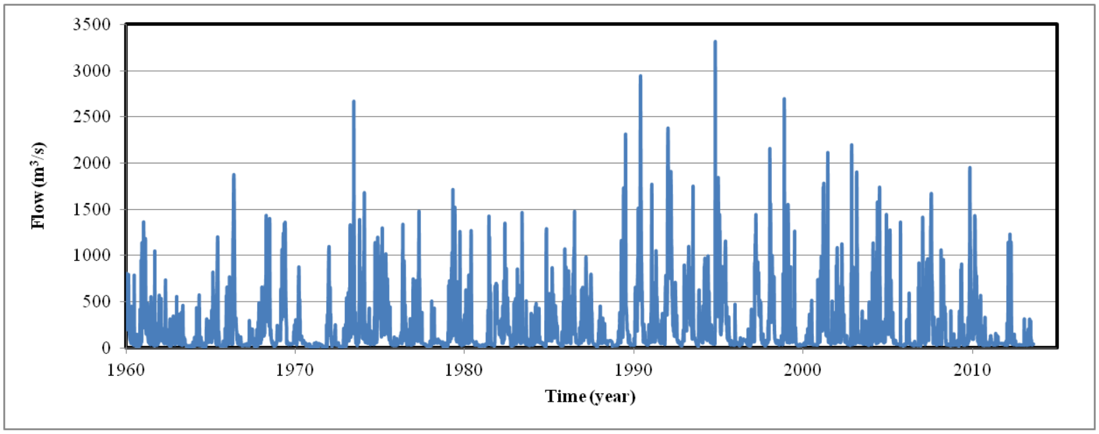


Figure 9: Flow hydrograph of Trinity River

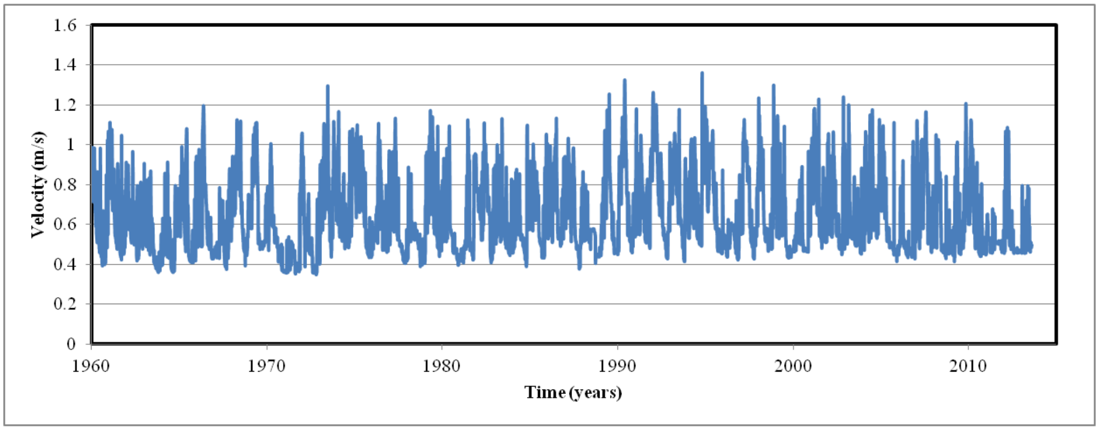


Figure 10: Velocity hydrograph of Trinity River

3.2.3 SH 63 at Sabine River (Texas-Louisiana border)

Erosion next to the bridge on the west side has been progressively getting closer to the foundations of the bridge. Figure 11 shows the progression of the erosion between 1989 and 2004. Flow and velocity hydrographs are shown in Figure 12 and Figure 13, respectively.

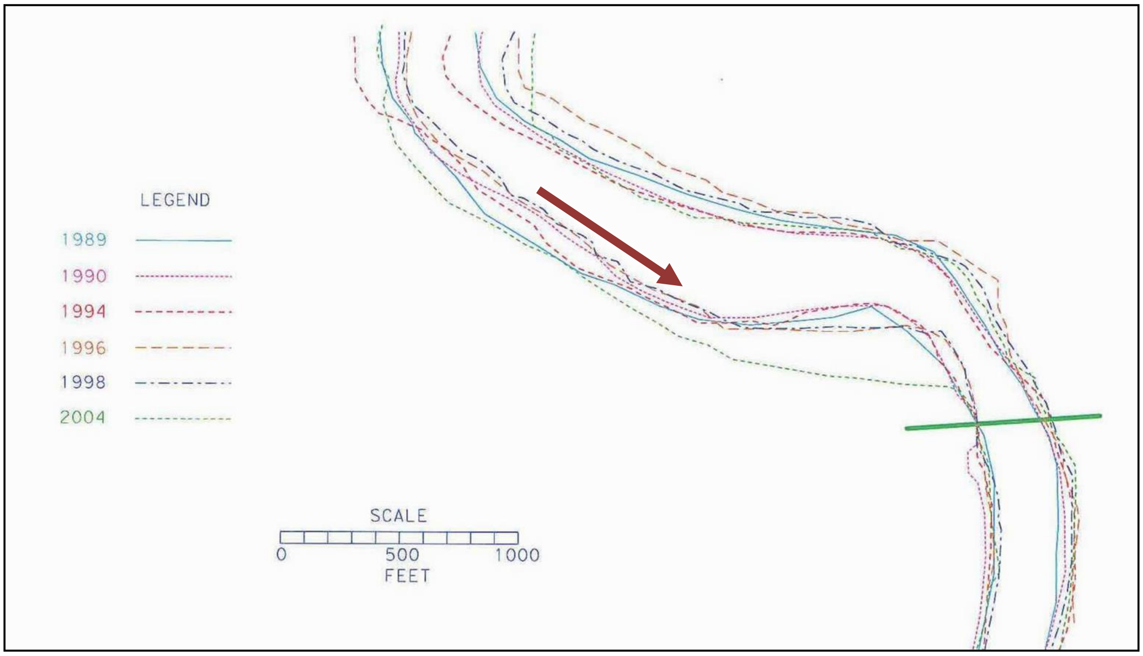


Figure 11: Meander movement of Sabine River between 1989 and 2004

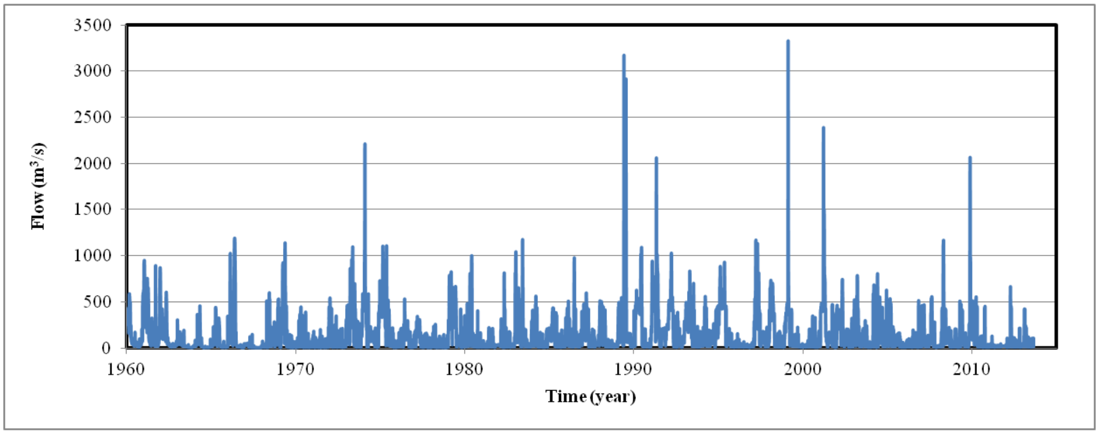


Figure 12: Flow hydrograph of Sabine River

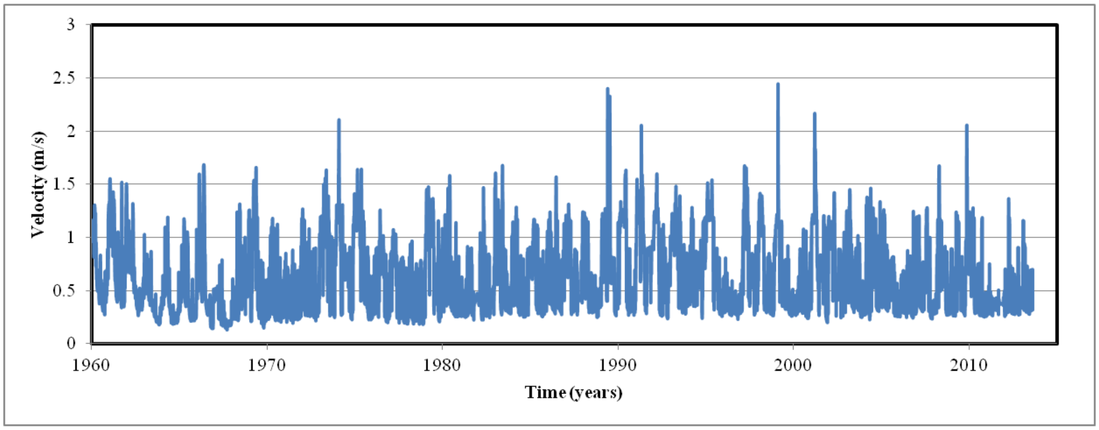


Figure 13: Velocity hydrograph of Sabine River

3.2.4 SH 34 at North Sulfur River (Ladonia, TX)

Figure 14 shows the vertical degradation of the North Sulfur River at the bridge in SH 34. This site has no meander and the erosion is because of straightening of the river in the 1920. Clay at the bottom of the river eroded and blue shale was exposed. The sediments of the river then were deposited on top of the blue shale. Figure 15 and Figure 16 show flow and velocity hydrographs, respectively, for this river.

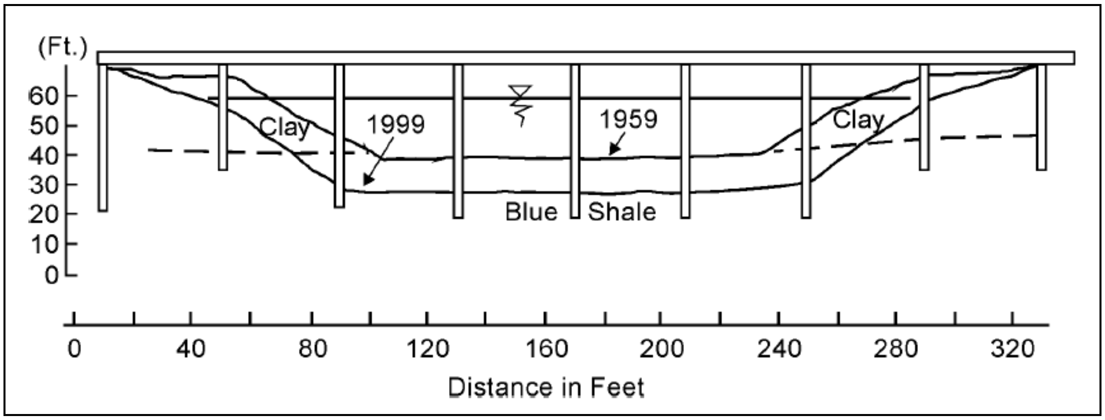


Figure 14: Vertical degradation of North Sulfur River at SH 34

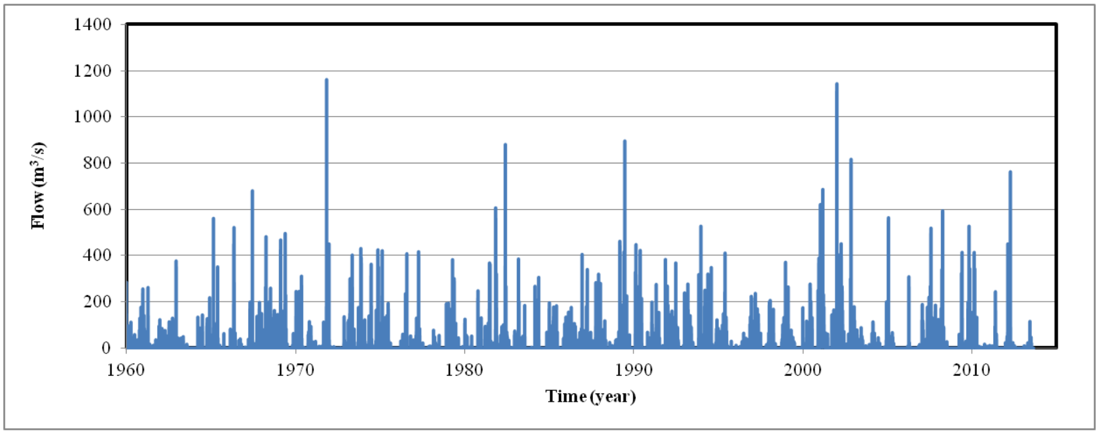


Figure 15: Flow hydrograph of North Sulfur River

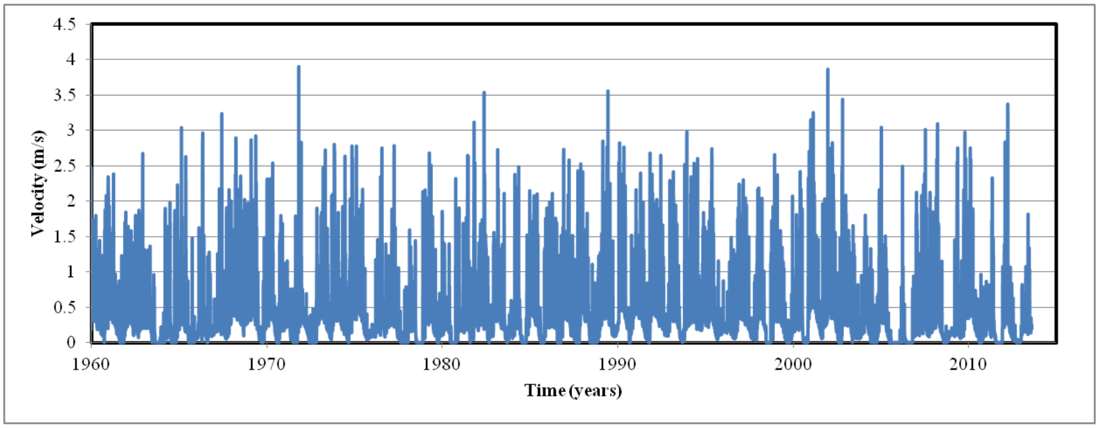


Figure 16: Velocity hydrograph of North Sulfur River

3.2.5 US 90 at Nueces River (Uvalde, TX)

The erosion at the Nueces River is in the same fashion as in the Brazos River. Erosion occurs at the meander to the north of the bridge. However, there are two big differences at this site. First, this river is dry most of the year. Only certain times during the year there is flow of the river and also during big floods. Second, there is a big concern of erosion at the bridge. In 1998 there was a big flood that resulted in failures in the riprap at the west side of the bridge. Figure 17 shows the progression of erosion at this site between 1995 and 2008. A flow hydrograph is shown in Figure 18 and a velocity hydrograph is shown in Figure 19.

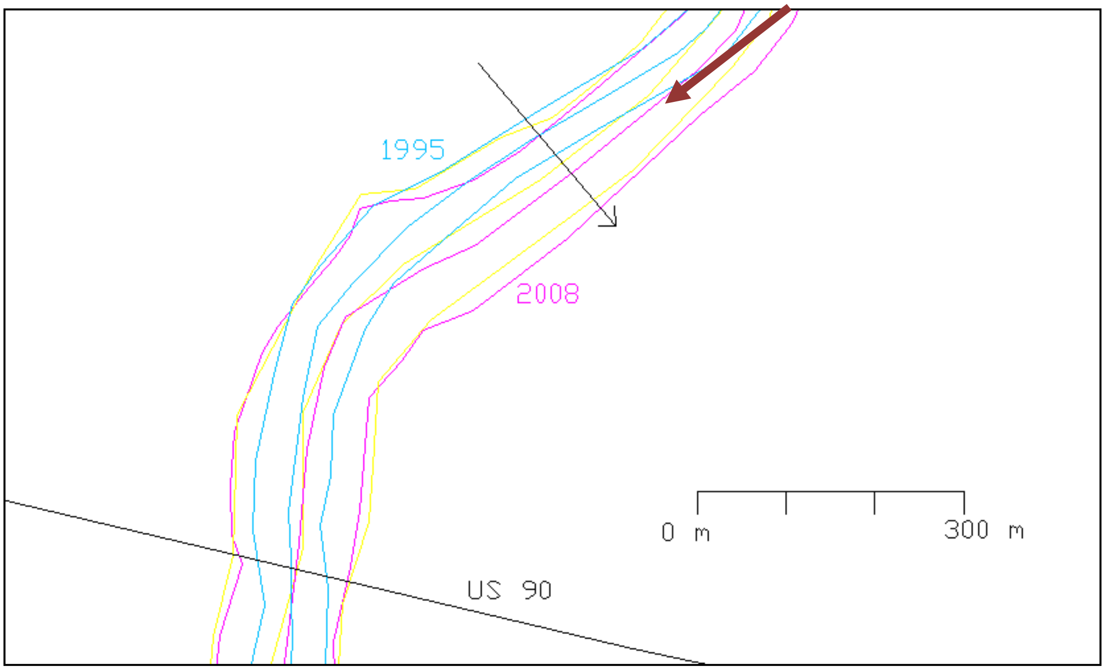


Figure 17: Meander movement of Nueces River between 1995 and 2008

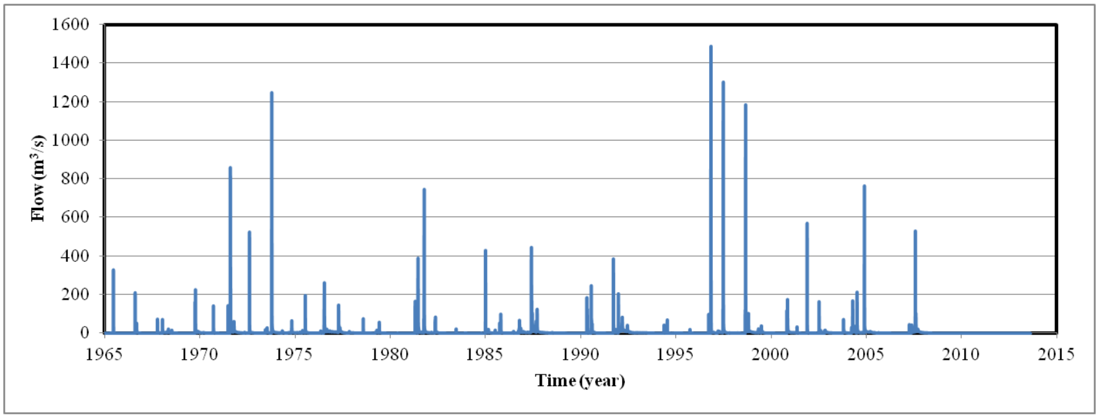


Figure 18: Flow hydrograph of Nueces River

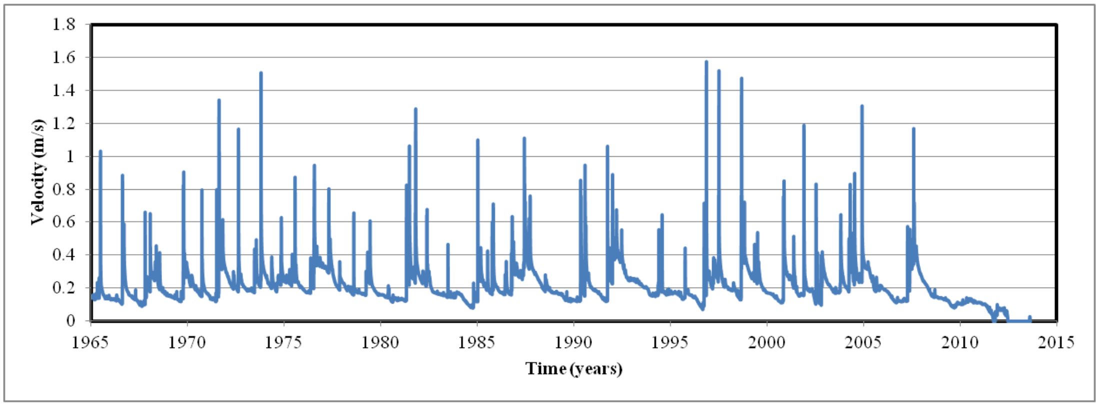


Figure 19: Velocity hydrograph of Nueces River

3.2.6 FM 973 at Colorado River (Austin, TX)

Figure 20 shows the change of the bottom of the river between two different profiles: one in 1991 and the other in 2005. The black line corresponds to the river in 1991 and the red line corresponds to an inspection in 2005. Data from inspections after 2005 shows that there are not significant changes since. The measurements to get these profiles were done from the top of the river. The north points from left to right in this figure. Figure 21 shows a table of the exposure of the drilled shafts in feet from an inspection 2005. Figure 22 and Figure 23 show the flow and velocity hydrographs of this river, respectively.

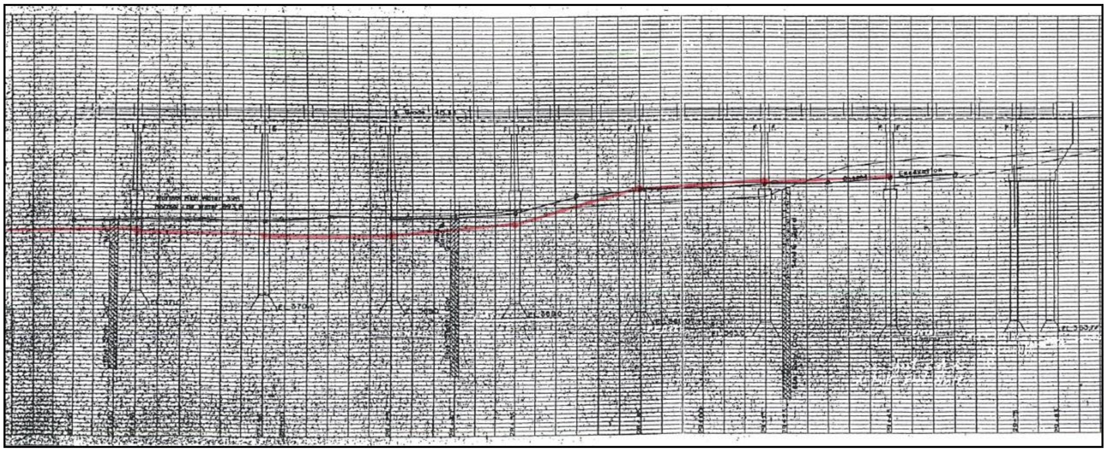
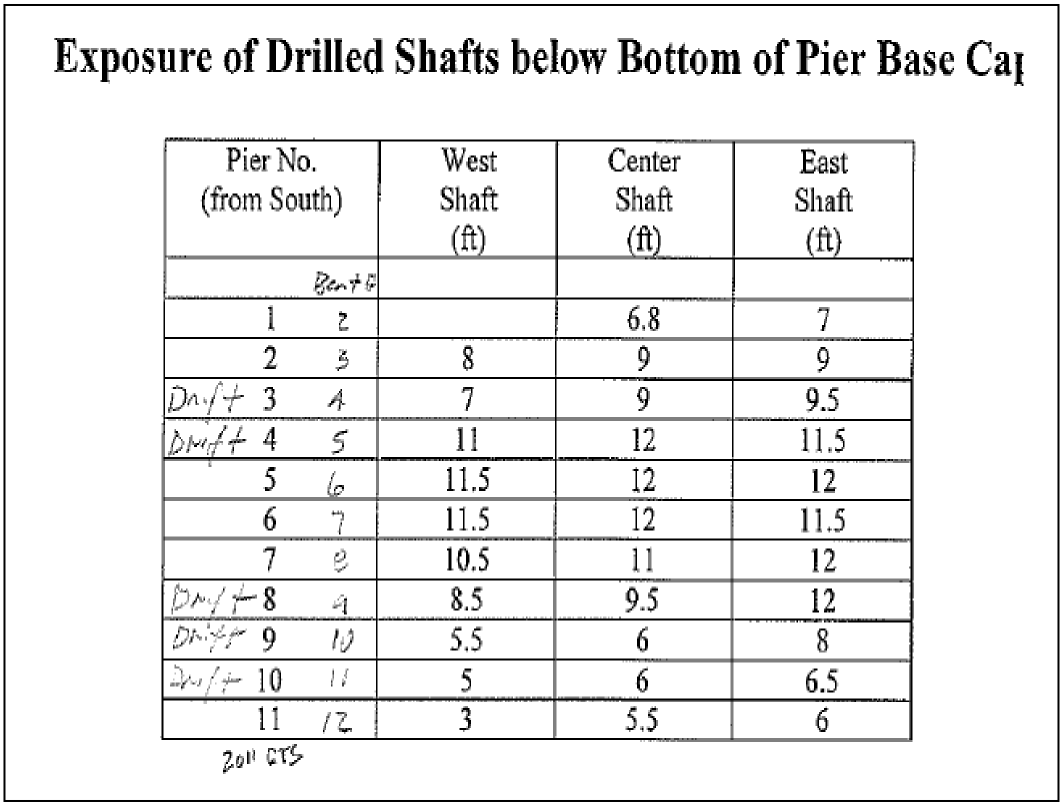


Figure 20: Profiles of Colorado River at FM 973 (cross section)



Exposure of Drilled Shafts below Bottom of Pier Base Ca

Pier No. (from South)	West Shaft (ft)	Center Shaft (ft)	East Shaft (ft)
Bent #			
1 2		6.8	7
2 3	8	9	9
Drift 3 4	7	9	9.5
Drift 4 5	11	12	11.5
5 6	11.5	12	12
6 7	11.5	12	11.5
7 8	10.5	11	12
Drift 8 9	8.5	9.5	12
Drift 9 10	5.5	6	8
Drift 10 11	5	6	6.5
11 12	3	5.5	6

2011 CTS

Figure 21: Exposure of drilled shafts

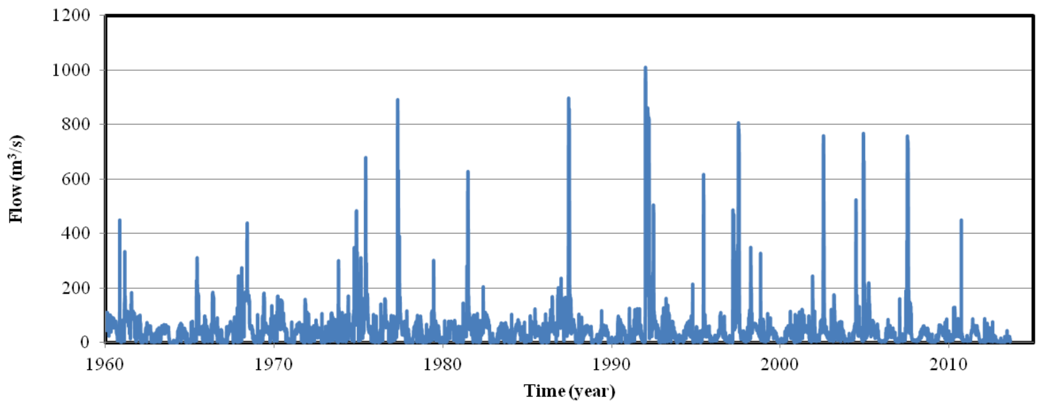


Figure 22. Flow hydrograph of the Colorado River

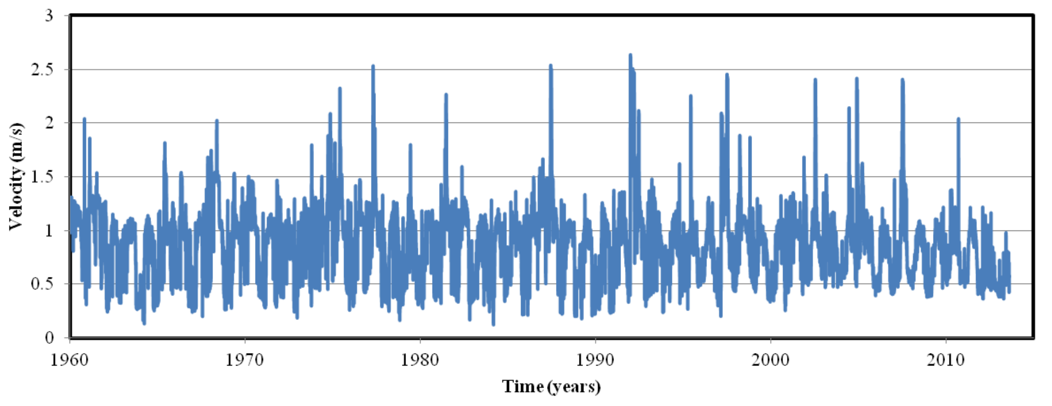


Figure 23. Velocity hydrograph of the Colorado River

3.3 OBTAINING SAMPLES AT EACH SITE

Each soil sample was collected in two ways: driving a modified Shelby tube and putting the soil in bags. At each location, a muffler tube was driven into the ground using a 4x4 piece of wood with handles, as shown in the photos of Figure 24. Most of the samples were obtained from the ground surface. However, others had to be obtained after digging with shovels because of vegetation or to find a more uniform soil that could represent the area. The samples inside the tubes are tested in the EFA. For each tube that was driven, a soil from that same area was put inside bags. These samples are used for the following tests: size distribution using sieves and hydrometer, and Atterberg limits.

Figure 24: Obtaining samples with muffler tube

3.4 EROSION FUNCTION APPARATUS

The EFA test is used to obtain an erosion curve, where the engineer can obtain a critical velocity and erosion rate for a given river velocity (Briaud, 2013). The soil sample, in the Shelby tube, is raised and water erodes the top of the sample at certain rate. Soil can be classified, according to its erodibility, in one of six categories. Non-plastic silt and fine sand are classified in the Category I (Very High Erodibility), whereas intact rocks or jointed rocks are classified in the Category VI (Non-Erosive). The erosion charts were developed and proposed based on more than 15 years of research using the EFA. Figure 25 shows the EFA erosion categories. Figure 26 and show the EFA test results for erosion rate versus velocity for some of the samples collected at the sites.

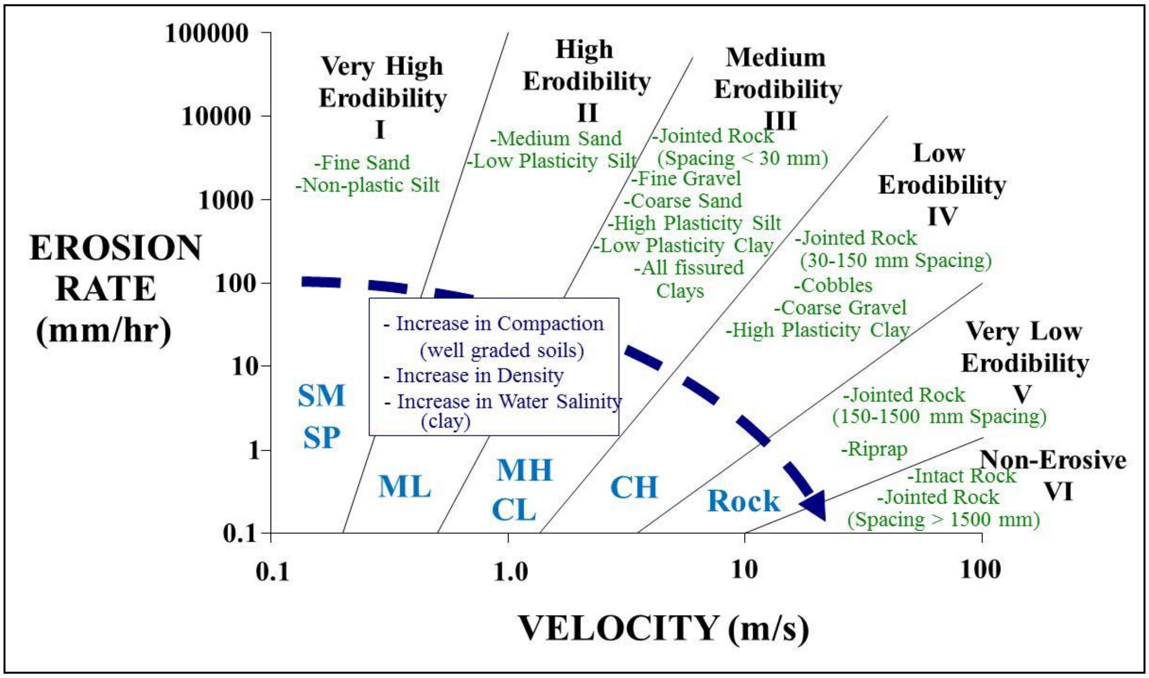


Figure 25: Erosion categories (Briaud, 2013)

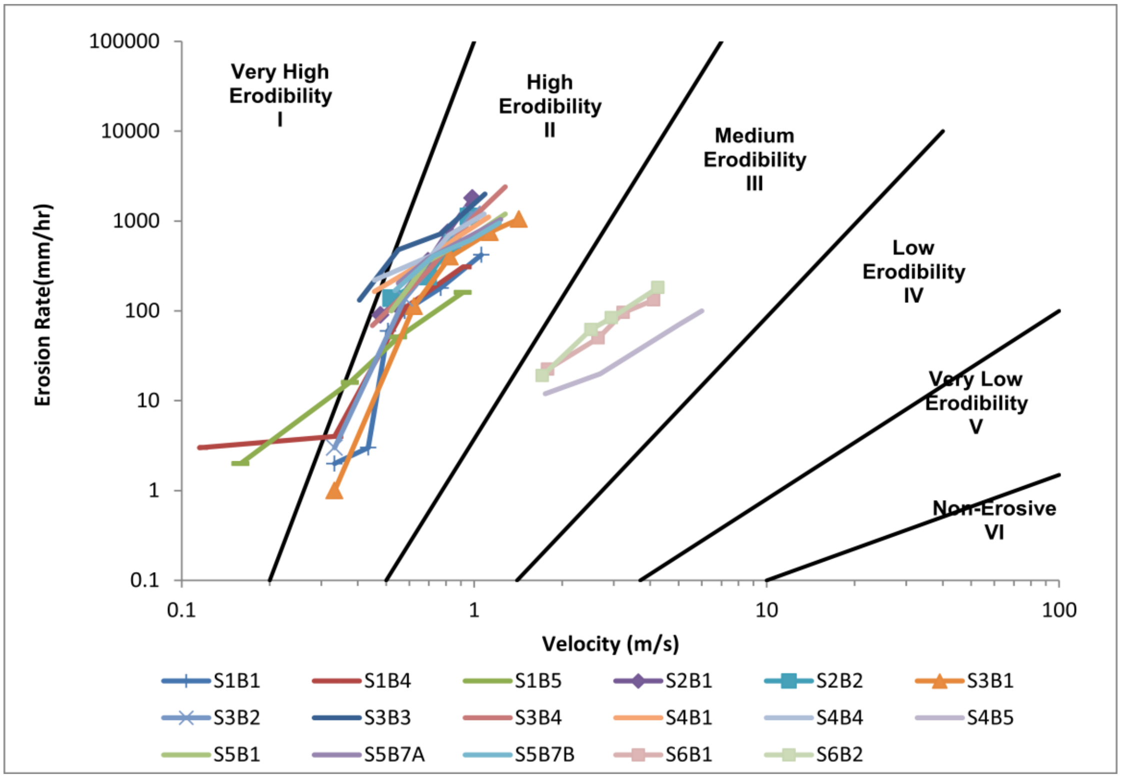


Figure 26. EFA test results for erosion rate versus velocity

CHAPTER 4: ANALYTICAL STUDY

4.1 INTRODUCTION

Meander migration is a process that has been studied for years and different methods have been proposed to predict it. The flow of water gradually erodes the banks and can cause a shift that could be a threat to existing bridges, highways and useful lands. Different approaches and procedures can be found in literature. Many of these methods are used to predict the migration rate and the final position of the bankline or centerline of a river. Some of these existing techniques used for meander migration that have been developed are summarized in the Technical Reports 2501-1, 2502-2 and 4378-1 of the Texas Transportation Institute (TTI). Some of the rivers in this project have been studied before and information can be found in these reports.

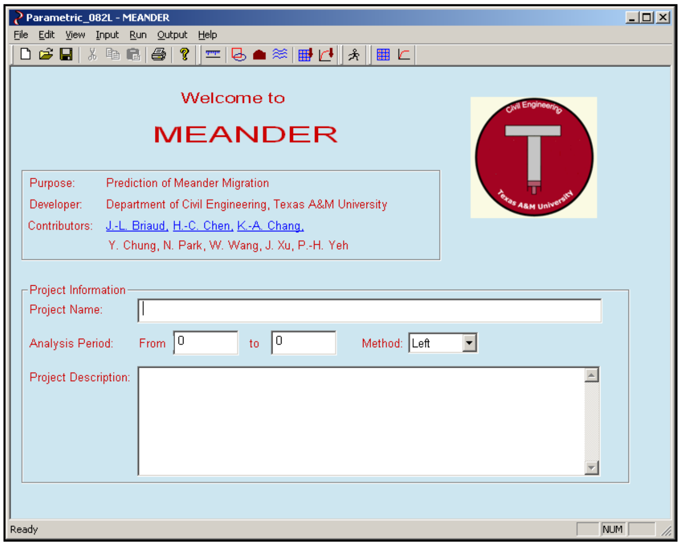
As mentioned before, there are different approaches to the meander migration problem. Some of these methods consist of numerous studies that result in empirical equations used to obtain the rate of migration. Other methods are based on the hydrologic characteristics of the stream. Techniques based solely on geometry of the bends have also been suggested. All of the proposed methodologies use different variables and consider that one or more of these variables are the most influencing parameters in the prediction.

A method for this project needs to be proposed, which will include most of the important influencing factors in meander migration. This method will combine flow and velocity data of the river, soil erodibility, and observations from aerial photographs and/or maps.

4.2 MEANDER PROGRAM

TTI developed the software called MEANDER, which is used to predict meander migration. MEANDER was developed in 2005 and the TTI Report 4378-1 explains in detail the development of this method. This program is available online and is free of charge. A tutorial to use the program is also included with the software. This software is based on a combination of review of existing knowledge, large flume experiments in two different soil types (i.e., sand and clay), three-dimensional numerical simulations, a hyperbolic model, and a risk analysis. The program consists of two major components: graphic user interface (GUI) and numerical implementation. The program uses the current or past geometry of the river, soil data obtained from erosion tests (EFA test results), and flow data. These also are the three aspects that are considered in the Observation Method developed in this project.

Figure 27 shows the interface of the MEANDER program when opened. The user buttons (command buttons) from left to right correspond to the interfaces that open when clicked: Units, Geometry input, Soil input, Water input, Table input, Plot input, Run function, and Plot output. The two unit systems, the metric system and U.S. system, can be used. The user needs to input the average river width and the path of coordinate file. The coordinate files correspond to the points that define the geometry of the river (initial conditions). If the "Fit Circles" button is clicked, circles will be fitted and drawn on the dialog.



Welcome to

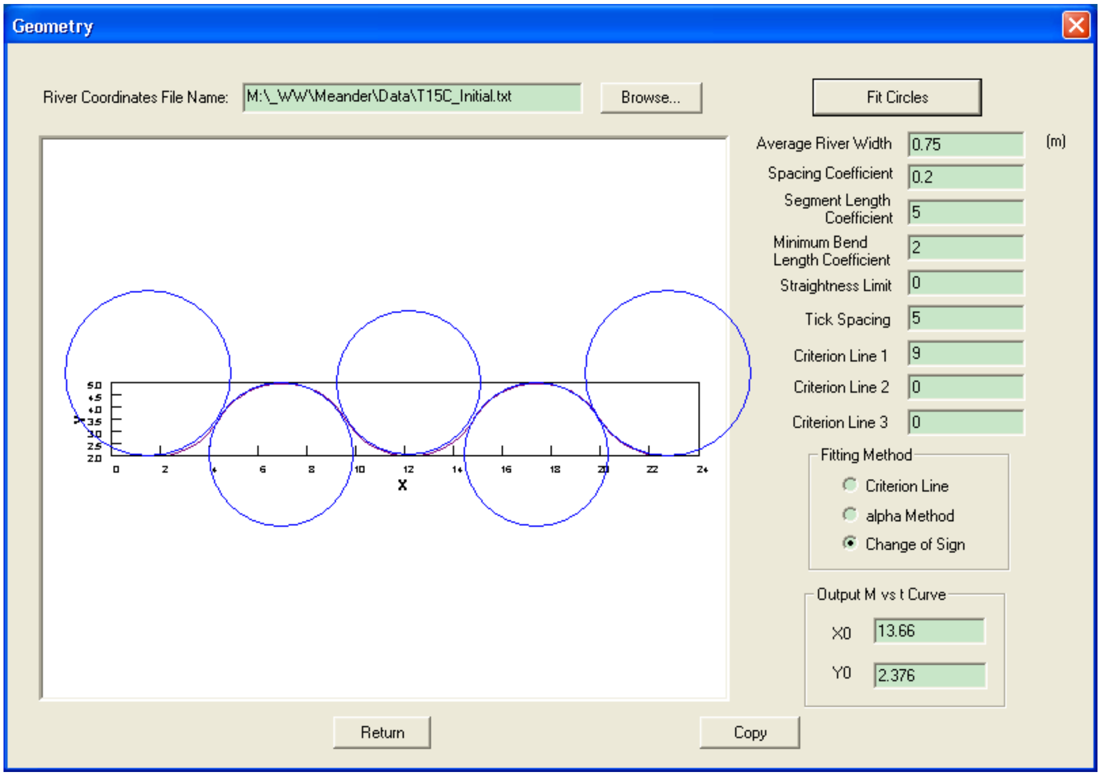
MEANDER

Purpose: Prediction of Meander Migration
Developer: Department of Civil Engineering, Texas A&M University
Contributors: J.-L. Briaud, H.-C. Chen, K.-A. Chang,
Y. Chung, N. Park, W. Wang, J. Xu, P.-H. Yeh

Project Information
Project Name:
Analysis Period: From 0 to 0 Method: Left
Project Description:

Figure 27: Main interface of the MEANDER program

Before curve fitting is done, the center line or bank of the river is divided into many segments. The three numerical methods used to fit the circles are Criterion Line, Alpha Method and Change of Sign. Only one can be selected and the user is free to change the method as desired, to get better results.



River Coordinates File Name: M:_WW\Meander\Data\T15C_Initial.txt

Average River Width 0.75 (m)

Spacing Coefficient 0.2

Segment Length Coefficient 5

Minimum Bend Length Coefficient 2

Straightness Limit 0

Tick Spacing 5

Criterion Line 1 9

Criterion Line 2 0

Criterion Line 3 0

Fitting Method

○ Criterion Line

○ alpha Method

● Change of Sign

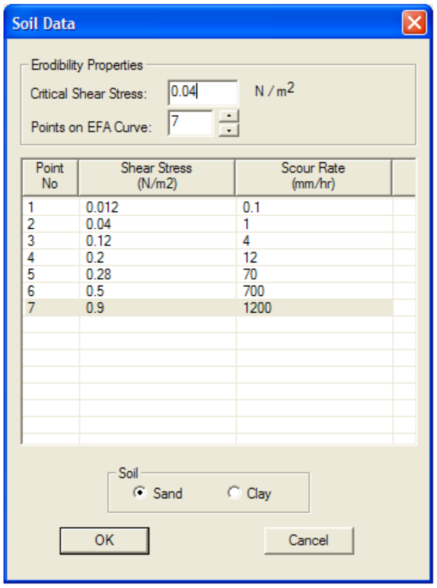
Output M vs t Curve

X0 13.66

Y0 2.376

Figure 28: Geometry input

Figure 29 corresponds to the soil data input interface. The first item is critical shear stress, which corresponds to erosion rate of 0.1 mm/hr. The number of points on an EFA curve needs to be specified and a table with the data is created. Since the equations for the modeling used for sand and clay are different, the two options for choosing the type of soil are also provided.



Erodibility Properties

Critical Shear Stress: 0.04 N / m2

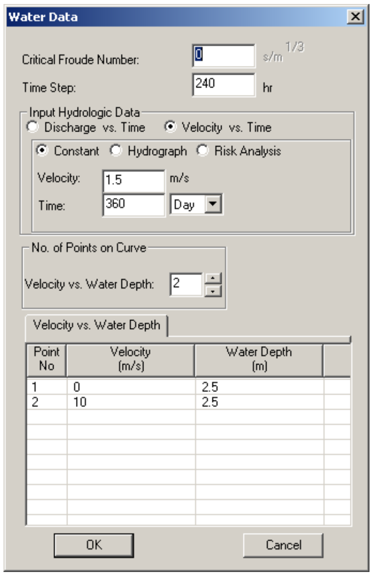
Points on EFA Curve: 7

Point No	Shear Stress (N/m2)	Scour Rate (mm/hr)
1	0.012	0.1
2	0.04	1
3	0.12	4
4	0.2	12
5	0.28	70
6	0.5	700
7	0.9	1200

Soil
● Sand ○ Clay

Figure 29: Soil data input

The interface for entering flow conditions is shown in Figure 30. The flow can be in terms of flow or velocity. Three types of analyses are available for the prediction: constant flow, hydrograph, and risk analysis. Risk analysis takes as input either a 100-year and 500-year flood or a hydrograph. One of the choices can be used to calculate the probability associated with the migration movement of the river over a period of time. If the input is flow or discharge, the Discharge versus Velocity table and Discharge versus Water depth table are required by MEANDER. All these tables can be obtained from simulation programs such as HEC-RAS (US Army Corps of Engineers) or TAMU-FLOW.



Critical Froude Number: 0 s/m 1/3

Time Step: 240 hr

Input Hydrologic Data

○ Discharge vs. Time ● Velocity vs. Time

● Constant ○ Hydrograph ○ Risk Analysis

Velocity: 1.5 m/s

Time: 360 Day

No. of Points on Curve

Velocity vs. Water Depth: 2

Velocity vs. Water Depth

Point No	Velocity (m/s)	Water Depth (m)
1	0	2.5
2	10	2.5

Figure 30: Water data input

The Output Plots box is the final user interface and contains the following buttons: “Center Line or One Bank”, “Both Banks, Risk Analysis”, and “M vs. t for one point”. The program has options such as: show the migrated channel of each step for the center line or a bank; show initial banks, predicted final banks, and measured final banks; or run a risk analysis. The migration process is shown on the next figure.

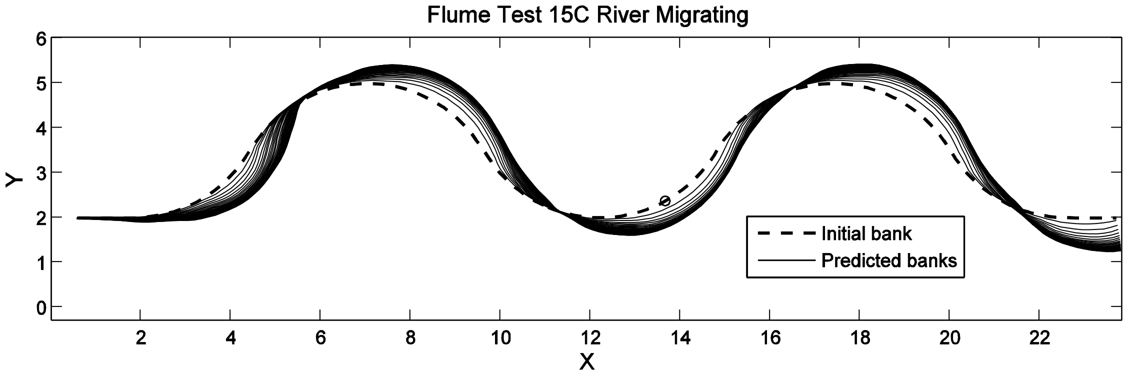


Figure 31: Prediction of meander position

4.3 OBSERVATION METHOD

The observation method for predicting meander migration and vertical degradation is a much simpler method that considers the three variables mentioned before: soil, flow and geometry. The necessary information to use the model is similar to the steps used in the MEANDER program.

Data of the variation of the discharge of a river can be obtained from the United States Geological Survey. Gage stations in Texas provide daily information of flow of a river. A hydrograph can be used to study the average daily flow of water over a period of time. Also, a graph of velocity versus time can be obtained from a hydrograph, considering the geometry, cross section and roughness of the river. This helps to study the variation of velocity for a determined period of time. With this information we can also know if there was a sudden increase (spike or peak) in the velocity of the river due to a flood or any other event which may have caused it.

Floods can significantly alter a steady flow rate of a river. Therefore, the migration rate (migration movement with time) of a meander can increase drastically. The extrapolation method used with aerial photographs assumes that the flow hydrologic conditions of the river will be the same in the future as they were in the past. This is not true if very different floods occur in the future. Floods can be observed on a hydrograph as high peaks in a period of time. The hydrograph and aerial photographs help to determine if there was a significant movement of the meander in the period that the flood occurred.

A prediction of a future flood is important to predict the movement of the meander. These predictions can be obtained with sufficient data. In this case, the worst scenario could be a 100-year flood or a 500-year flood. If no probabilistic approach is used, previous data from the flow could be used. Periods of flow from 10 years were used in this project to make predictions. These periods were used from the same data used to construct a future hydrograph for the prediction.

The migration rate can be related or compared to the erosion of the soil of the bank. Many of the methods used to predict meander migration do not consider the erodibility of the soil. For a complete study of the migration, erosion tests must be performed. The EFA is used to obtain a curve that relates erosion rate to velocity and erosion rate to shear stress. The critical velocity for erosion can be obtained from the curve. The critical velocity at the site may not be the same and has to be found. If no erosion tests could be performed, the erosion categories can be used using the classification of the soil at the site.

Using the hydrographs of a river, observed data from maps, aerial photos and cross sections, and the erodibility of the soil, a method to predict the meander position and vertical degradation has been developed. This method has been called the Observation Method because it is based on real, observed data to make a prediction of the river in the future.

4.4 METHODOLOGY DEVELOPMENT AND PROCEDURE

The procedure used to predict the meander position during a period of time and where it will be is explained in the following sections. A similar approach is applied for vertical degradation of the bank of the river for these cases. Two software programs were used to verify the Observation Method: MATLAB and Microsoft Excel. A code was written for both programs and a step-by-step example is explained in the next chapter.

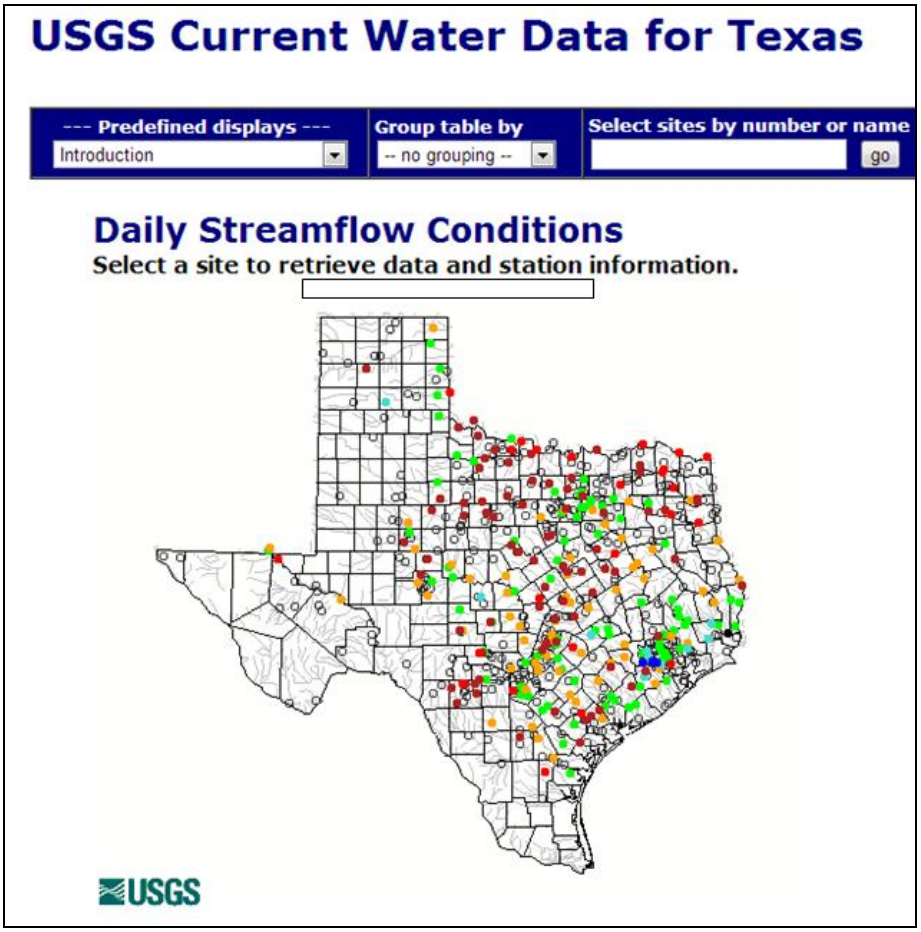
I. Site selection

The sites of concern for this project are located at six different rivers in Texas. Each one has had erosion problems, and in some of them, different remedies have been implemented for control purposes. Meander migration and degradation at the bottom of the rivers are some of the issues of these rivers. In general, aerial photos of these rivers can be used to compare the river movement due to the erosion and deposition of the soil and sediments. Cross sections from different years can be used to see the progress in vertical degradation at the bridge location. Again, the sites selected for the project and for which each one has been used to design the model were:

- SH 105 at Brazos River (Navasota, TX) – Meander migration
- FM 787 at Trinity River (Cleveland, TX) – Meander migration
- SH 63 at Sabine River (Texas-Louisiana border) – Meander migration
- SH 34 at North Sulfur River (Ladonia , TX) – Vertical degradation
- US 90 at Nueces River (Uvalde, TX) – meander migration
- FM 973 at Colorado River (Austin, TX) – vertical degradation

II. Obtaining the river hydrographs

The first step for the Observation Method is to obtain a hydrograph of the rivers from the USGS stations. The average daily flow can be obtained for a period specified by the user in the USGS website. In some cases, the bridge of interest has no gage installed. A gage downstream or upstream has to be used instead. Figure 32 shows the interface of the USGS website for the gages located in Texas. The data used from each gage is the average daily data. It is important to have the data starting from the date of the first map or photo. The period is selected and ends with the date of the last map or photo. To observe the daily flow, the data is copied in Excel and used in a chart of flow versus time. This generated graph of flow versus time is known as hydrograph. The flow, however, has to be converted to velocity to be used in this method.



USGS Current Water Data for Texas

--- Predefined displays ---: Introduction

Group table by: -- no grouping --

Select sites by number or name

Daily Streamflow Conditions

Select a site to retrieve data and station information.

Figure 32: Gage locations in Texas

There are several ways to obtain the velocity of the river from the flow. The most precise way is to obtain the geometry and cross sections of the river and simulate the river in programs such as HEC-RAS or TAMU-FLOW. HEC-RAS was developed by the US Army Corps of Engineers and TAMU-FLOW by Texas A&M University. Both of these programs can be obtained online with no cost. The first one is a robust program that has many functions and could be more complicated to obtain the velocities. This program needs the geometry from the top view, cross sections, roughness and slope of the river. Figure 33 shows the interface of HEC-RAS.

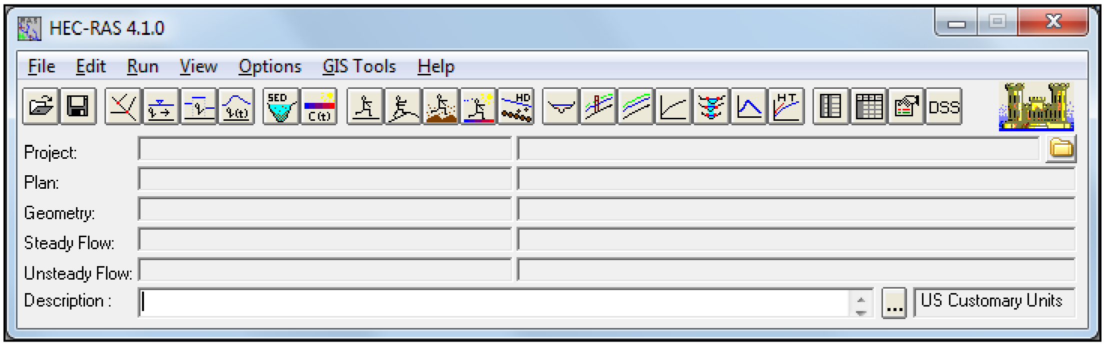
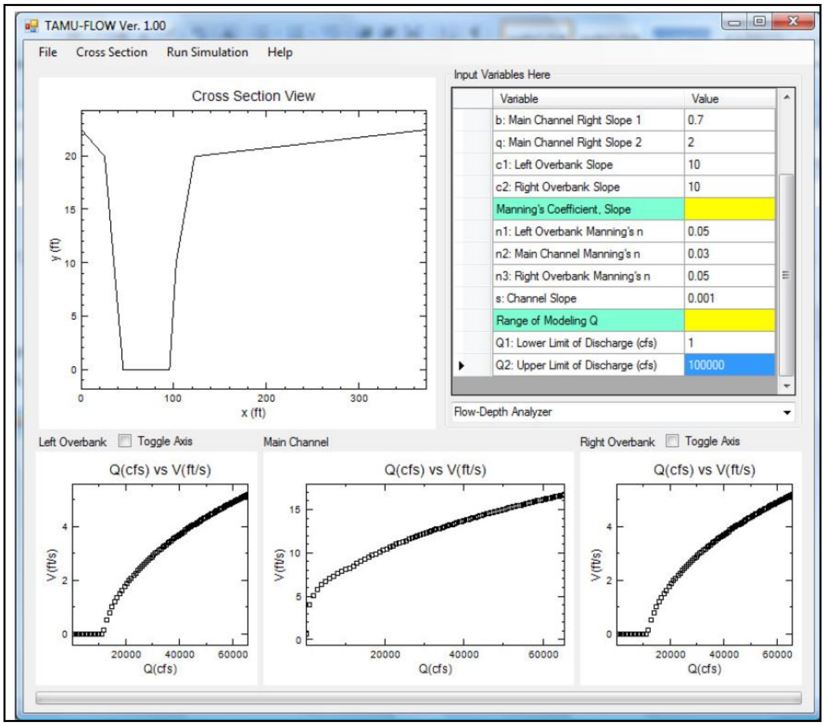


Figure 33: HEC-RAS interface

TAMU-FLOW is a much simpler program and can be used solely for this specific task. The user interface (Figure 34) is simplistic and the only purpose of the program is to obtain the velocity by using only one cross section. The cross section of the river can be assumed to be constant along the river for simplification or the cross section at the area of interest of the river can be used. The coordinates of the cross section of the river are put in the program and then after running the simulation, a curve of velocity versus time can be obtained. The data is saved as a text file that can be opened in Excel. The manual of TAMU-FLOW can be accessed directly from the Help tab. Some of the variables used to run the simulation are the Manning’s coefficient and the slope of the river. Any custom or trapezoidal cross-section can be drawn or imported into the TAMU-FLOW program.



Input Variables Here

Variable	Value
b: Main Channel Right Slope 1	0.7
q: Main Channel Right Slope 2	2
c1: Left Overbank Slope	10
c2: Right Overbank Slope	10
Manning's Coefficient, Slope	
n1: Left Overbank Manning's n	0.05
n2: Main Channel Manning's n	0.03
n3: Right Overbank Manning's n	0.05
s: Channel Slope	0.001
Range of Modeling Q	
Q1: Lower Limit of Discharge (cfs)	1
Q2: Upper Limit of Discharge (cfs)	100000

Flow-Depth Analyzer

Figure 34: TAMU-FLOW interface

Another way of obtaining the velocity is to use an equation that relates flow with velocity from observed data of a similar river. Rivers that are similar may have a similar relationship between velocity and time. This can be done if a quick verification of the data wants to be obtained, but is not recommended.

In general, after obtaining the relationship between velocity and flow, the velocity and flow are plotted versus time (Figure 35 and Figure 36).

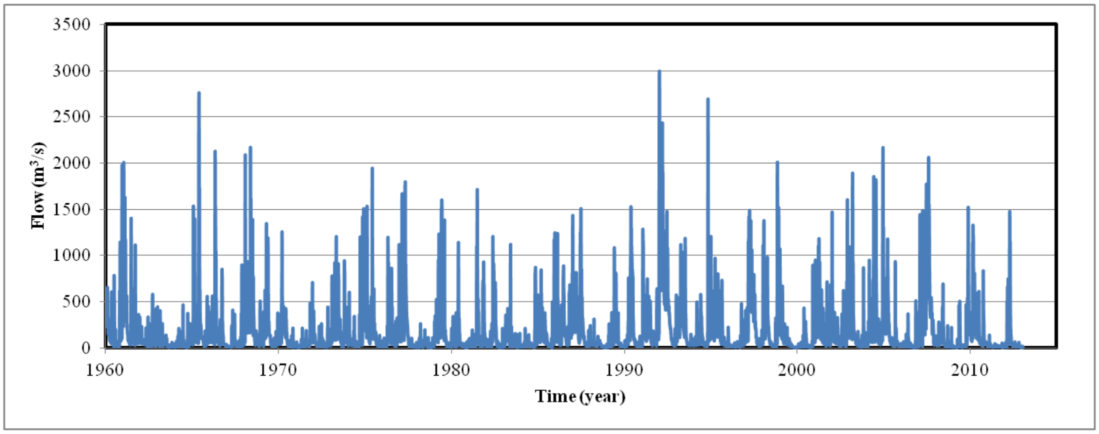


Figure 35: Flow hydrograph

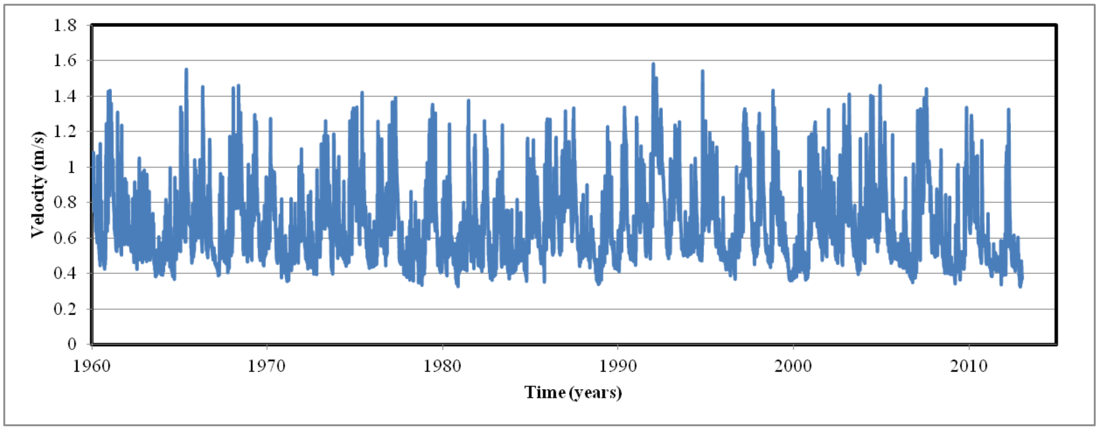


Figure 36: Velocity hydrograph

III. Generate the EFA curve

After collecting the soil samples from the field, laboratory testing is necessary to study the erodibility of the soils and their soil classification. The EFA (Figure 37) is used to obtain the erosion function and to classify the soil according to its erodibility. The soil is pushed out of the Shelby tube as it is being eroded. The soil can be classified in one of six categories. If no soil can be tested in the EFA, the engineer can make an assumption of an erosion curve by using the soil classification and its corresponding erosion category (Figure 38).

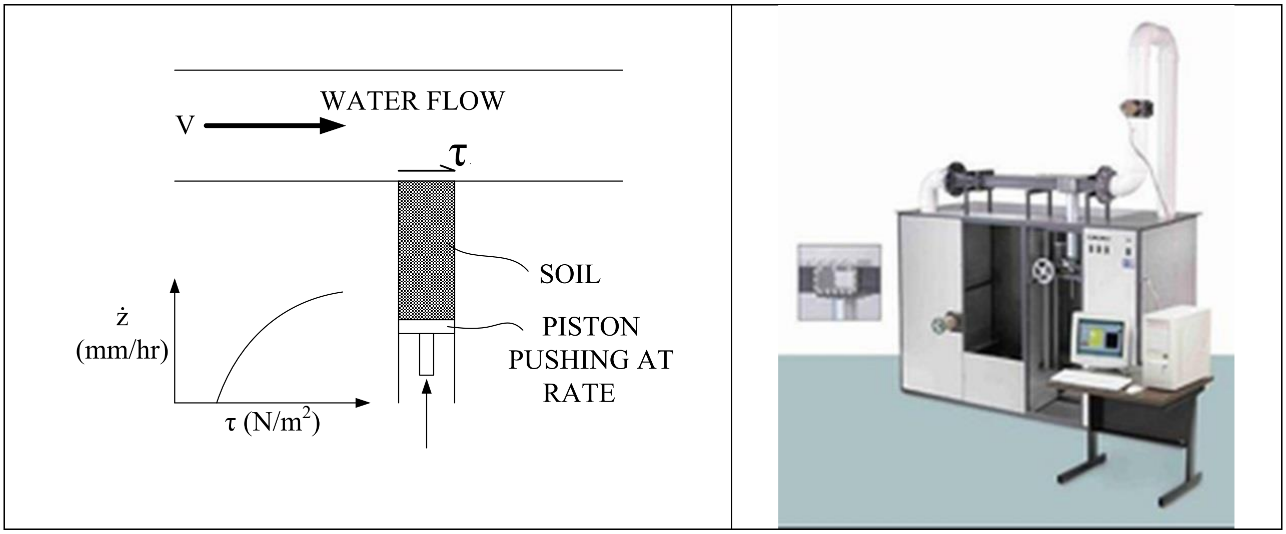


Figure 37: Erosion Function Apparatus setup and test (Briaud, 2007)

Sieve analysis, hydrometer and Atterberg limits tests are used for the classification of soils. Several EFA tests have been performed to obtain the erodibility of the soil of the rivers selected for this project. Not all of the soil samples in the sampling tubes are tested, but only those that represent well the general conditions at each site and where the most critical erosion occurs. Again, the erosion categories according to the soil classification are shown in Figure 38.

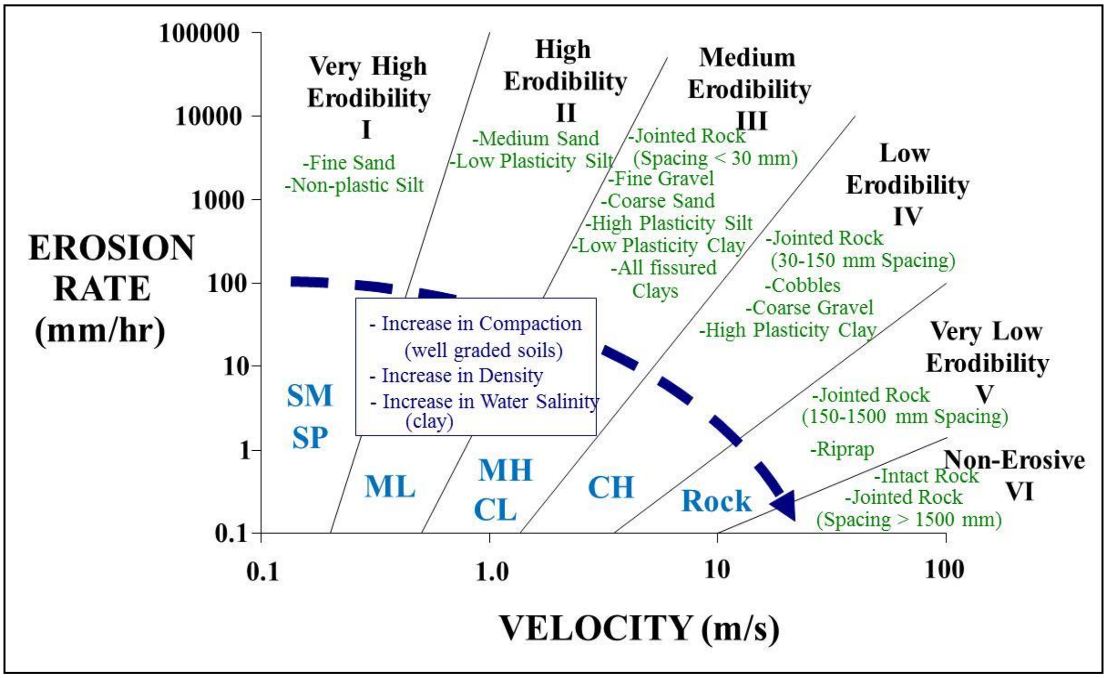


Figure 38: Erosion categories according to soil classification (Briaud, 2013)

The EFA curve, which describes the relationship of the erosion of the soil to the water velocity, is represented as a line in a log-log scale graph. Several readings from an EFA test are used to generate this line. The erosion of the soil sample is measured in millimeters and then these readings are converted to erosion rate in millimeters per hour (mm/hr). A typical EFA curve obtained from the test has erosion in units of millimeters per hour versus the velocity in meters per second. Generally, this kind of test is run to obtain at least 8 points that are used to generate the curve. However, for these samples only between 3 to 6 points could be obtained because of the length of the sample and the erodible material tested.

For the Observation Method, the erosion is first converted from millimeters per hour to meters per second. This information is later used to know how many meters the soil erodes per second because the average flow obtained from the USGS is in meters per second as well. The consistency in the units is very important to calculate the erosion and the critical velocity from the model.

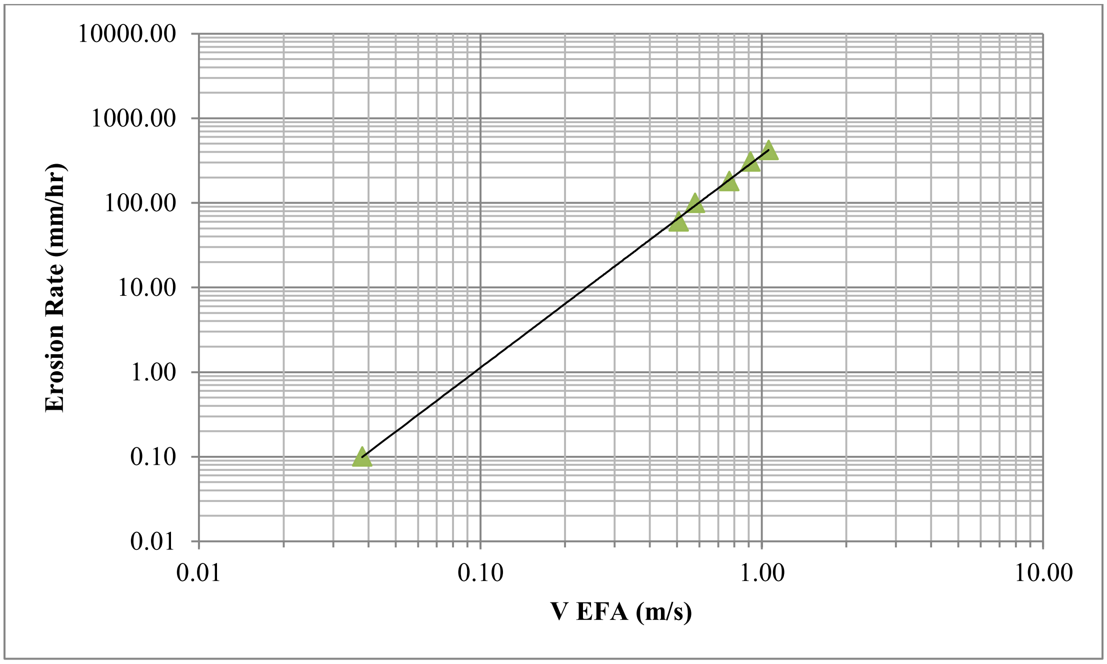


Figure 39: Erosion function

A coefficient and an exponent can be obtained from the general equation of an EFA curve, which have been called α and β. A regression line can be obtained using Excel by using the curve fitting option in the graph and both parameters can be seen in the equation of the curve above. The equation for the erosion function is:

$$\dot{z} = \alpha v^{\beta}$$

Where:

$\dot{z}$: erosion rate

v: velocity

α and β: parameters.

The α and β are obtained when the units of erosion rate and velocity are both in meters per second. Obtaining an equation that could be used with *any* units is one aspect of the Observation Method. For this reason, the α coefficient is not used, as it changes with a change of units.

Figure 40 shows the classification of the soils and the β exponent that define the divisions between the erosion categories. Using an average line, a line that divides two categories or a user-selected line can be another option if an EFA curve is not obtained or if an EFA test is not performed.

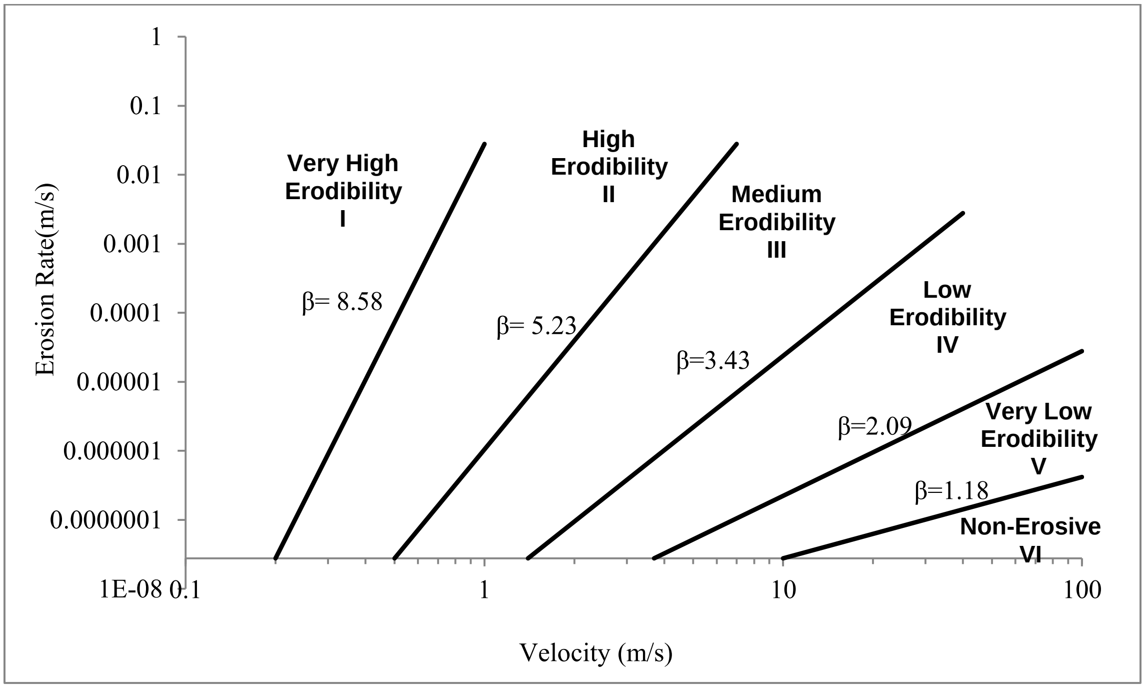


Figure 40. Erosion categories with β values

Sometimes in hydraulics and other fields of science, it is preferred to have the equations with no units on both sides of the equation. The model used in the Observation Method uses the critical velocity, v_c, from the EFA curve to obtain a new equation. Dividing both the erosion rate and the velocity by the critical velocity from the EFA curve, the equation obtained is

$$\frac{\dot{z}}{v_c} = \alpha' \left(\frac{v}{v_c} \right)^{\beta}$$

The critical velocity v_c used in the equation corresponds to an erosion rate of 2.78e-8 m/s or 0.1 mm/hr. The α' coefficient is not the same α coefficient from the EFA curve. To obtain this new parameter, the equation used is

$$\alpha' = \frac{\dot{z}_c}{v_{cEFA}}$$

Where:

v_{cEFA}: critical velocity from the EFA curve

$\dot{z}_c$: 2.78e-8 m/s or 0.1 mm/hr (erosion rate at critical velocity)

The critical velocity of the soil sample tested in the EFA can be estimated after performing the erosion test. However, it can be argued that this critical velocity from the sample does not necessarily correspond to the minimum velocity for erosion to occur at the site. It has been proved that shear stresses imposed by small scale testing apparatuses, such as the EFA, can be significantly larger than those stresses observed in the rivers (Perri et al., 2010). There are many factors that could increase the critical velocity at the site such as the vegetation, geometry, compaction, countermeasures, etc.

Also, sometimes the critical velocity cannot be observed during an EFA test and has to be extrapolated. This may result in an inaccurate result. It was found that that the critical velocity occurred at a very low velocity when extrapolating. This is why the critical velocity and the equation used for the Observation Method cannot be applied to each of the velocities obtained from the velocity hydrograph. Erosion occurs at a certain minimum velocity at a site and below that velocity no erosion occurs. The critical velocity at the site must be found.

IV. Observed river movement

The fourth step of the Observation Method is related to the movement of the river in terms of meander migration or vertical degradation. The movement of the meander can be analyzed with several aerial photographs and/or maps. The aerial photos can be obtained online from different websites or programs such as Google Earth. The aerial photos from Google Earth are limited because it only contains photos from the early 1990s to present time. Other sources have to be used to obtain older photos. Also, there are databases and libraries that store maps from different years that can be used for this purpose. High resolution photos are always desired and preferred over maps because sometimes the details in topographic maps along the slopes of the river cannot be distinguished as easily as in a photo. However, maps are easier to find than photos for dates from 30 years ago or earlier. The maps and/or photos are overlaid, using the same principle of the extrapolation method by putting together many of them and seeing the progress of the meander migration. Two or more reference points, that have not changed their location, are used to overlay the photos or maps. Different colors or line styles can be used to differentiate the different years in drafting software such as AutoCAD and make a visual comparison of the progress of the erosion. Figure 41 shows an example of the river movement of the Brazos River. The red arrow here is used to show the most critical direction and the movement is then recorded from this reference line.

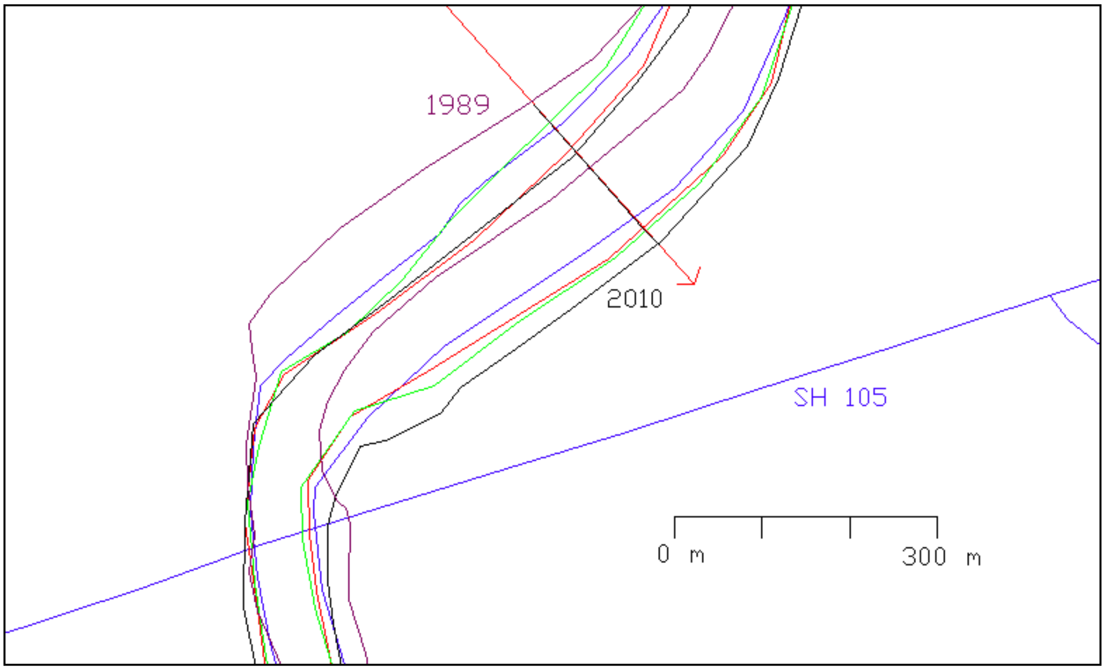


Figure 41: Progress of erosion in Brazos River

A point of reference (or interest) of a meander is used to study its displacement with time. In the case of Figure 41, the red arrow represents the most critical direction of erosion and a point of reference moves along this direction during the period of years used in the maps. This point could either be in the centerline or in the outer bend of the river. With this information, the movement can be plotted in a graph of the meander position (or displacement) of this point with time.

After obtaining the data of the average daily flow from USGS, only the period between the first and last map, photo or cross section is used. The point of reference is used to represent the movement of a critical area of the meander with time. It would be tempting to estimate the migration rate of the river as the slope of the meander position versus time, but the migration rate is not constant as it was mentioned before. The units of the migration rate are distance over time. Figure 42 shows an example of the magnitude of migration versus time for a certain point.

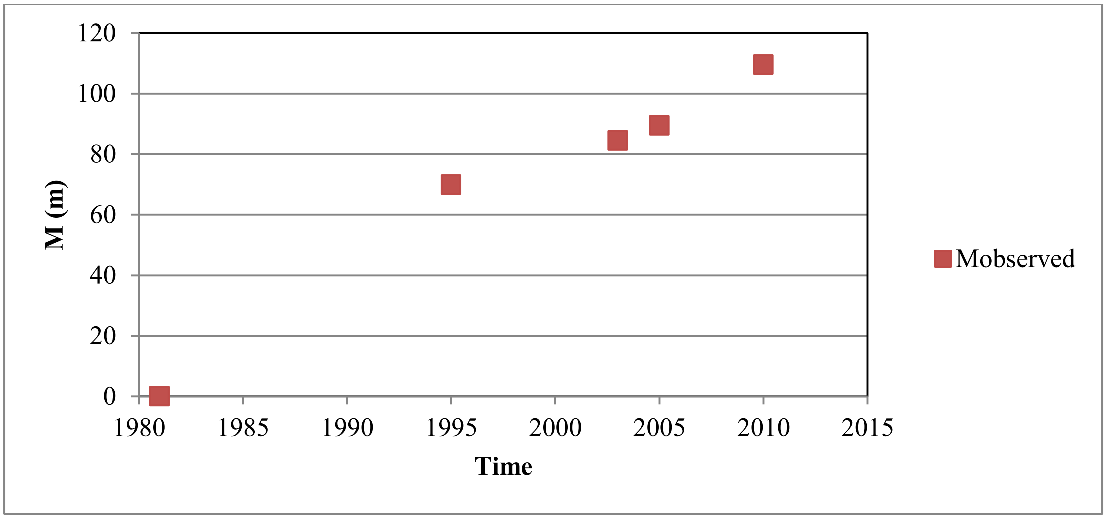


Figure 42: Meander position versus time

V. Obtain the critical velocity by regression (calibration step)

The most important part of this method is to obtain the critical velocity of the river (or site critical velocity). As said before, the critical velocity obtained from the EFA test does not necessarily correspond to the critical velocity in the field which is typically higher because of tree roots and vegetation for example. Also, this critical velocity will only correspond to the point along the critical direction mentioned in the previous step.

The critical velocity of the site is used in the equation of the model from the step 3 and it is assumed that the river will not erode below this velocity. To obtain this velocity, a code was written in MATLAB and Excel using the equation of the model. The input data used in the code are:

- the α' and β coefficients from the erosion function of the soil at the site
- the average velocities (in meters per second) for the period that is being considered and the time (in years) corresponding to each day
- the observed data, which is the movement of the point from the meander position or bottom of the river when vertical degradation occurs. The initial value for river position can be 0 or other depending on the reference used. The precision of the critical velocity will increase when more data is accumulated from different maps or photos.

The code calculates the migration in meters as a function of time over the duration of the hydrograph by using α’ and β values from the EFA results but for a chosen range of trial and error critical velocities v_c. This step is called the calibration step. The calibration step is used to obtain the critical velocity of the river, which is then used to predict the migration of the meander in the future. The magnitude of migration or degradation (M) is estimated for each day by using the velocity assigned for each day. The velocity data and each day (in years) is imported and then the code iterates multiple times (in the case of MATLAB), using the range of critical velocities. Usually this range can be between the minimum and the maximum velocity found in the velocity hydrograph for the river being studied. The equation used to find the daily erosion and the progress of the movement of the point of reference in the river is based on the model equation from step III.

$$M = \alpha' \left(\frac{v}{v_c} \right)^{\beta} \times v_c \times \Delta t$$

Where Δt is in days. This equation is obtained by multiplying the model equation by time and critical velocity on both sides of the equation. The increment of each step for the calculation of M is one day or 86400 seconds. Erosion will only occur when the ratio v/v_c is larger than 1.

The code compares the magnitude M with the observed data for each critical velocity from the range. If only five points were obtained from the maps, the code will only compare the migration estimated with the model for the last four points. The precision of this method is improved with the quantity of observed data (Figure 43).

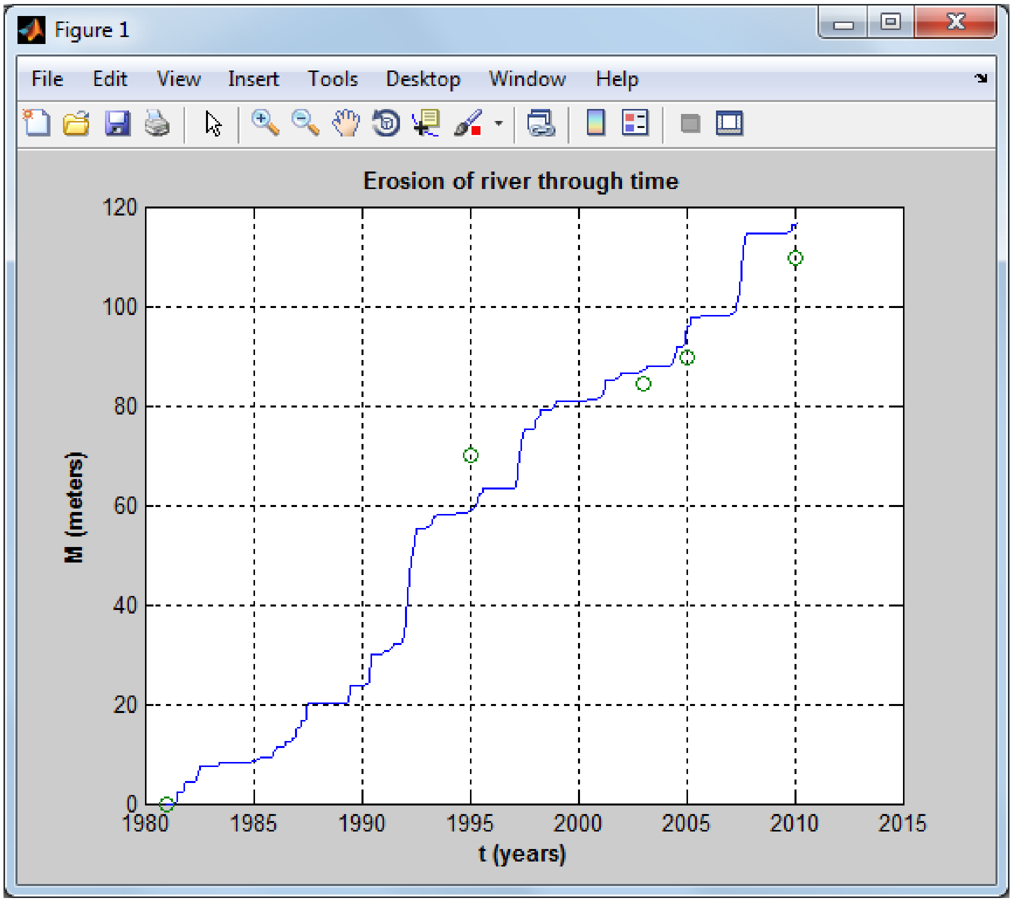


Figure 43: Observed data (green) and predicted data (blue)

The program (in MATLAB) runs until the difference between the points of observed data and the points generated is the smallest for a certain date. The method used to minimize the difference is by obtaining a Ranking Index (RI). The precision of the points is better when the RI is the smallest that it can be (Briaud and Tucker, 1988). The RI is calculated with the following equation

$$RI = \left|\mu(a)\right| + \sigma(a)$$

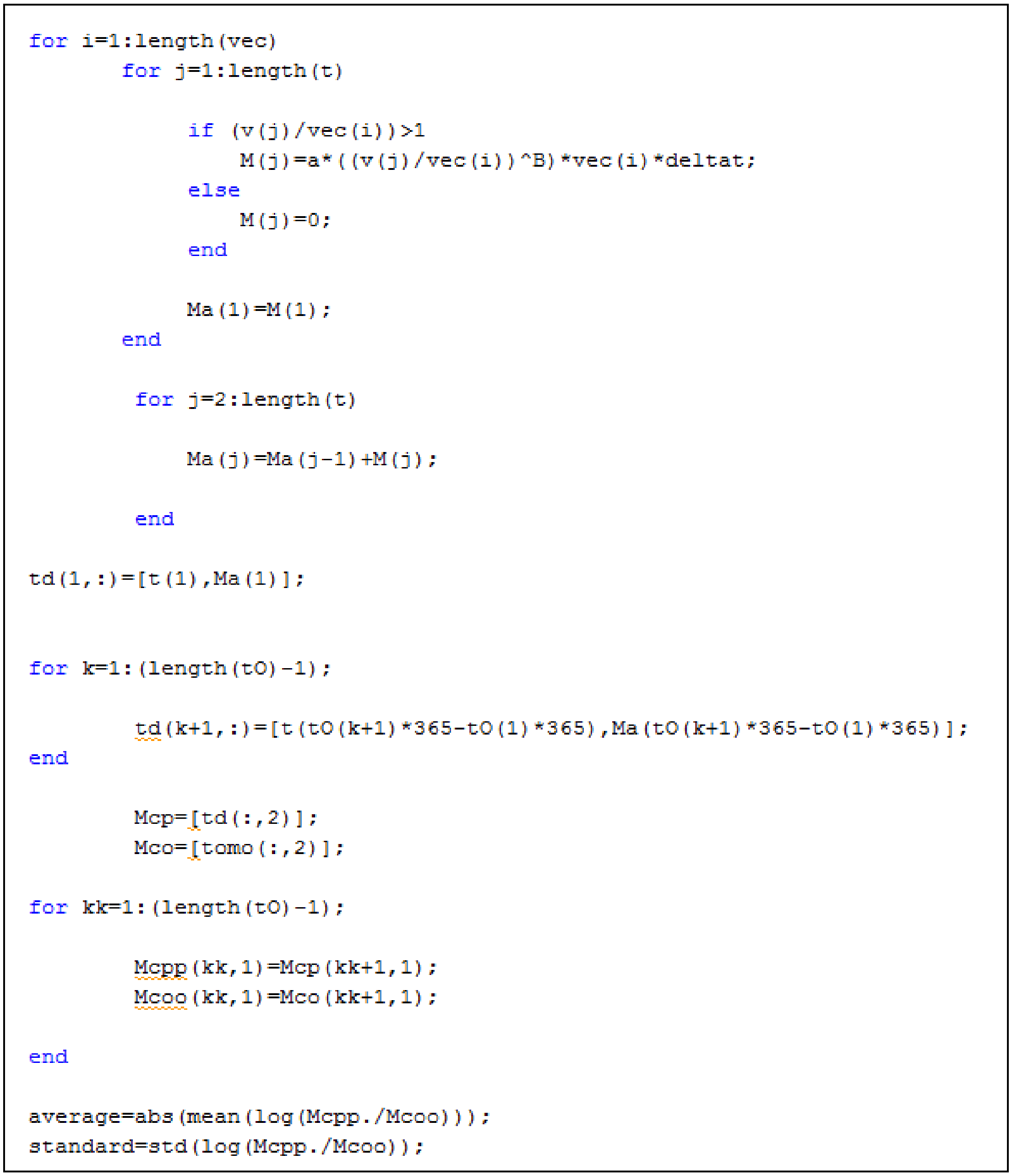
Where:

μ: mean value

σ: standard deviation

a: ratio of the calibration or generated value of meander position over the observed (Mc/Mo).

After finding the smallest RI for a selected range of velocities, the critical velocity is obtained and the meander position is generated versus time. Figure 44 shows a sample of how the code looks in MATLAB and the iteration process used.



```
for i=1:length(vec)
       for j=1:length(t)

            if (v(j)/vec(i))>1
                M(j)=a*((v(j)/vec(i))^B)*vec(i)*deltat;
            else
                M(j)=0;
            end

            Ma(1)=M(1);
       end

        for j=2:length(t)

            Ma(j)=Ma(j-1)+M(j);

        end

td(1,:)=[t(1),Ma(1)];


for k=1:(length(tO)-1);

        td(k+1,:)=[t(tO(k+1)*365-tO(1)*365),Ma(tO(k+1)*365-tO(1)*365)];
end

        Mcp=[td(:,2)];
        Mco=[tomo(:,2)];

for kk=1:(length(tO)-1);

        Mcpp(kk,1)=Mcp(kk+1,1);
        Mcoo(kk,1)=Mco(kk+1,1);

end

average=abs(mean(log(Mcpp./Mcoo)));
standard=std(log(Mcpp./Mcoo));
```

Figure 44: Sample of code in MATLAB

Figure 45 shows the progress of the erosion of the river when plotted with time. The line shows the position of the river from the reference direction selected in step IV. As seen, the river position can be stable and sudden big jumps may occur. This happens when a big flood occurs for consecutive days and the velocity of the river increases abruptly. This proves that big changes occur at rivers when big floods occur. In a matter of 24 or 48 hours, the river can even move from 10 to 20 meters when large volume of water during a flood (and the high velocities that come with) washes away the soil from the banks of the river.

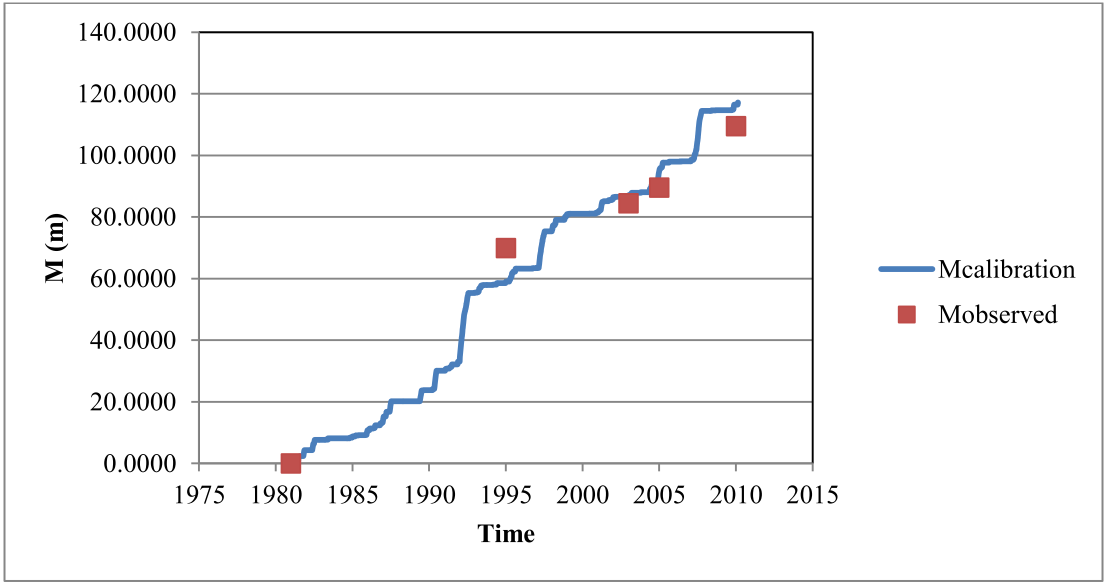


Figure 45: Estimated erosion progress with time

The calibrated values and the observed values can be compared to see how different they are. A fitted line can be drawn in a graph of M_c versus M_o (Figure 46).

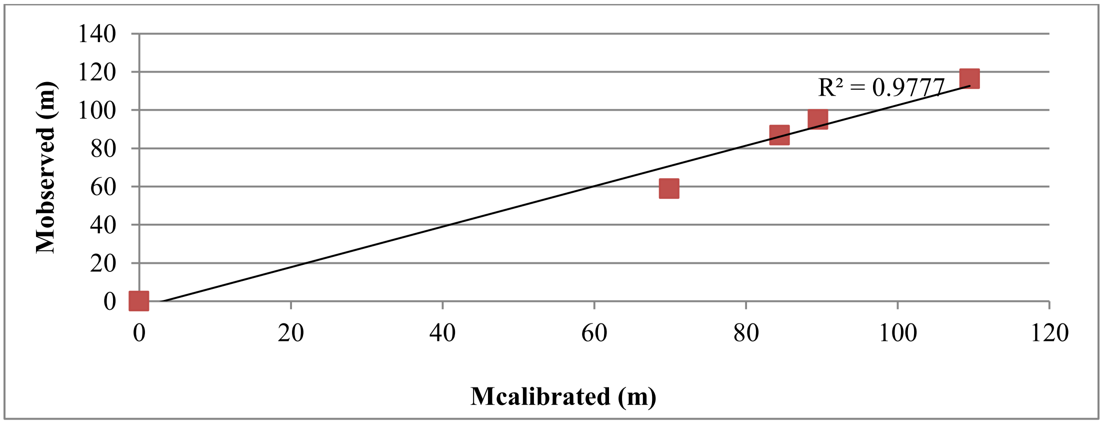


Figure 46: Observed data versus calibrated data

VI. Use the model to predict meander migration (prediction step)

The program (or the user) stops the iterating process when the critical velocity is found with the smallest RI. This is the end of the calibration step. This critical velocity is then used on the next step to predict the position of the meander or the vertical degradation in the future by using either a full hydrograph or a single value of velocity. After generating the data from the calibration step and using the critical velocity, a prediction of the meander can be performed by using velocities that could occur in the future. As expected, big floods are responsible for big changes in the meander position. Using a user generated hydrograph of velocities or repeating the recent data, the position of the meander can be predicted and an approximation can be obtained.

Also, the calibration step approach could be used to verify the model. For example if data between 1990 and 2000 is used, the critical velocity can be obtained from the back calculation process and then used to estimate the position of the river after the year 2000. Then, the hydrograph for the period between 2000 and 2010 can be used with the critical velocity to estimate the position of the river in the year 2010. Because this also is a date from the past, the observed data from 2010 can be compared with the estimated position of the river for the 2010. The model can be verified and it can be seen how precise the approximation of the data used was if done this way.

CHAPTER 5: OBSERVATION METHOD

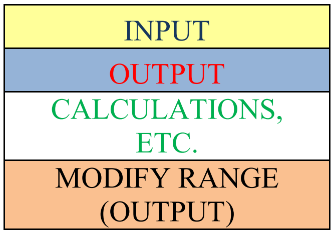
5.1 INTRODUCTION

The Observation Method is used to be able to find the critical velocity in the field and determine the erosion in function of the river velocity. As said before, the Observation Method is based on observed data. It is important to generate the history of the movement of the river. Based on the principles explained on the previous chapter, a step-by-step example is explained in this chapter using the two codes developed in this project. One code was written in MATLAB and the other one in Visual Basic for Applications for Microsoft Excel. The Brazos River case is used as an example.

5.2 GENERAL STEPS

The following steps are performed first before using either the MATLAB code or the Excel spreadsheet. The Excel spreadsheet is used for the erosion function results, even if MATLAB is used later to perform the calibration and prediction steps. The colors of the boxes in Excel are used not only to distinguish the input from the output, but also from calculations and others. The yellow cells with blue font correspond to input. The blue cells with red font correspond to output. The white boxes with green font are used for calculations and automatic counting and should not be edited. The orange cells indicate that the selection of a range of cells has to be modified for the calculations to work. These cells are also output values.

Table 1. Colored cells in Excel for input, output and more



INPUT
OUTPUT
CALCULATIONS, ETC.
MODIFY RANGE (OUTPUT)

1. Select a river and find the nearest USGS station.
    a. The USGS contains information of stations that measure the average daily flow in the United States at http://waterdata.usgs.gov/nwis/dv/?referred_module=sw. Select here by State/Location and then select Texas.

USGS Surface-Water Daily Statistics for the Nation

Surface-water daily data example.

Select sites which meet all of the following criteria:

Define one or more values for each of the following site-selection criteria: --- or select new criteria

State/Territory -- select one or more

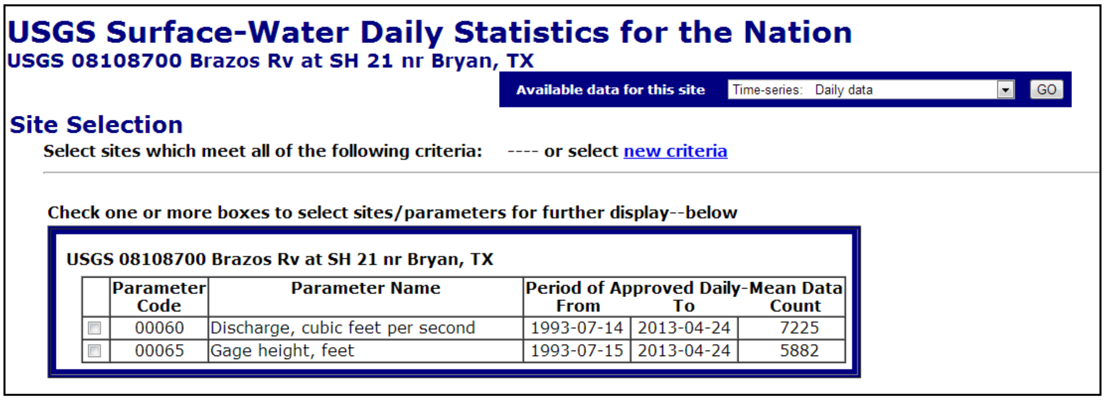
Figure 47. USGS website for average daily flow at each state

    b. A list of all the gage stations and their locations show up. Select the gage station that corresponds to the river. Most of these bridge locations have a gage station nearby. Data from a gage station nearby is used when there is no gage station at the location. If there is insufficient data but there is a gage at the site (gage station not working anymore or only recent data is available), a gage station from upstream or downstream from the same river has to be used to complete the hydrograph. This happens for the Brazos River. For this case, the closest gage stations corresponding to the Brazos River for this case are 8110200 and 8111500. The 8110200 is at the location, but it was operating only in the 1970s and 1980s. The 8111500 station is located downstream in Hempstead, TX. An estimation of the flow can be obtained if the drainage area at the gage stations is known. The following formula can be used to estimate the flow when data at the gage station of the bridge is missing.

$$Q_2 = Q_1 \frac{A_2}{A_1}$$

Where Q is flow and A is the drainage area, which can also be obtained from the USGS data. In this case, Q_2 corresponds to the unknown data and Q_1 to the known. The USGS provides the drainage area at the gage station, but if there are no gage stations, then the drainage area has to be estimated using other methods. Geographic Information Systems (GIS) can be used to get the drainage area at a point of interest.

c. After selecting the gage station, select at the top Time-Series: Daily Data. Also a Map of the location of the gage is available here.



USGS Surface-Water Daily Statistics for the Nation

USGS 08108700 Brazos Rv at SH 21 nr Bryan, TX

Site Selection

Select sites which meet all of the following criteria: ---- or select new criteria

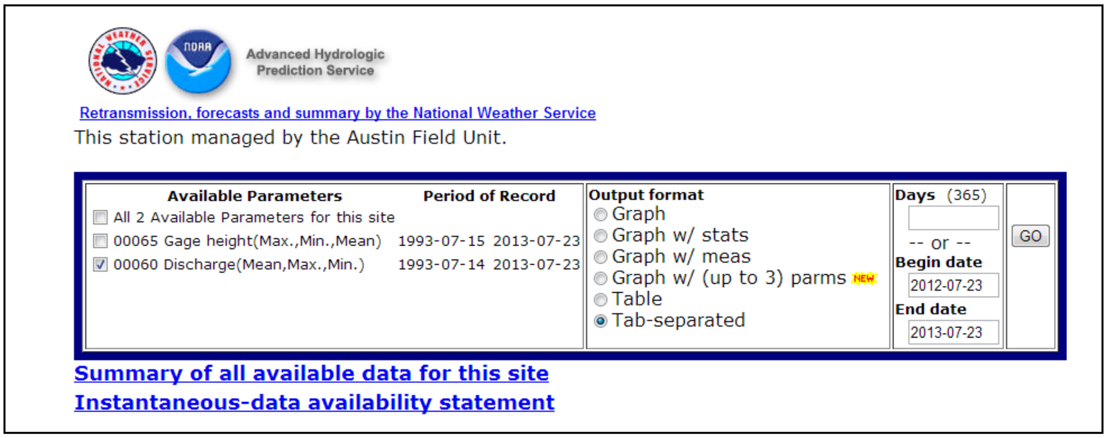
Check one or more boxes to select sites/parameters for further display--below

USGS 08108700 Brazos Rv at SH 21 nr Bryan, TX

	Parameter Code	Parameter Name	Period of Approved Daily-Mean Data From	To	Count
☐	00060	Discharge, cubic feet per second	1993-07-14	2013-04-24	7225
☐	00065	Gage height, feet	1993-07-15	2013-04-24	5882

Figure 48. USGS gage selection

d. Select Discharge under Available Parameters, Tab-separated under Output Format and set the Date Range. Click Go and the Data should show up. Click File > Save As… and save the information in a text file. Open the text file from Microsoft Excel to view the information.



Retransmission, forecasts and summary by the National Weather Service

This station managed by the Austin Field Unit.

Available Parameters	Period of Record	
☐ All 2 Available Parameters for this site		
☐ 00065 Gage height(Max.,Min.,Mean)	1993-07-15	2013-07-23
☑ 00060 Discharge(Mean,Max.,Min.)	1993-07-14	2013-07-23

Output format

○ Graph
○ Graph w/ stats
○ Graph w/ meas
○ Graph w/ (up to 3) parms NEW
○ Table
● Tab-separated

Days (365)

-- or --

Begin date 2012-07-23

End date 2013-07-23

Summary of all available data for this site

Instantaneous-data availability statement

Figure 49. USGS parameters

e. Convert all the dates from the column of time in years. To do this, you have to remember that every day is 1/365 years (approximately, one day is 0.0027 years). The code does not recognize the format of the dates and they have to be converted to a number. Here is an example of the format of the each date.

Table 2. Format for time in years to use in both MATLAB and Excel

Time (Days)	Time (Year)	Gauge Station	Date
1	1960.00274	8109000	1/1/1960
2	1960.005479	8109000	1/2/1960
3	1960.008219	8109000	1/3/1960
4	1960.010959	8109000	1/4/1960
5	1960.013699	8109000	1/5/1960
6	1960.016438	8109000	1/6/1960
7	1960.019178	8109000	1/7/1960
8	1960.021918	8109000	1/8/1960
9	1960.024658	8109000	1/9/1960

f. Plot the flow hydrograph to get a better understanding of the river flow in flow versus time format and select the time range that will be used.

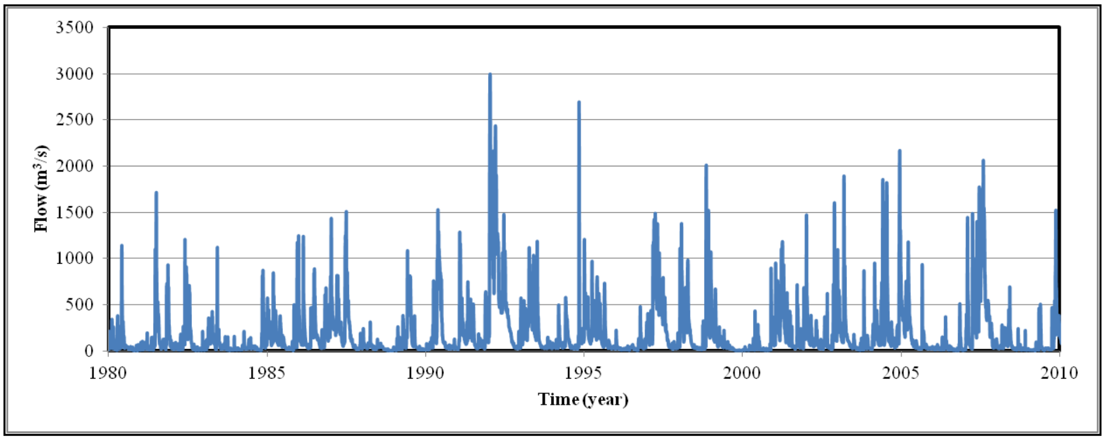


Figure 50. Flow hydrograph for the selected period

2. Convert the flow hydrograph to velocity hydrograph.

   a. As explained in section 4.4, the flow hydrograph has to be converted to velocity using one of the following methods:

i. TAMU-FLOW: This software is available online, free of cost at: https://ceprofs.tamu.edu/briaud/research_wip.html

An easy, step-by-step instruction manual is included with the software. Velocity is obtained from one cross section of the river.

ii. HEC-RAS: This software is available online, free of cost at: http://www.hec.usace.army.mil/software/hec-ras/

iii. Other similar software or using an equation to convert from flow to velocity from a similar river.

b. The flow is converted to velocity (in m/s) and the dates are reduced to the range of interest.

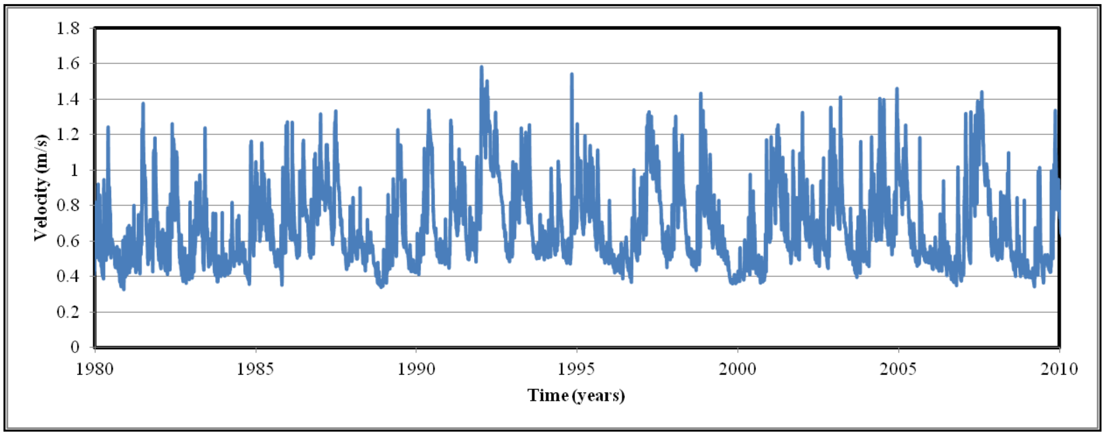
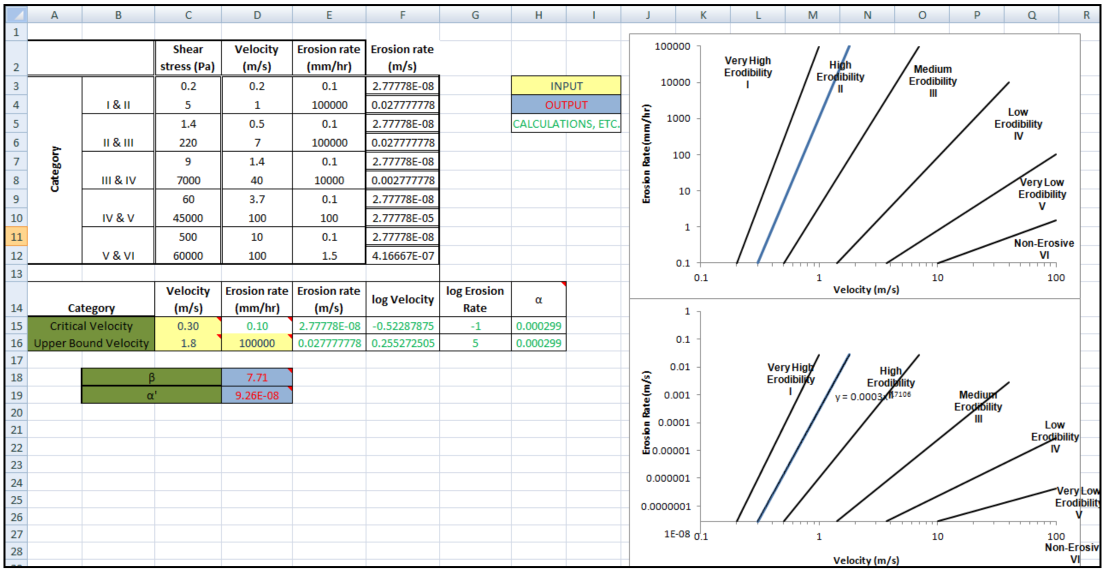


Figure 51. Velocity hydrograph for the selected period

3. Generate the EFA curve and obtain the α' and β parameters.

a. There are two options to generate the EFA curve that will be used in the model to obtain the critical velocity: using a line from the Erosion Categories or using the results of an EFA test. Both methods can also be used to compare results and a sheet is included to obtain the parameters for each method in the Excel file.

b. The first sheet in the Excel file corresponds to the Erosion Categories. The input values in this sheet are the critical velocity corresponding to an erosion rate of 0.1 mm/hr or 2.78e-8 m/s and a higher velocity (upper bound velocity) to create a line. An erosion rate that corresponds to this velocity is selected as well and the line is generated in both graphs. The slope of this EFA curve needs to be compared to the other 5 lines to see where this generated line is. Also a table with the five lines that divide the categories is included. These lines can also be used. The α’ and β parameters are automatically calculated.



Category		Shear stress (Pa)	Velocity (m/s)	Erosion rate (mm/hr)	Erosion rate (m/s)
Category	I & II	0.2	0.2	0.1	2.77778E-08
		5	1	100000	0.027777778
	II & III	1.4	0.5	0.1	2.77778E-08
		220	7	100000	0.027777778
	III & IV	9	1.4	0.1	2.77778E-08
		7000	40	10000	0.002777778
	IV & V	60	3.7	0.1	2.77778E-08
		45000	100	100	2.77778E-05
	V & VI	500	10	0.1	2.77778E-08
		60000	100	1.5	4.16667E-07

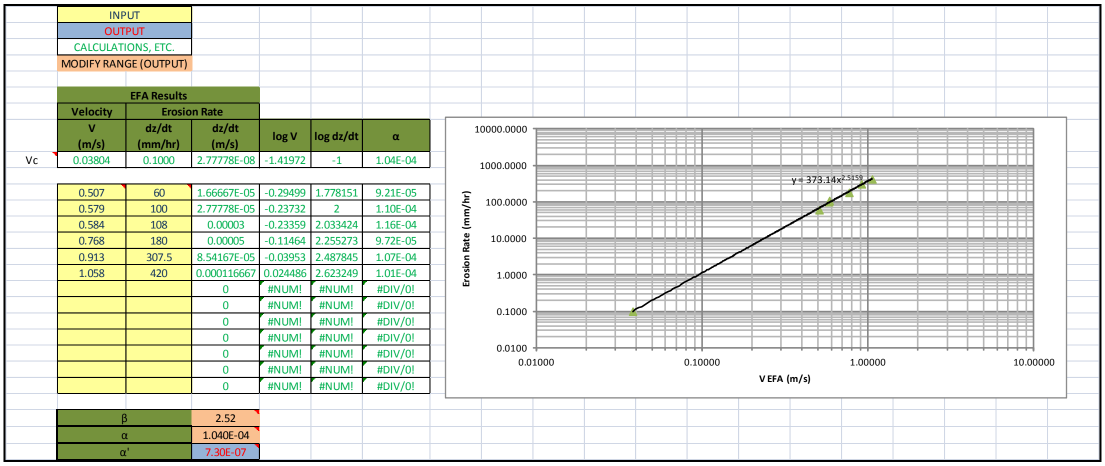
INPUT
OUTPUT
CALCULATIONS, ETC.

Category	Velocity (m/s)	Erosion rate (mm/hr)	Erosion rate (m/s)	log Velocity	log Erosion Rate	α
Critical Velocity	0.30	0.10	2.77778E-08	-0.52287875	-1	0.000299
Upper Bound Velocity	1.8	100000	0.027777778	0.255272505	5	0.000299

β	7.71
α'	9.26E-08

Figure 52. Erosion function categories spreadsheet.

c. The second sheet in the Excel file is used to obtain the α’ and β parameters with the EFA test results. The results of the EFA test are entered in the columns of velocity in meters per second and erosion rate in millimeters per hour. The Excel sheet obtains the critical velocity by extrapolation and calculates the α’ and β parameters automatically.



INPUT
OUTPUT
CALCULATIONS, ETC.
MODIFY RANGE (OUTPUT)

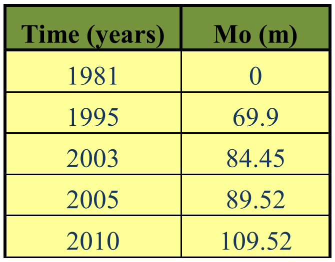
	EFA Results					
	Velocity	Erosion Rate				
	V (m/s)	dz/dt (mm/hr)	dz/dt (m/s)	log V	log dz/dt	α
Vc	0.03804	0.1000	2.77778E-08	-1.41972	-1	1.04E-04
	0.507	60	1.66667E-05	-0.29499	1.778151	9.21E-05
	0.579	100	2.77778E-05	-0.23732	2	1.10E-04
	0.584	108	0.00003	-0.23359	2.033424	1.16E-04
	0.768	180	0.00005	-0.11464	2.255273	9.72E-05
	0.913	307.5	8.54167E-05	-0.03953	2.487845	1.07E-04
	1.058	420	0.000116667	0.024486	2.623249	1.01E-04
			0	#NUM!	#NUM!	#DIV/0!
			0	#NUM!	#NUM!	#DIV/0!
			0	#NUM!	#NUM!	#DIV/0!
			0	#NUM!	#NUM!	#DIV/0!
			0	#NUM!	#NUM!	#DIV/0!
			0	#NUM!	#NUM!	#DIV/0!
			0	#NUM!	#NUM!	#DIV/0!

β	2.52
α	1.040E-04
α'	7.30E-07

Figure 53. Erosion function results and parameters

4. Use the observed data to obtain the maximum movement of the river.
    a. Use the overlay technique to prepare a sequence of maps and/or aerial photos to study the meander migration or use different cross-sections of the river at the bridge location for vertical degradation. Recent aerial photos (from 1990 to present) can be accessed with Google Earth. Older photos and maps can be found online or from other sources.
    b. For the meander migration case, draw a line to obtain the movement of the point along the line through time. This point is a point of interest or a critical point (or direction). Using a program such as AutoCAD for meander migration can be convenient. This technique can also be done by hand.
    c. Prepare a table with the years of the observations and the movement of the river in units of distance (the units have to be consistent with the units of daily average velocity).

Table 3. Observed data in a table



Time (years)	Mo (m)
1981	0
1995	69.9
2003	84.45
2005	89.52
2010	109.52

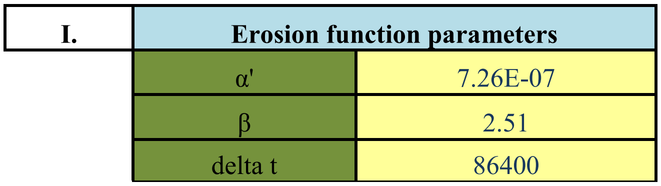
5.3 USE OF EXCEL SPREADSHEET

After performing the previous steps, the critical velocity of the river at the field needs to be found. This step is called the calibration step. The calibration step to find the critical velocity can be done using the Excel file or the MATLAB code. Only the Excel file can be used for the prediction step (after finding the critical velocity). This section explains the use of the Excel file for the calculation of the critical velocity.

1. Enter the α’ and β parameters and the delta t (Δt) in the space provided. The α’ and β parameters were obtained from the previous section and the delta t is the increments in time between each velocity. Because the velocity data is in meters per second and

there is only one average velocity per day, the delta t is 86400 seconds (seconds in one day).This assumes that the velocity is constant every second of the day.

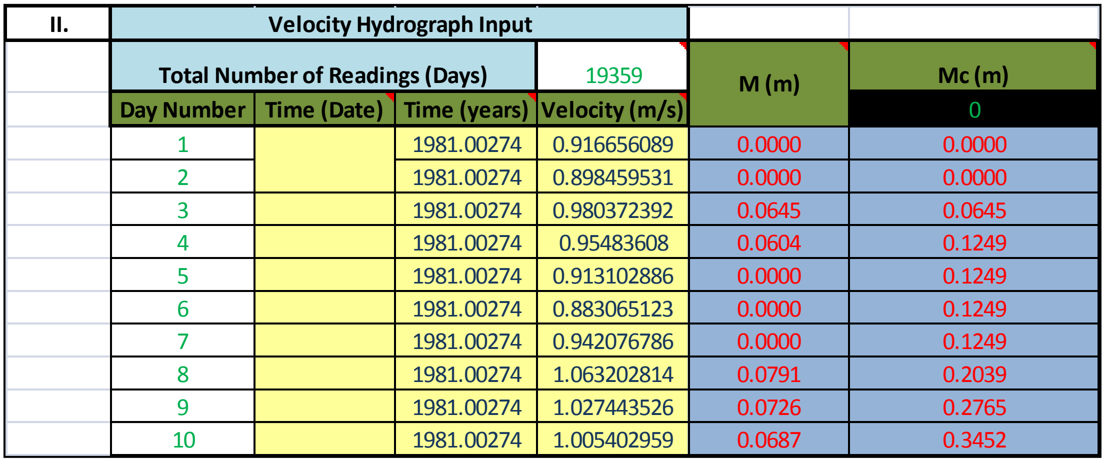
Table 4. Erosion function parameters and increment in time



I.	Erosion function parameters	
	α'	7.26E-07
	β	2.51
	delta t	86400

2. Enter the daily average velocity, the date in year format and the date in the format provided by the USGS. The M column is the daily erosion and M_c (or $M_{calibration}$) is the total accumulated erosion. Both are automatically calculated and generated after step 4.

Table 5. Velocity hydrograph input and output of movement



II.	Velocity Hydrograph Input					
	Total Number of Readings (Days)			19359	M (m)	Mc (m)
	Day Number	Time (Date)	Time (years)	Velocity (m/s)		0
	1		1981.00274	0.916656089	0.0000	0.0000
	2		1981.00274	0.898459531	0.0000	0.0000
	3		1981.00274	0.980372392	0.0645	0.0645
	4		1981.00274	0.95483608	0.0604	0.1249
	5		1981.00274	0.913102886	0.0000	0.1249
	6		1981.00274	0.883065123	0.0000	0.1249
	7		1981.00274	0.942076786	0.0000	0.1249
	8		1981.00274	1.063202814	0.0791	0.2039
	9		1981.00274	1.027443526	0.0726	0.2765
	10		1981.00274	1.005402959	0.0687	0.3452

3. Enter the observed data from the meander migration or vertical degradation. A column for time and position of the river is provided. The time and position of the river have to be all consistent with the data entered in the previous two steps.

Table 6. Observed data

Time (years)	Mo (m)
1981	0
1995	69.9
2003	84.45
2005	89.52
2010	109.52

4. Enter the first critical velocity to evaluate. Start with a low velocity and click the run button. The Ranking Index will be calculated based on this velocity. The method will be more precise as this Ranking Index approximates to zero. A graph on the right is generated and the position of the river (M_c) can be compared with the observed data (M_o). Use a larger velocity and run again. The Ranking Index will be different. Increase and decrease the critical velocity until it has the smallest possible RI. This critical velocity is the optimum critical velocity and is used in the prediction step.

Table 7. Critical velocity and Ranking Index

IV.	V_c	0.82	m/s
	Ranking Index (RI)	0.1172502	
	Mean for RI	0.00491245	
	Strd Deviation for RI	0.112337765	

Table 8. Calibrated data output

III.	Comparison of Observed Data and Calibrated Data			
		Number of Data Points		5
Time (years)	Mo (m)	Time (years)	Mc(m)	ln(Mc/Mo)
1981	0	1981.019	0	#DIV/0!
1995	69.9	1995.013699	58.85989457	-0.171905698
2003	84.45	2003.013699	86.97915399	0.029508837
2005	89.52	2005.010959	95.16623174	0.061163106
2010	109.52	2010.008219	116.4766862	0.061583953

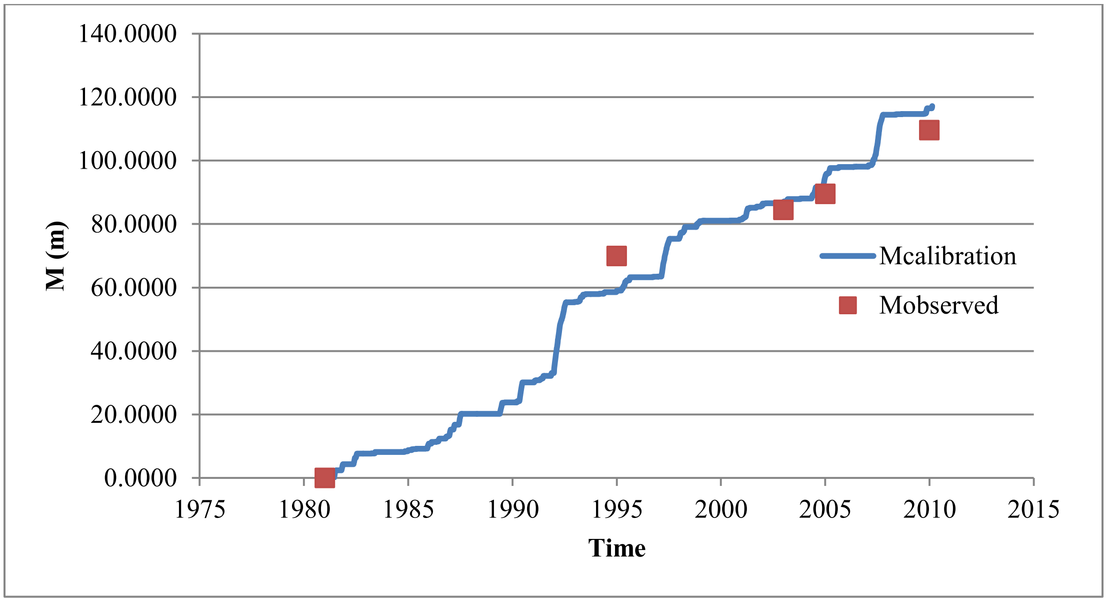
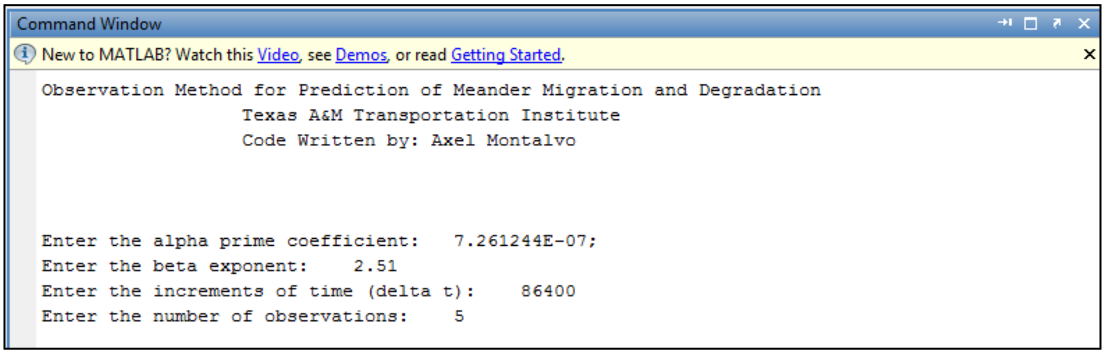


Figure 54. Observed and calibrated data

5.4 USE OF MATLAB CODE

The MATLAB code written for this project is an alternative to the Excel File. If this method is used, the section 6.3 can be skipped. If the Excel file is used, this section can be ignored. However, both methods yield the same results and can be used for verification. The advantage of this method is that the MATLAB code iterates and calculates everything without the iterating process of step 4 from the previous section. The disadvantage of this method is that Excel is more visual and the data can be manipulated more easily. The MATLAB file comes with blank velocity.txt and time.txt files.

1. Copy the velocity column to the text file velocity.txt.
2. Copy the dates in year format to the text file time.txt.
3. Run the program.
4. Enter the α’ coefficient (alpha prime) and press Enter.
5. Enter the β exponent (beta exponent) and press Enter.
6. Enter the increments of time or delta t (86400) and press Enter.
7. Enter the total number of observations. In the case of the Brazos River, the number of observations is 5.



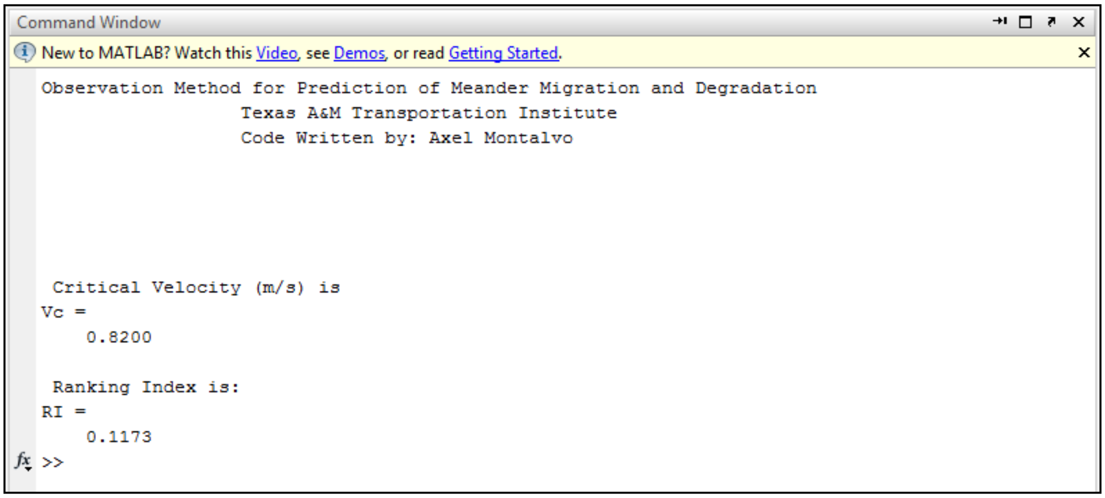
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

```
Observation Method for Prediction of Meander Migration and Degradation
                  Texas A&M Transportation Institute
                  Code Written by: Axel Montalvo



Enter the alpha prime coefficient:   7.261244E-07;
Enter the beta exponent:    2.51
Enter the increments of time (delta t):    86400
Enter the number of observations:    5
```

Figure 55. Input of erosion parameters, time increments and number of observations

8. Enter the year of the first observation and press Enter.
9. Enter the position of the river at this year, which is 0, and press Enter.
10. The program will ask for the second year and the position of the river for that year. Enter the data and press enter. The program will keep asking for the data until it reaches the total number of observations.

11. The program shows the lowest Ranking Index and the corresponding critical velocity found. This velocity is used in the prediction step (prediction step is available only in Excel).



```
Observation Method for Prediction of Meander Migration and Degradation
                  Texas A&M Transportation Institute
                  Code Written by: Axel Montalvo




 Critical Velocity (m/s) is
Vc =
    0.8200

 Ranking Index is:
RI =
    0.1173
>>
```

Figure 56. Results of critical velocity and Ranking Index

12. The program shows 4 figures: position of the river through time with the observed data; the dimensionless EFA curve; the velocity hydrograph; and the observed versus predicted data compared to a 1:1 line.

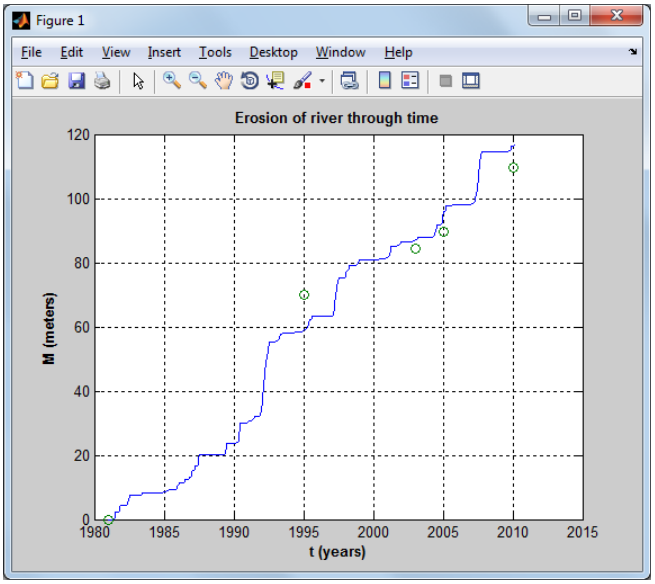


Figure 57. Movement of point with time

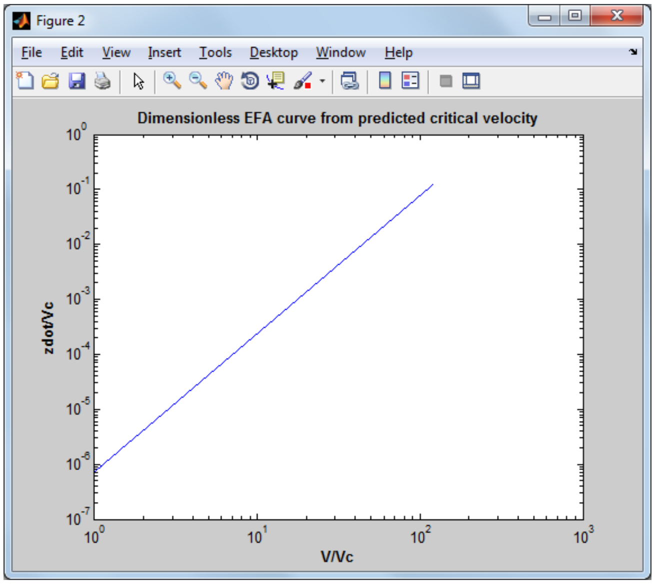


Figure 58. Dimensionless EFA curve

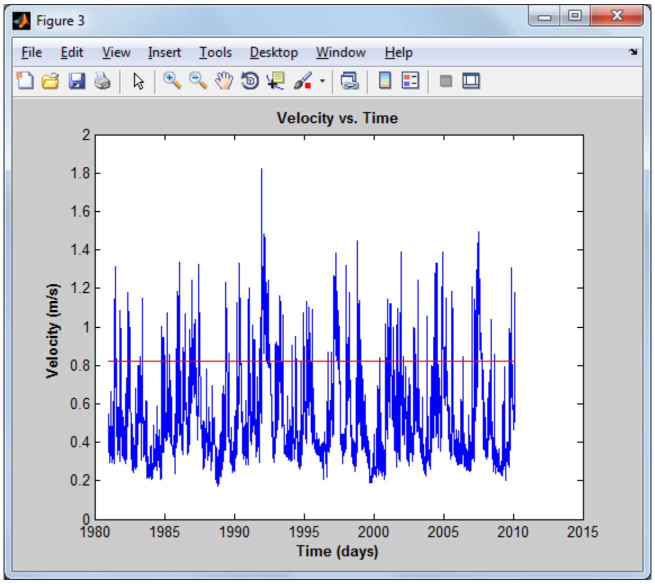


Figure 59. Velocity hydrograph and critical velocity

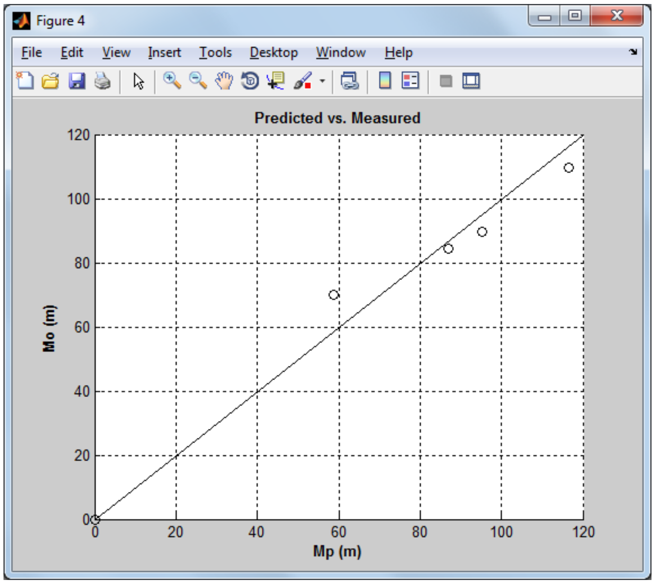


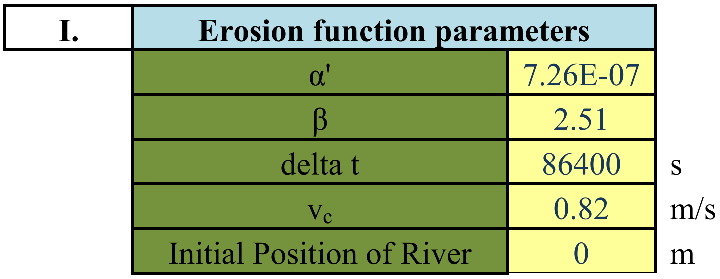
Figure 60. 1:1 slope line with results of Observed data vs. Calibrated data

5.5 PREDICTION STEP

After using the parameters α’ and β to obtain the critical velocity, the next step is to use the same model of erosion to make a prediction of the meander migration or vertical degradation. Only the Excel spreadsheet can be used for this step, even if MATLAB was used to obtain the critical velocity. The sheet used for the prediction step looks very similar to the sheet used in Section 6.2. It also works in a similar fashion, but now the iteration process is not necessary because the critical velocity has already been found. The following steps describe the process of the prediction step.

1. In the input boxes, enter the α’ and β parameters, the increment in time delta t, the critical velocity obtained from the calibration step and the initial position of the point. Because it is a prediction, the last observed data can be used or it can be 0 instead. It is recommended to use 0 for simplification.

Table 9. Input data for Prediction Step



I.	Erosion function parameters		
	α'	7.26E-07	
	β	2.51	
	delta t	86400	s
	v_c	0.82	m/s
	Initial Position of River	0	m

2. There are two options to enter the velocity data: use a complete hydrograph or just a few velocities. For this project (Chapter VI), the data that was used was from the last 10 years and was repeated to predict the movement of the point, starting from the last observed data point. If the last data observed was (for example) from 2010, and the velocities used are from 2000 to 2010, the dates have to be changed to correspond to the period that will be extrapolated, if the data was copied from the previous period (the dates are changed to 2010 to 2020). The spreadsheet also lets you use a few velocities, like for example, if only one or two velocities need to be evaluated (24 or 48-hour flood).

Table 10. Input of velocity hydrograph for Prediction Step

II.	Velocity Hydrograph Input			
	Number of Readings (Days)			3653
	Day Number	**Time (Date)**	**Time (years)**	**Velocity (m/s)**
	1		2010	0.251014368
	2		2010.00274	0.258465523
	3		2010.005479	0.248601791
	4		2010.008219	0.251543731
	5		2010.010959	0.253377771
	6		2010.013699	0.253117523
	7		2010.016438	0.250215763
	8		2010.019178	0.247239275
	9		2010.021918	0.24668969
	10		2010.024658	0.243901169

3. The figure obtained represents the magnitude of the movement for the period of time designated after the last observation. In this example, the period is 2010 to 2020. M_p corresponds to the predicted data.

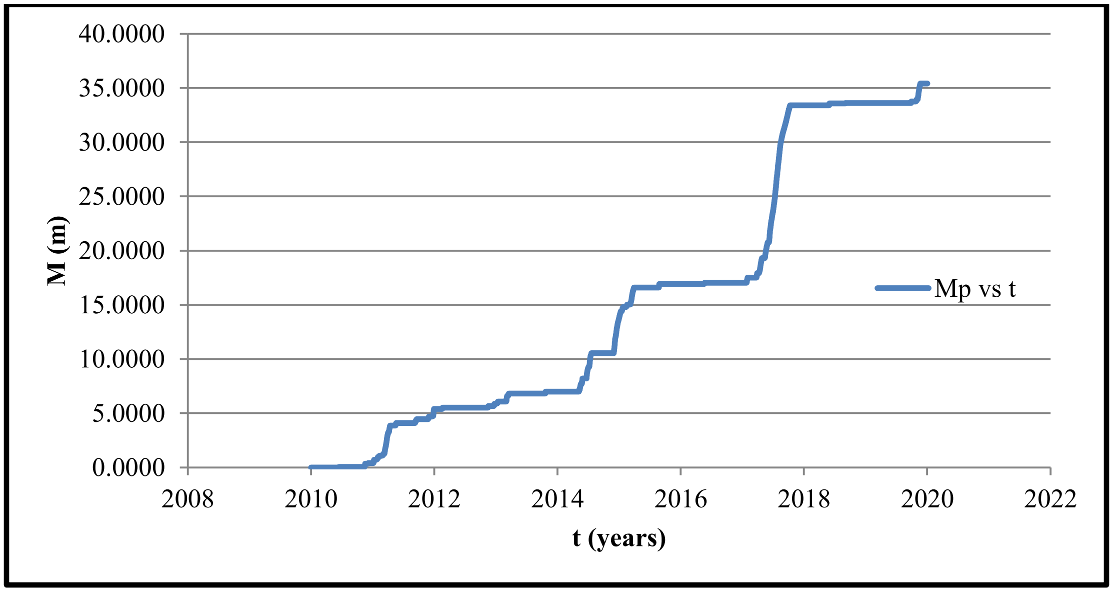


Figure 61. Predicted data versus time

5.6 VERIFICATION OF THE OBSERVATION METHOD

It is very important to verify the results of a mathematical model when it is used to compare predicted data versus observed data. In the previous step, the critical velocity is used to make a prediction of the position of the river in the future by using the same equation and the same parameters. One way to study the effectiveness of the Observation Method is to obtain the critical velocity by calibration and then make a prediction, but with knowledge of the real position of the river. For example, if data is known from 1990 to 2005, with four points of observation in 1990, 1995, 2000 and 2005, the calibration step can be used to obtain the critical velocity between 1990 and 2000. Using this velocity and the real hydrograph between 2000 and 2005, the position of the river can be predicted for 2005 and then compared with the observed data of 2005.

The next four figures correspond to several runs of the Observation Method that were performed for verification of the method and used to observe the predicted data versus the observed data. The dots in the figures are known values of observed data and the predicted line was obtained using the field critical velocity found in the calibration step with of all the observed data minus the last one. This verification step was performed for the Brazos, Trinity, Sabine and Nueces Rivers. The other two rivers, North Sulfur and Colorado, only had two points and this verification step could not be applied.

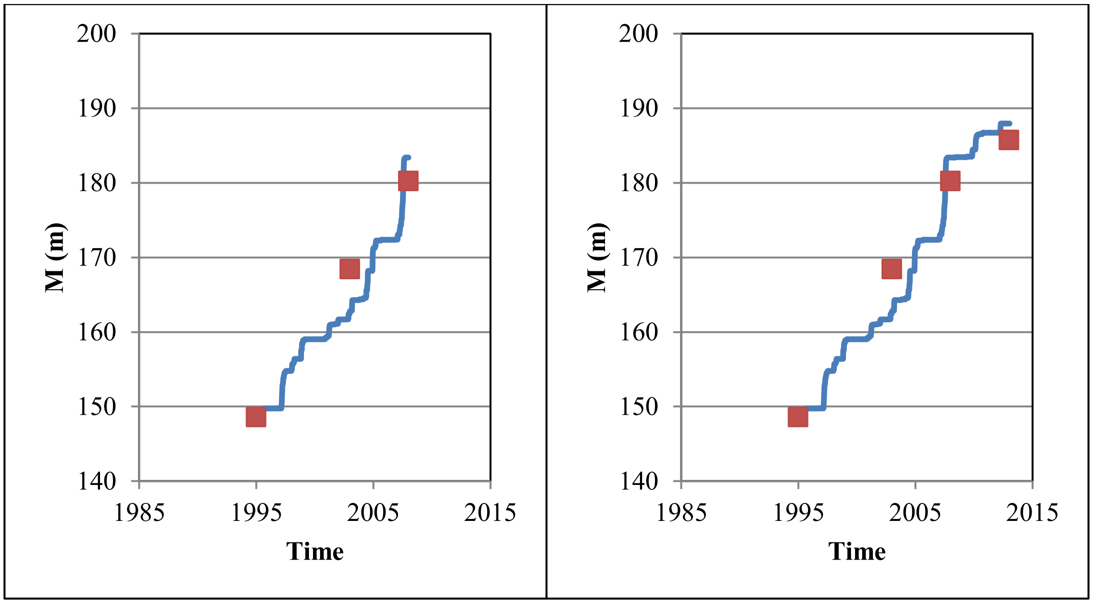


Figure 62. Brazos River verification of prediction with field critical velocity of 0.99 m/s

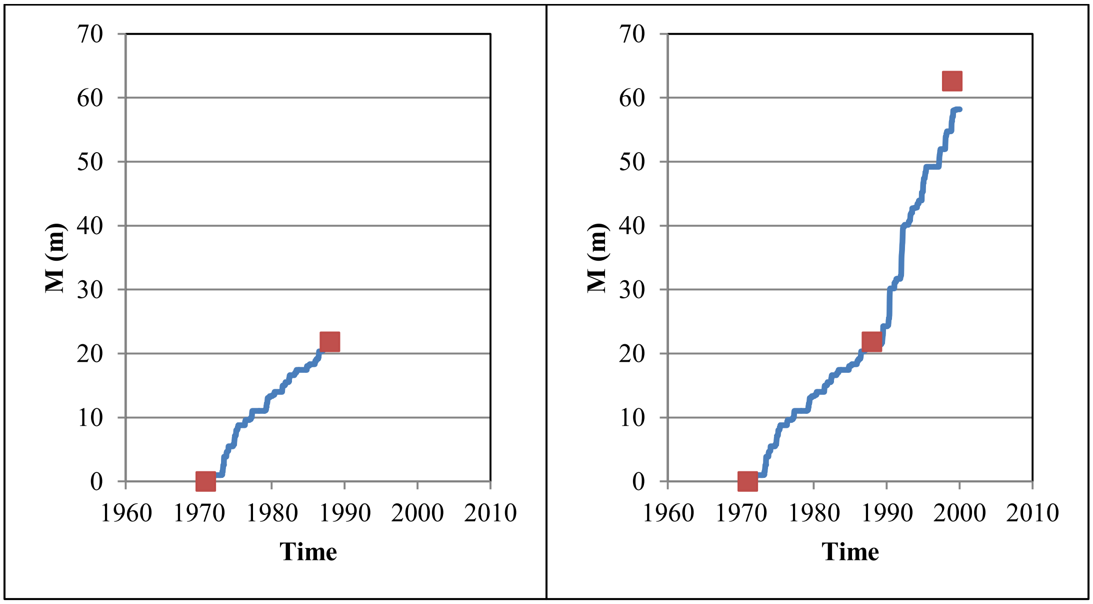


Figure 63. Trinity River verification of prediction with field critical velocity of 0.90 m/s

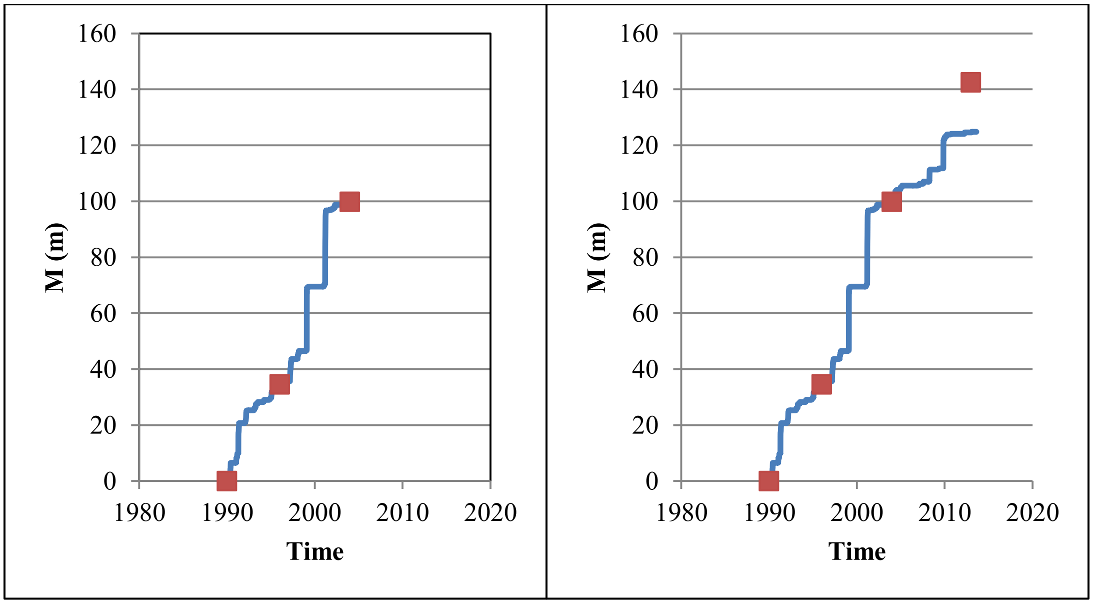


Figure 64. Sabine River verification of prediction with field critical veloctiy of 1.12 m/s

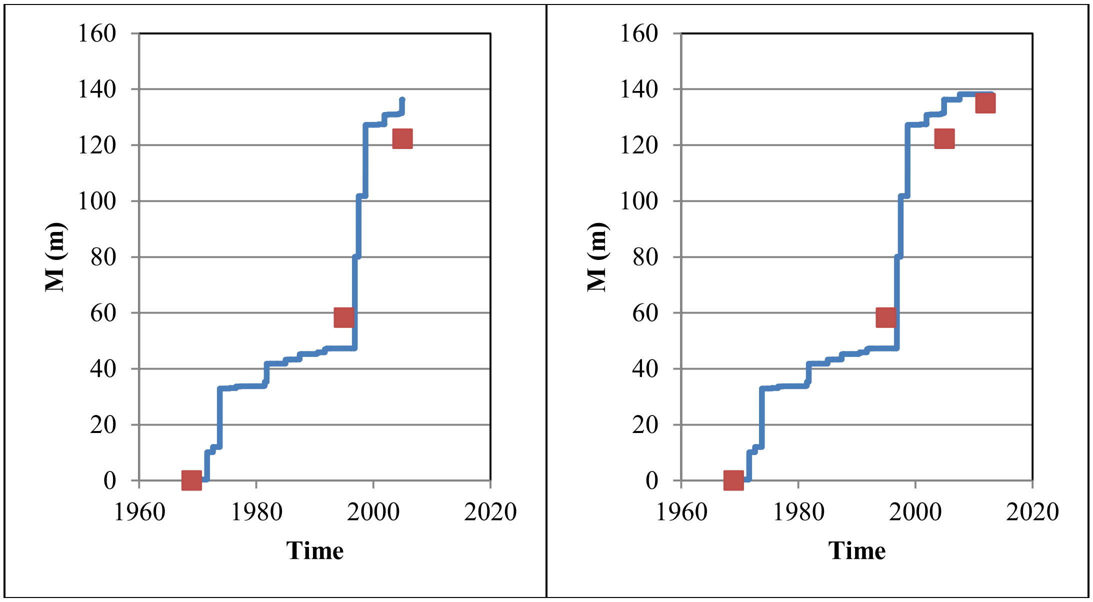


Figure 65. Nueces River verification of prediction with field critical veloctiy of 0.61 m/s

CHAPTER 6: RESULTS USING THE OBSERVATION METHOD

6.1 INTRODUCTION

The following figures show the results for the critical velocity of each case history. The critical velocity for each case was found by using the Excel spreadsheet and the MATLAB code written for this project and then using the Excel spreadsheet for prediction. Two sets of results are shown for each case: one using the results obtained from the EFA test and another using the chart of erosion categories. The meander migration cases (Brazos, Trinity, Sabine and Nueces) use the line that separate Categories I and II and the vertical degradation cases (North Sulfur and Colorado) use the line that separate Categories II and III. The calibrated step and prediction step results are shown in the next two sections.

6.2 RESULTS FOR CRITICAL VELOCITY (CALIBRATION STEP)

The first step before predicting the magnitude of the movement of the river (meander migration or vertical degradation) is finding the critical velocity at the site. Following the steps in the previous chapter, the critical velocity is found for each site using the EFA results or a line from the erosion categories chart. The first set of results for each river corresponds to the parameters obtained from the EFA curve after testing a sample obtained at the site. The second set of results corresponds to the line obtained from the erosion categories chart. The critical velocity varies when using both methods. The observed data and the calibrated data are included in a table and plotted in their corresponding figure. The critical velocity and the parameters are then used in the prediction step.

6.2.1 Brazos River

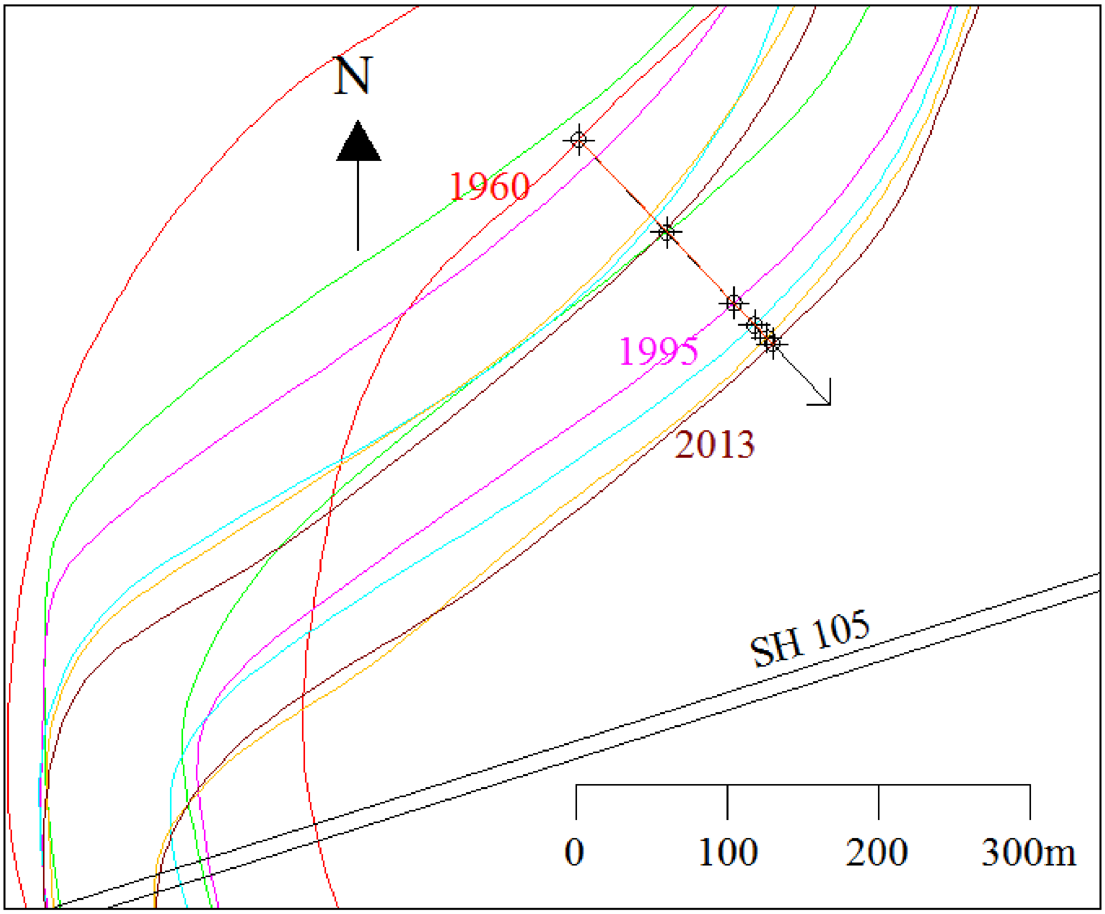


Figure 66. Brazos River meander migration

I - Results using the EFA curve from the soil samples for the Brazos River case.

Table 11. Brazos River data with parameters from EFA curve

α'	7.26E-07
β	2.51
v_c	0.95 m/s
RI	0.1241771

Time (years)	**M_o (m)**	**M_c(m)**
1960	0	0
1989	84	86.042
1995	148.6	130.559
2003	168.4	165.897
2008	180.2	199.637
2013	185.7	210.914

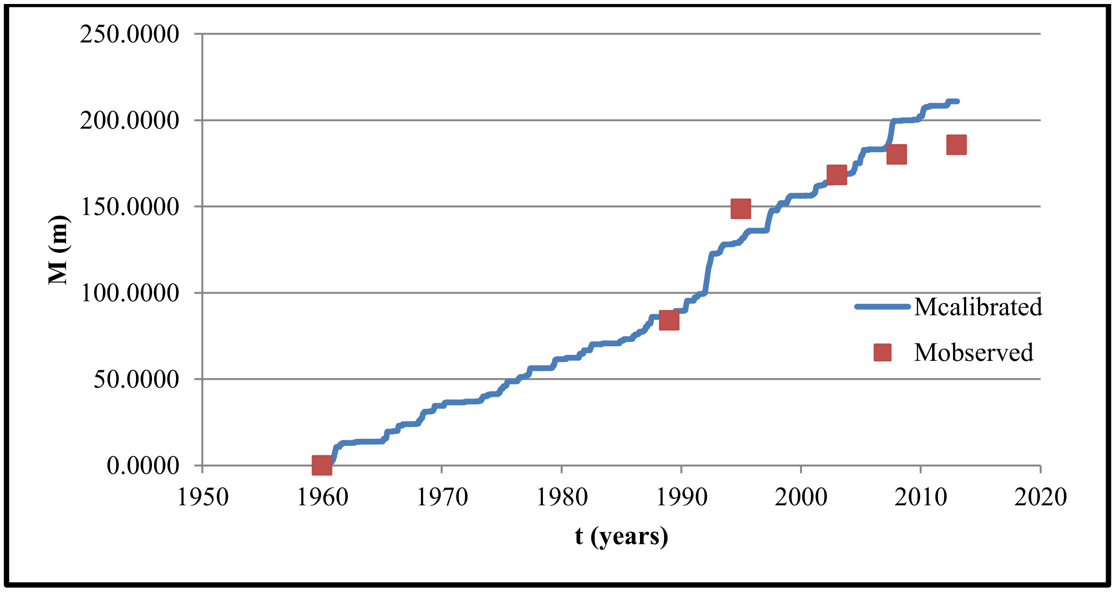


Figure 67. Brazos River meander migration with parameters from EFA curve

II -Results using the parameters from erosion categories chart for the Brazos River case.

Table 12. Brazos River data with parameters from erosion categories chart

α'	1.39E-07
β	8.58
v_c	0.92 m/s
RI	0.1229011

Time (years)	M_o (m)	M_c(m)
1960	0	0
1989	84	76.936
1995	148.6	130.733
2003	168.4	157.869
2008	180.2	195.428
2013	185.7	203.937

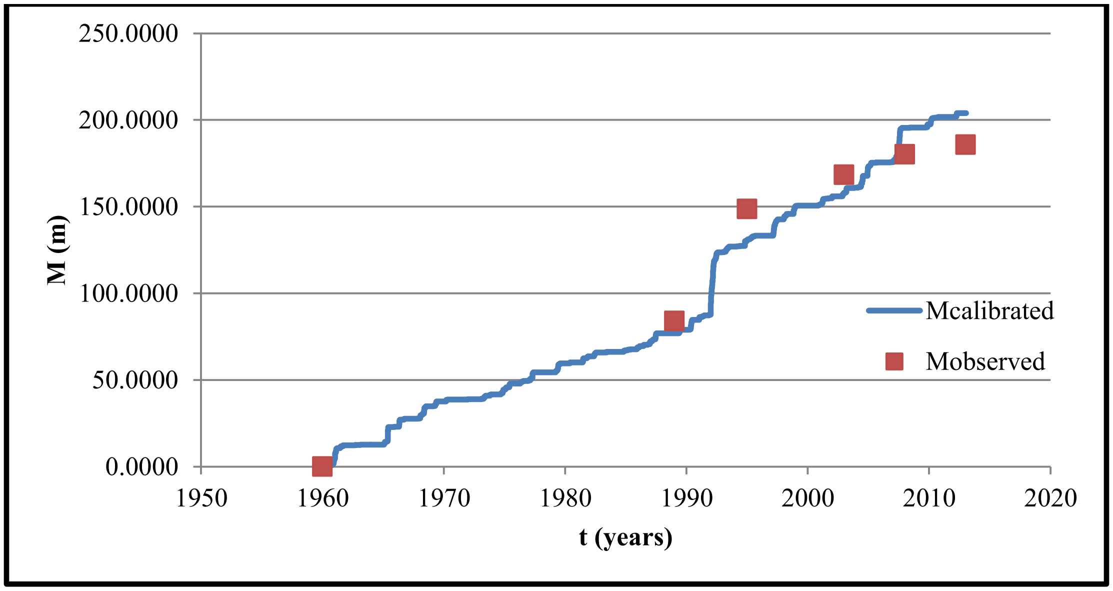


Figure 68. Brazos River meander migration with parameters from erosion categories chart

6.2.2 Trinity River

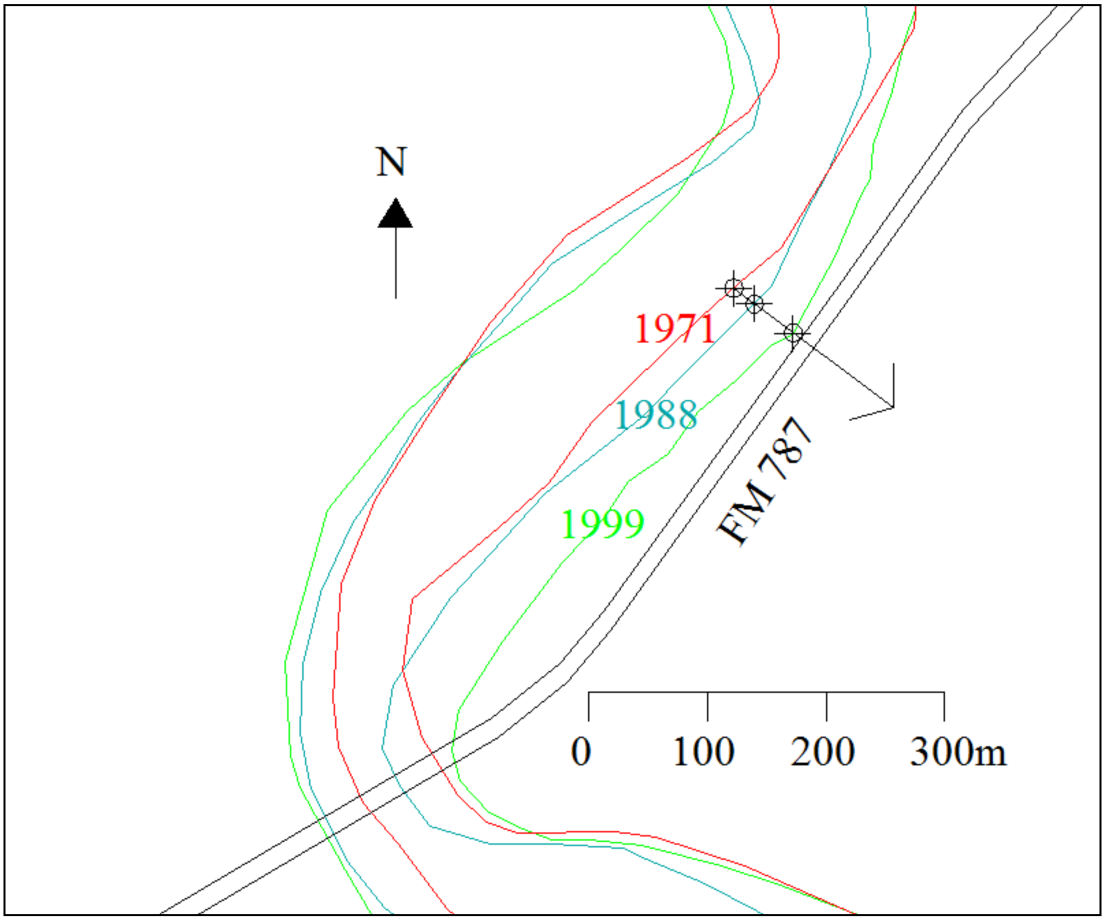


Figure 69. Trinity River meander migration

I - Results using the EFA curve from the soil samples for the Trinity River case.

Table 13. Trinity River data with parameters from EFA curve

<table>
<tr><td>α'</td><td colspan="2">2.85E-07</td></tr>
<tr><td>β</td><td colspan="2">4.21</td></tr>
<tr><td>v_c</td><td colspan="2">0.91 m/s</td></tr>
<tr><td>RI</td><td colspan="2">0.1541382</td></tr>
<tr><th>Time (years)</th><th>M_o (m)</th><th>M_c(m)</th></tr>
<tr><td>1971</td><td>0</td><td>0</td></tr>
<tr><td>1988</td><td>21.85</td><td>24.262</td></tr>
<tr><td>1999</td><td>62.6</td><td>56.094</td></tr>
</table>

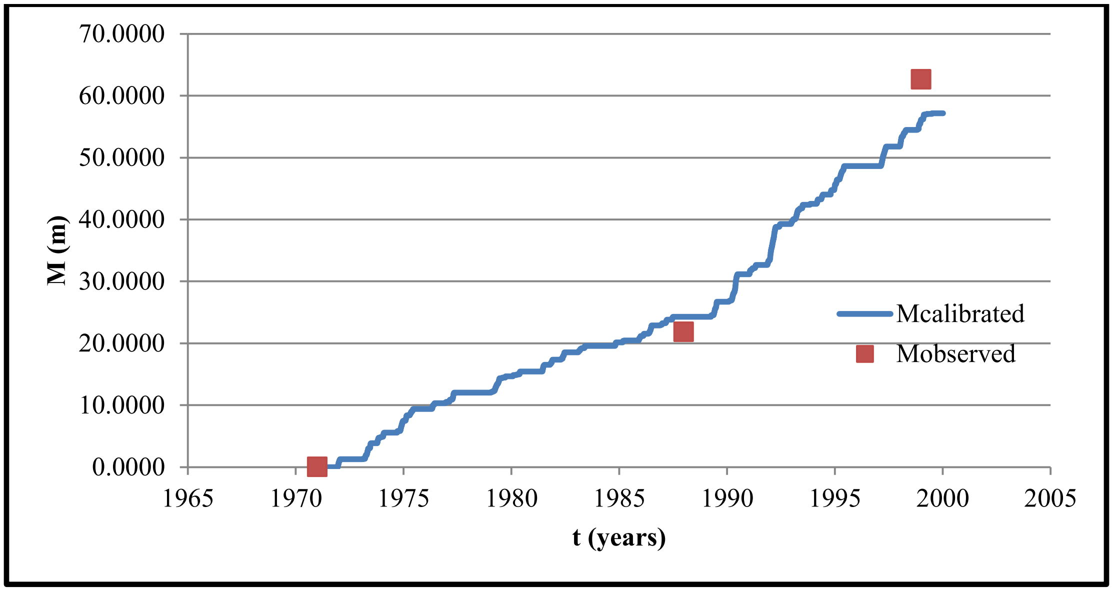


Figure 70. Trinity River meander migration with parameters from EFA curve

II -Results using the parameters from erosion categories chart for the Trinity River case.

Table 14. Trinity River data with parameters from erosion categories chart

<table>
<tr><td>α'</td><td colspan="2">1.39E-07</td></tr>
<tr><td>β</td><td colspan="2">8.58</td></tr>
<tr><td>v_c</td><td colspan="2">0.90 m/s</td></tr>
<tr><td>RI</td><td colspan="2">0.1102222</td></tr>
<tr><td>Time (years)</td><td>M_o (m)</td><td>M_c(m)</td></tr>
<tr><td>1971</td><td>0</td><td>0</td></tr>
<tr><td>1988</td><td>21.85</td><td>21.454</td></tr>
<tr><td>1999</td><td>62.6</td><td>56.958</td></tr>
</table>

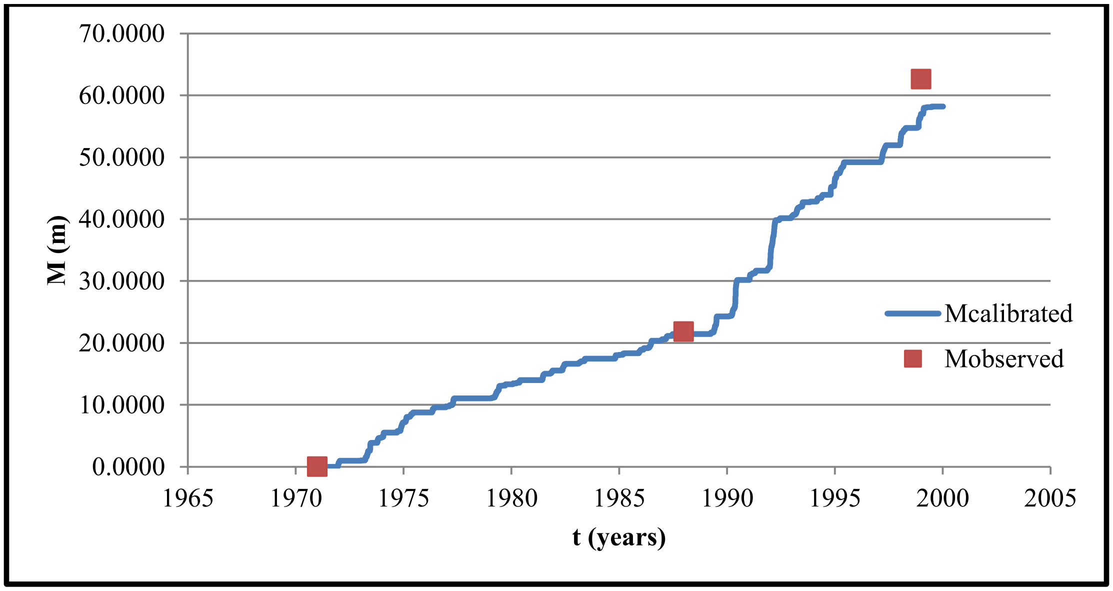


Figure 71. Trinity River meander migration with parameters from erosion categories chart

6.2.3 Sabine River

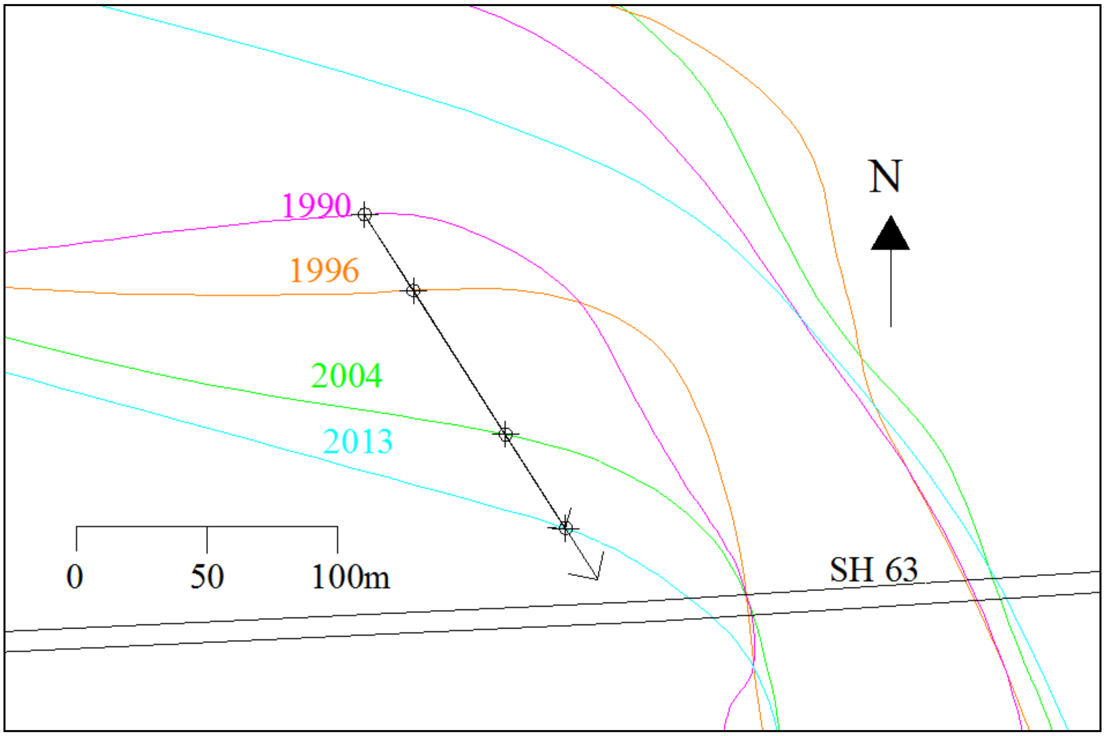


Figure 72. Sabine River meander migration

I - Results using the EFA curve from the soil samples for the Sabine River case.

Table 15. Sabine River data with parameters from EFA curve

α'	5.19E-06
β	3.23
v_c	1.47 m/s
RI	0.1522763

Time (years)	M_o (m)	M_c(m)
1990	0	0
1996	34.6	40.106
2004	99.8	101.082
2013	142.55	122.881

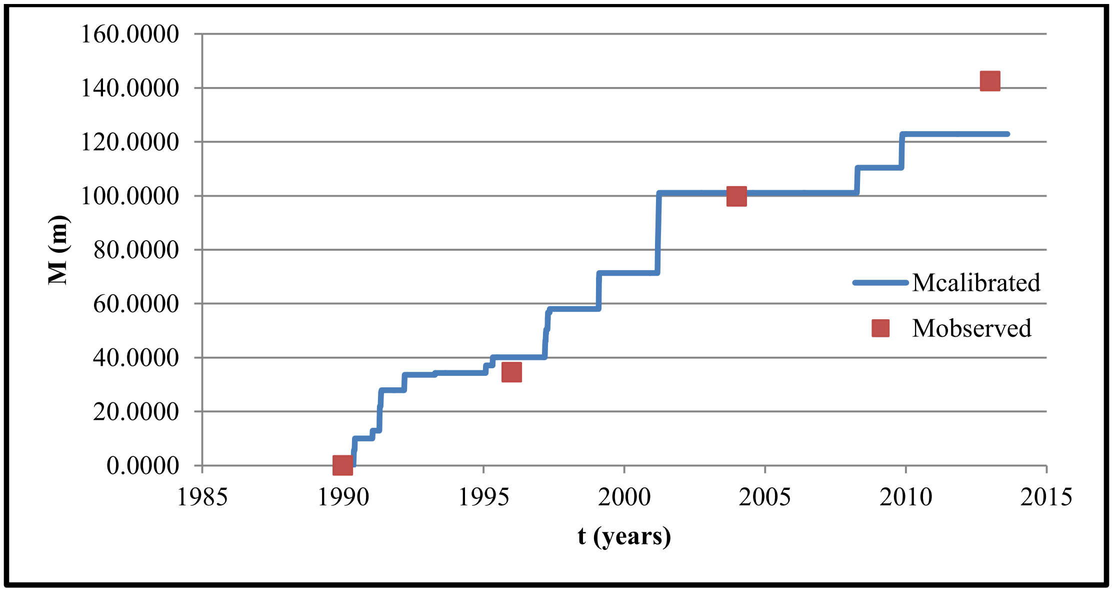


Figure 73. Sabine River meander migration with parameters from EFA curve

II -Results using the parameters from erosion categories chart for the Sabine River case.

Table 16. Sabine River data with parameters from erosion categories chart

<table>
<tr><td colspan="2">α'</td><td>1.39E-07</td></tr>
<tr><td colspan="2">β</td><td>8.58</td></tr>
<tr><td colspan="2">v_c</td><td>1.12 m/s</td></tr>
<tr><td colspan="2">RI</td><td>0.1214589</td></tr>
<tr><th>Time (years)</th><th>Mo (m)</th><th>Mc(m)</th></tr>
<tr><td>1990</td><td>0</td><td>0</td></tr>
<tr><td>1996</td><td>34.6</td><td>35.606</td></tr>
<tr><td>2004</td><td>99.8</td><td>100.616</td></tr>
<tr><td>2013</td><td>142.55</td><td>124.607</td></tr>
</table>

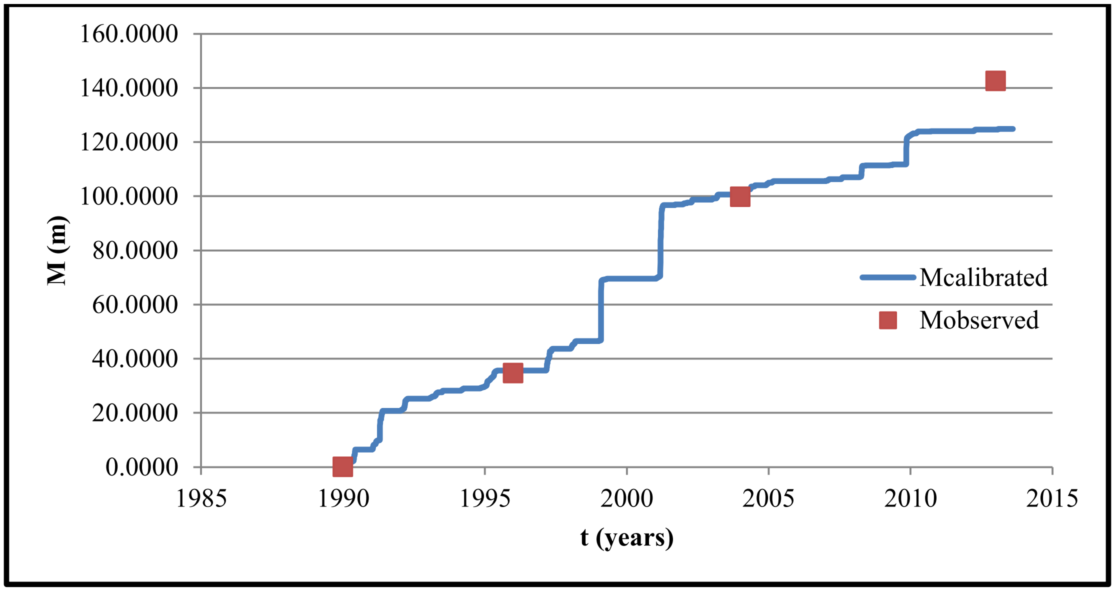


Figure 74. Sabine River meander migration with parameters from erosion categories chart

6.2.4 North Sulfur River

I - Results using the EFA curve from the soil samples for the North Sulfur River case.

Table 17. North Sulfur River data with parameters from EFA curve

<table>
<tr><td colspan="2">α'</td><td>1.13E-6</td></tr>
<tr><td colspan="2">β</td><td>1.76</td></tr>
<tr><td colspan="2">v_c</td><td>2.87 m/s</td></tr>
<tr><td colspan="2">RI</td><td>0.0013</td></tr>
<tr><td>Time (years)</td><td>Mo (m)</td><td>Mc(m)</td></tr>
<tr><td>1959</td><td>0</td><td>0</td></tr>
<tr><td>1999</td><td>3.7</td><td>3.704</td></tr>
</table>

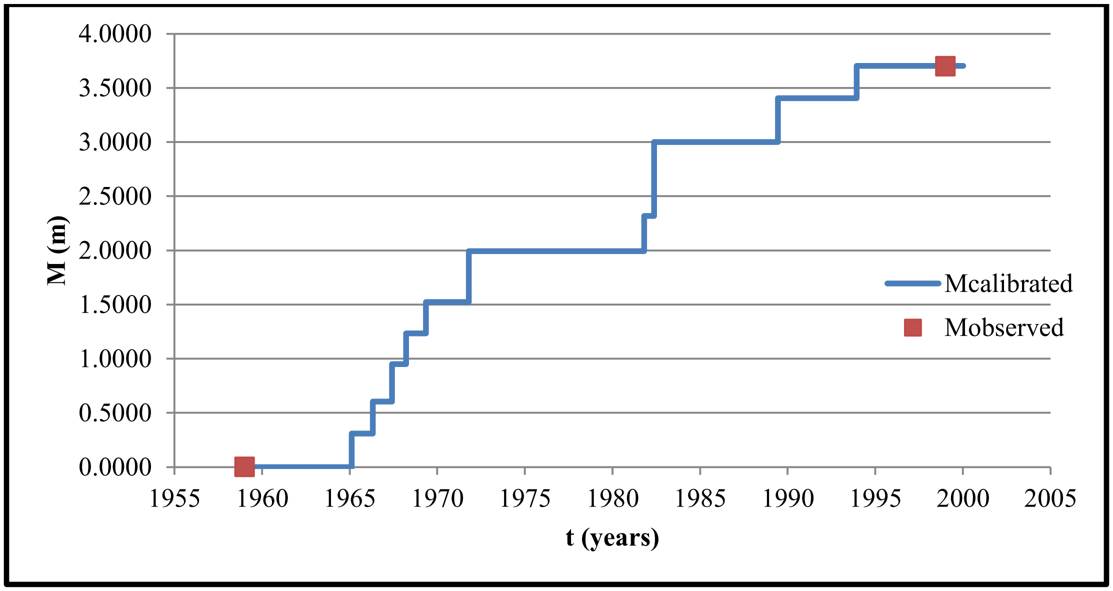


Figure 75. North Sulfur River vertical degradation with parameters from EFA curve

II -Results using the parameters from erosion categories chart for the North Sulfur River case.

Table 18. North Sulfur River data with parameters from erosion categories chart

α'	5.56E-08	
β	5.24	
v_c	2.09 m/s	
RI	0.0109	
Time (years)	**Mo (m)**	**Mc(m)**
1959	0	0
1999	3.7	3.704

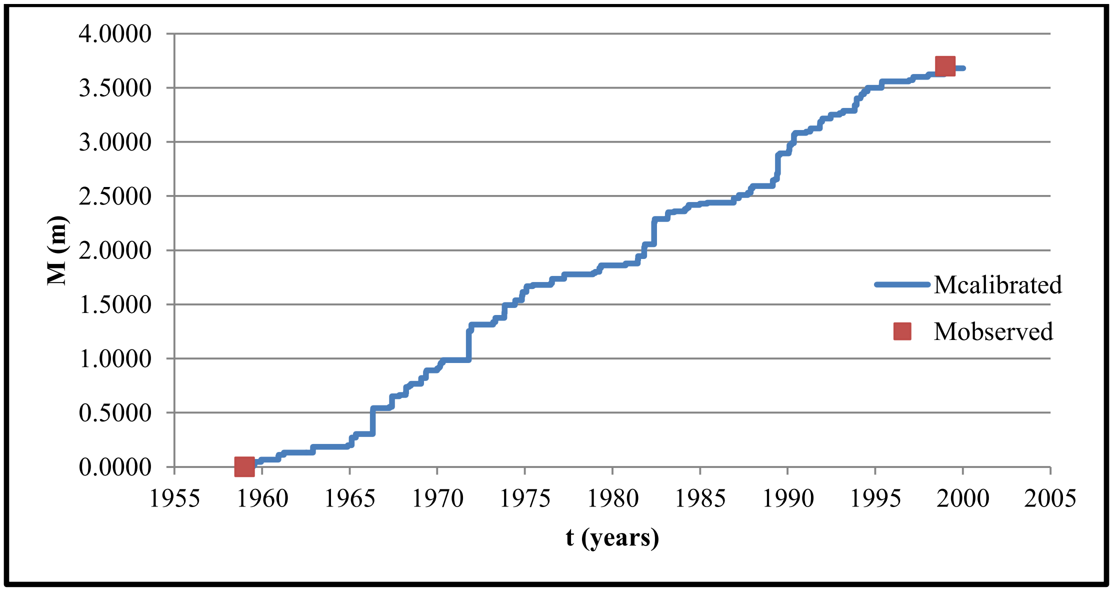


Figure 76. North Sulfur River vertical degradation with parameters from erosion categories chart

6.2.5 Nueces River

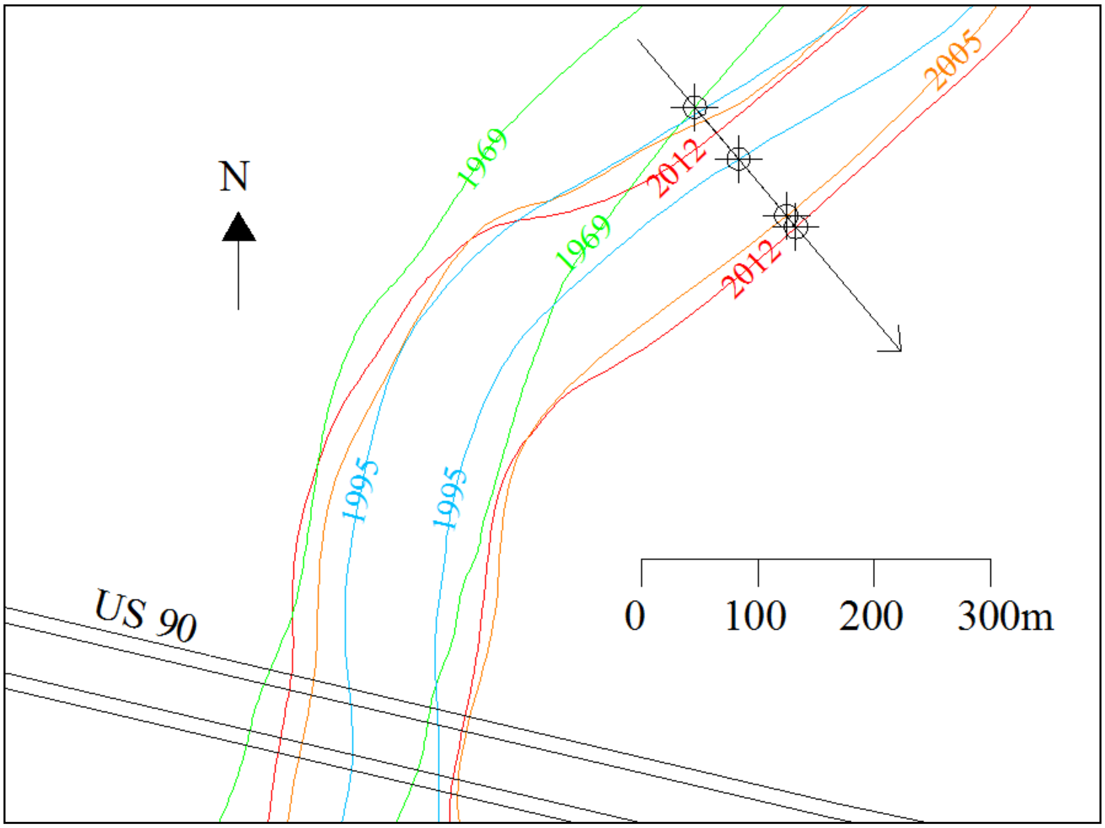


Figure 77. Nueces River meander migration

I - Results using the EFA curve from the soil samples for the Nueces River case.

Table 19. Nueces River data with parameters from EFA curve

α'	2.01E-06	
β	2.06	
v_c	0.38 m/s	
RI	0.2349285	
Time (years)	**Mo (m)**	**Mc(m)**
1969	0	0
1995	58.3	73.209
2005	122.2	106.846
2012	135	115.762

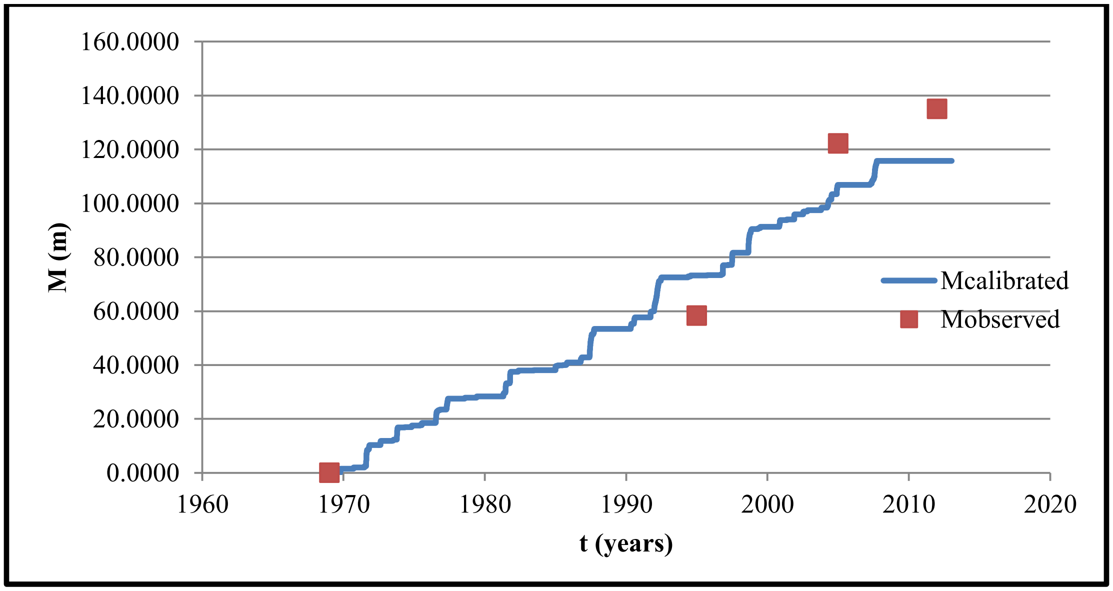


Figure 78. Nueces River meander migration with parameters from EFA curve

II -Results using the parameters from erosion categories chart for the Nueces River case.

Table 20. Nueces River data with parameters from erosion categories chart

α'	1.39E-07
β	8.58
v_c	0.61 m/s
RI	0.1903521

Time (years)	**Mo (m)**	**Mc(m)**
1969	0	0
1995	58.3	47.2883
2005	122.2	136.271
2012	135	138.220

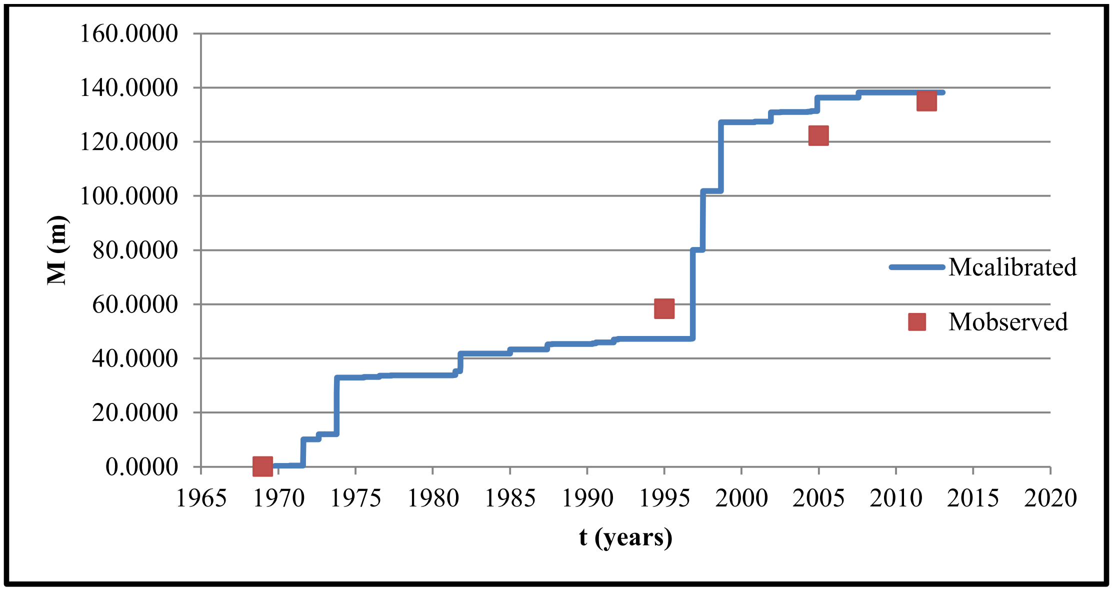


Figure 79. Nueces River meander migration with parameters from erosion categories chart

6.2.6 Colorado River

I - Results using the EFA curve from the soil samples for the Colorado River case.

Table 21. Colorado River data with parameters from EFA curve

<table>
<tr><td colspan="2">α'</td><td>1.83E-07</td></tr>
<tr><td colspan="2">β</td><td>2.20</td></tr>
<tr><td colspan="2">v_c</td><td>2.374 m/s</td></tr>
<tr><td colspan="2">RI</td><td>0.0088</td></tr>
<tr><td>Time (years)</td><td>Mo (m)</td><td>Mc(m)</td></tr>
<tr><td>1958</td><td>0</td><td>0</td></tr>
<tr><td>2005</td><td>3.65</td><td>3.68</td></tr>
</table>

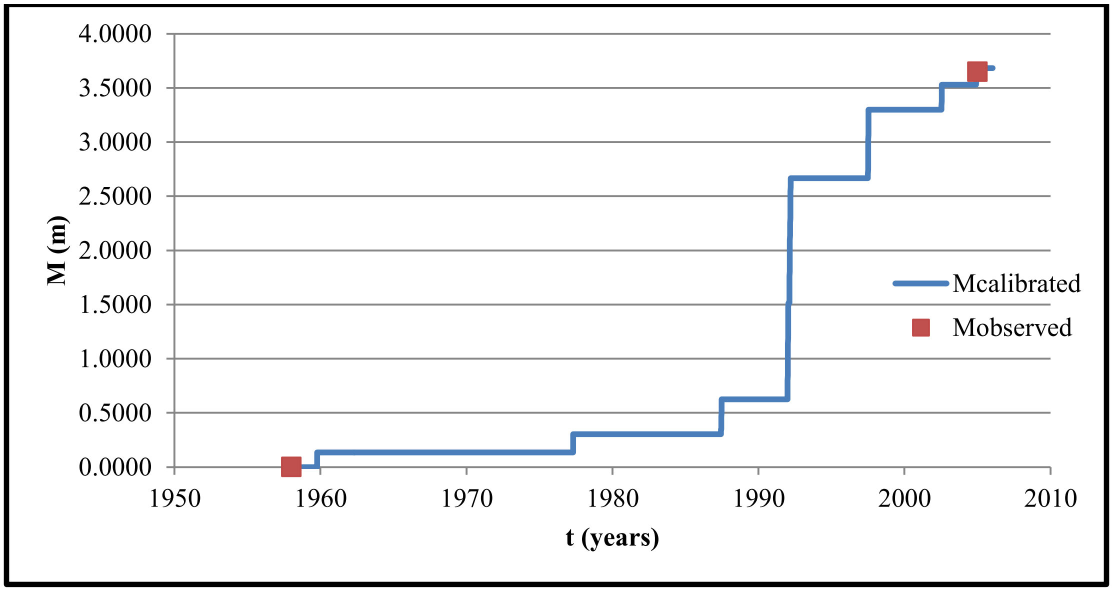


Figure 80. Colorado River vertical degradation with parameters from EFA curve

II -Results using the parameters from erosion categories chart for the Colorado River case.

Table 22. Colorado River data with parameters from erosion categories chart

<table>
<tr><td>α'</td><td colspan="2">5.56E-08</td></tr>
<tr><td>β</td><td colspan="2">5.24</td></tr>
<tr><td>v_c</td><td colspan="2">2.04 m/s</td></tr>
<tr><td>RI</td><td colspan="2">0.0044</td></tr>
<tr><td>Time (years)</td><td>Mo (m)</td><td>Mc(m)</td></tr>
<tr><td>1958</td><td>0</td><td>0</td></tr>
<tr><td>2005</td><td>3.65</td><td>3.63</td></tr>
</table>

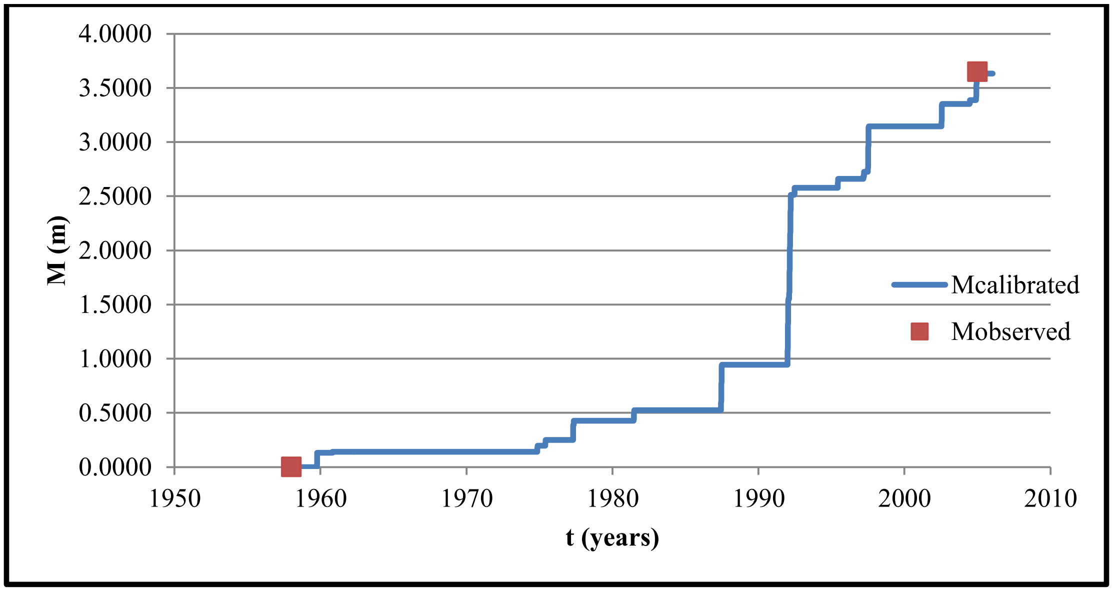


Figure 81. Colorado River vertical degradation with parameters from erosion categories chart

6.3 RESULTS FOR PREDICTION

The following conditions were used for the prediction step after the calculation of the critical velocity in the calibration step:

1. The position of the point at the last observed data was set to zero. This is not necessary, although it is easier to see the magnitude of the total predicted erosion.
2. The hydrograph used for each river corresponds to the last 10 years of velocities before the last observed data. If the last observed data corresponds to 1999, then the period is 1989-1999, as in the North Sulfur River case.
3. Some rivers have old observed data and not recent. For example, the last Trinity River and North Sulfur River observations are from 1999. The period of 10 years are assumed from this last observed data.
4. The α' and β coefficients used are from the EFA categories chart (second set of results from the calibration step). Also their corresponding critical velocity was used.

6.2.1 Brazos River

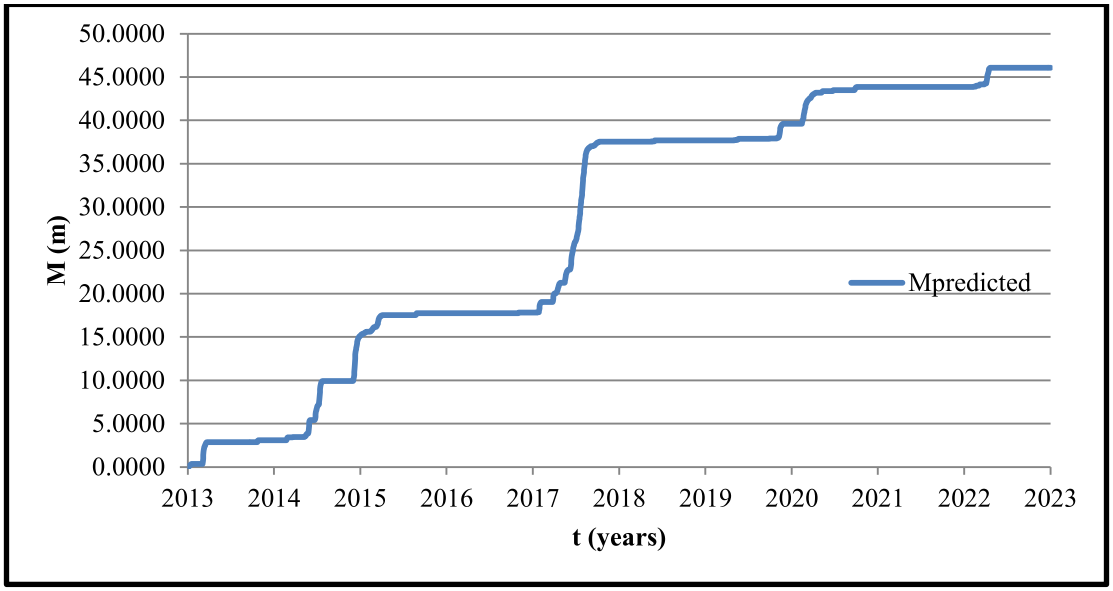


Figure 82. Brazos River prediction

6.2.2 Trinity River

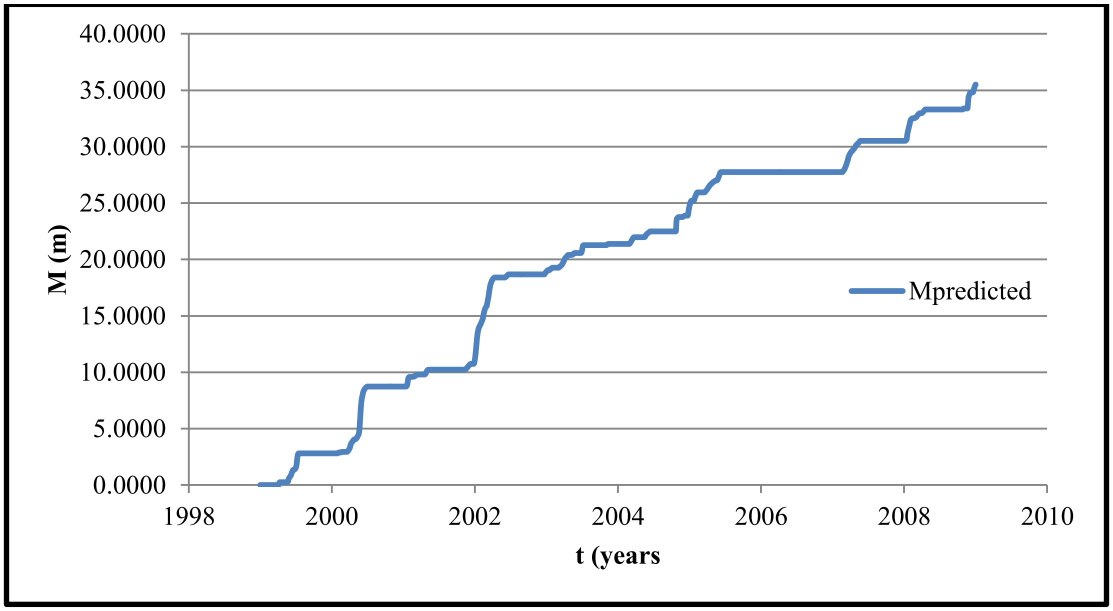


Figure 83. Trinity River prediction

6.2.3 Sabine River

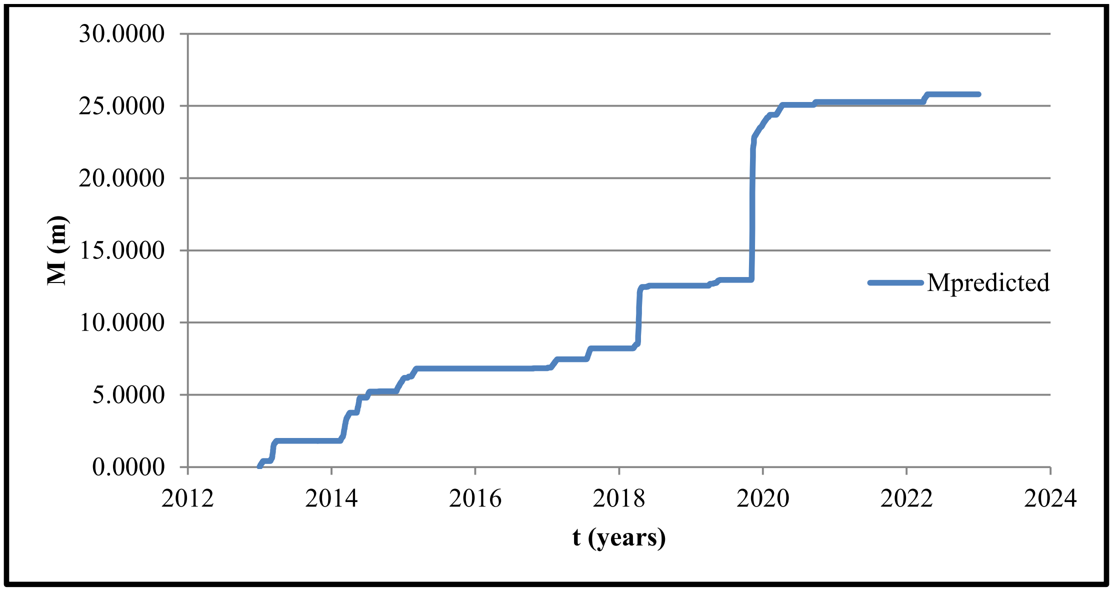


Figure 84. Sabine River prediction

6.2.4 North Sulfur River

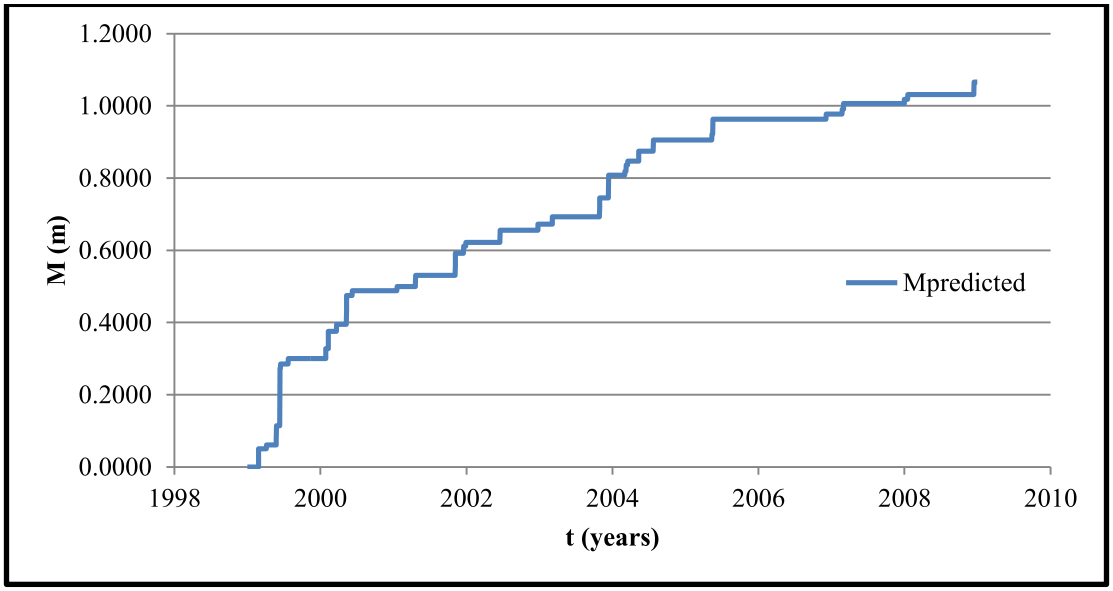


Figure 85. North Sulfur River prediction

6.2.5 Nueces River

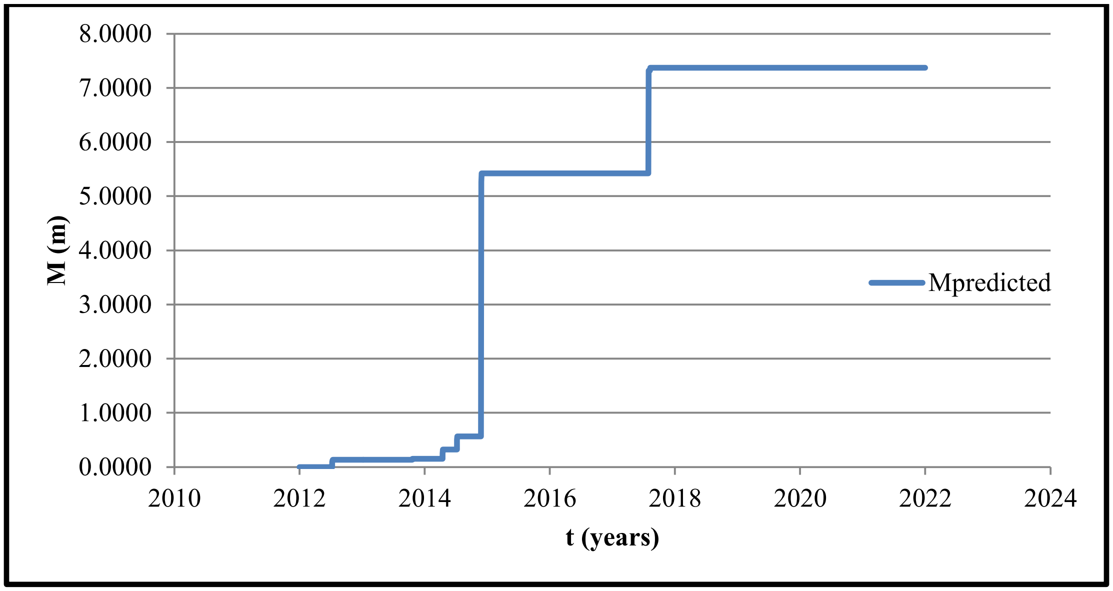


Figure 86. Nueces River prediction

6.2.6 Colorado River

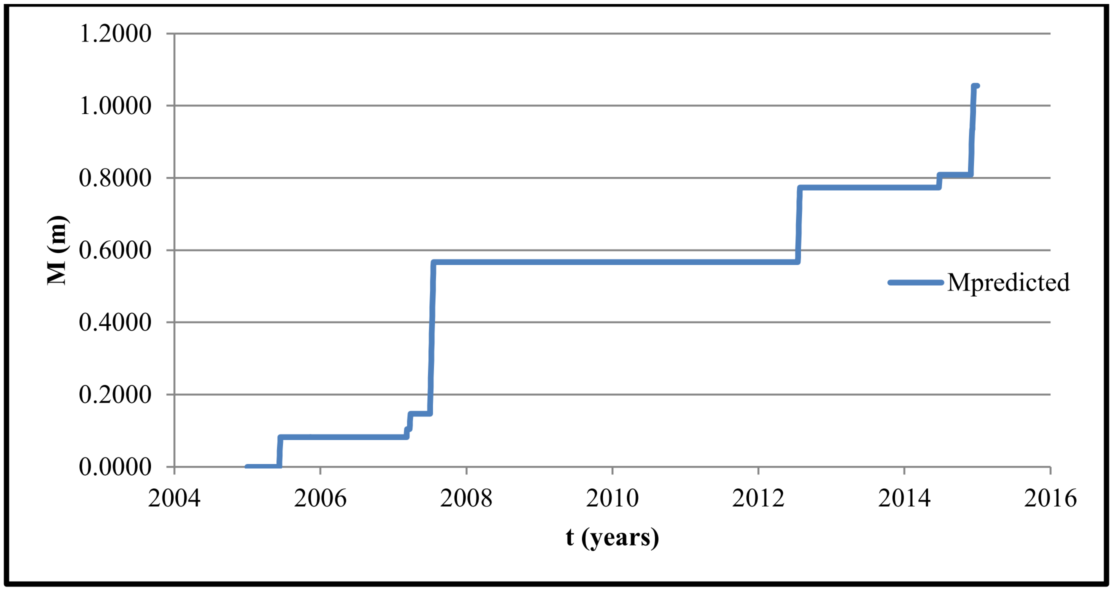


Figure 87. Colorado River prediction

6.4 DISCUSSION OF RESULTS

The results of the predictions are based on the critical velocity obtained from the calibration step. The lowest Ranking Index values were obtained from the results that used the α' and β parameters from the EFA categories chart. Only a period of 10 years was used for the hydrograph in the prediction, but this gives a general idea of how much the river will change in the period of 10 years after the last observed data. The critical velocities obtained from both methods of the calibration step used could either be very similar (Brazos River) or very different (Nueces River). The results depend on the geometry and the soil erosion parameters and the variability of the results is expected when considering all the factors.

In general, the behavior of each river looks that they follow the same pattern seen in the calibration step. For the Nueces, Brazos and Sabine Rivers, the data used corresponds to recent data. The last observation for each of these rivers is from 2012 or 2013. The predictions at these sites could be accurate if it is considered that no countermeasures have been installed where the point of reference was selected, as it is the case for these rivers.

In the other cases, the prediction may not represent what will happen or what has happened. The Trinity River has not changed much since the 1990s because countermeasures such as sheet piles have been installed to decrease the erosion rate. The erosion has been controlled since the repairs at the site. Also, the vegetation at the site guards the bend of the river. This case may not the best example to use the observation method.

As mentioned before, the North Sulfur River bridge was replaced in the 1990s and only two cross sections were used. Two cross sections were used for the Colorado River as well. Only two points in the calibration step were used for both of these cases. At least adding one more point to the observed data for both rivers could have been more precise to obtain the critical velocity.

CHAPTER 7: SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY

Meander migration and vertical degradation have been problems that have been studied for many years, but the uncertainty has been part of its nature. The “where” and “when” involved in these problems have been approached in multiple times and solutions have been proposed to make predictions based on data available. Rivers are continuously changing and different factors in nature are responsible for their changes. Meander migration and vertical degradation are problems that depend on three main aspects: the soil at the site, the water flow conditions and the geometry of the river itself.

The method that was proposed for this project takes in consideration each of the three important aspects, while other methods proposed in the past may have ignored some of them or does not take them in consideration. Not all soils are equal and their erodibility is greatly related to the changes of the position of a river. The observation method is based on observed data (data from the past) to predict the behavior in the future. Aerial photos, maps and cross sections correspond to these observed data and tell how the river geometry has evolved with time. The river hydrograph correspond to the part of the water flow of the problem. The extrapolation method by using the aerial photos ignores the constant change of water flow. One sudden increase in water velocity may erode a few meters from the bank of a river.

The observation method was applied to 6 different rivers in Texas. Each one of them has had different problems of erosion for years and in some of them there have been remedies that were needed to avoid the exposure of the banks to big floods. The observation method consists of two important steps: calibration step and prediction step. The calibration step is used to find the critical velocity at the field, which is the minimum velocity required for erosion to occur. The input data to obtain the critical velocity are the erosion parameters (α’ and β from EFA curve), the observed data from aerial maps, photos or cross sections, and the velocity hydrograph. The critical velocity for the 6 rivers was obtained by using the EFA curve from samples and from a chart that has all the erosion categories. For the prediction step, the input data is essentially the same as in the calibration step, but there is no iteration process and the critical velocity used is the one obtained from the calibration step.

For this project, the observation method was developed considering all the factors mentioned before and it can be applied by using two programs: MATLAB or Microsoft Excel. The method is relatively simple to use and the results can be compared to other methods. It is very important to know how much a river will change with time and this method is an alternative that provides a solution to the problem.

7.2 RECOMMENDATIONS

The observation method depends on previous or observed data to obtain the prediction of the magnitude of erosion. The method is as good as the observed data. Historic maps are not as good as high resolution photos for a few reasons. First, they could be hard to find for periods of time that the user would want. Also, the bends of the river can be confused with the water level of the river when the measurements were taken at the site to prepare the map. Photos are preferred over maps, but not enough of them could be found before 1990. The results could have been better with aerial photos. Also, the method yields better results when using a short period of time (10-20 years) with many observations, preferably with aerial photos.

Also, for the vertical degradation cases, the data that was available was very limited. Only two points were used for the North Sulfur River and the Colorado River. More points could have been better to estimate the critical velocity and to obtain a better prediction. When the code compares the calibrated data with the observed, the values were almost exactly the same, which may not be necessarily true. More points for these cases need to be used. The Observation Method also does not consider the deposit of sediments at the bottom of the river and assumes constant erosion only. This simplifies the problem, but the results may be inaccurate when this is not taken into account. Other physical or mathematical models could be used to compare the results for the vertical degradation cases.

The results from the Observation Method were not compared to other methods used for meander migration or vertical degradation. This method proved to be a simple and quick way to obtain results for the movement of one point of the river. In the future, the Observation Method could be used in conjunction with other methods to provide a solution to the prediction of meander migration and vertical degradation problems and compare the results for a better design or planning.

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