Assessment of the Effects of Regional Channel Stability and Sediment Transport on Roadway Hydraulic Structures: Final Report

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Final Report

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract (to date), including any art, method, process, machine, manufacture, design, or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable.

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Abstract

Rivers and streams evolve all the time. As a result, no stream channel is absolutely stable. Channels evolve at various speeds both vertically (degradation/aggradation) and horizontally (meander migration). They also respond to man-made changes ranging from in-stream modifications (such as bridges) to watershed changes (such as land use change and urbanization). Failure to consider these dynamics could result in costly repairs and even disastrous collapse. The current practice of using HEC-RAS in TxDOT to calculate local scour around hydraulic structures does not fully consider the effects of regional channel stabilities. The lengthy Federal Highway Administration (FHWA) publications on steam instabilities (e.g., HEC-11, 18, 20, and 23 series) are not consulted unless risks are apparent. In addition, there are no clear guidelines on how to address the problem in the current TxDOT Hydraulic Design Manual. A comprehensive investigation of the subject and synthetic study are needed. This final report is the compilation of all the interim technical memorandums submitted to TxDOT during the course of this project..

The researchers conducted a thorough literature review on the subject of degradation and aggradation, bank erosion, channel stability, fluvial geomorphology, river hydraulics, and erosion countermeasures. They also collected and integrated data from all possible sources into a GIS database which can be used by TxDOT engineers. Then the research team surveyed existing numerical models with the aim of identifying tools to evaluate different design options. The selected tools are tested on six sites in Texas where field observations and measurements were carried out in this project. During the field campaigns, the team followed the general procedure recommended by NCHRP and filled out the two forms, namely "Stream Reconnaissance Record Sheets" and "Rapid Assessment of Channel Stability". Sediment samples were taken from both the river bottom and the banks. The exact locations of the samples were recorded using a hand-held GPS. Samples were processed in the lab for grain size distributions. They are also tested using the Erosion Function Apparatus (EFA) at TAMU. The results from these tests were used in the predictive models. The final product is the analysis procedures and design guidelines for structures in unstable streams. The document is written in the format which can readily replace the relevant section in the current TxDOT Hydraulic Design Manual.

The researchers found that though general guidelines are available from the Federal Highway Administration, they are too lengthy (roughly 2,250 pages for the documents surveyed). They only provide very general information and sometime are not so useful considering the unique geophysiological and hydrological characteristics of Texas. By synthesizing the existing federal documents,

reports from relevant past TxDOT research projects, and the results from this project, the researchers summarized the current status in this field and provided updated information in the form of a concise report. The researcher also provided application examples with detailed documentation. Two predictive models were used. One is the TxDOT funded MEANDER program, which is developed by TAMU. MEANDER program is very simple to use and yet provide reasonable results. The other is the RVR Meander software, which considers more physics (hydrodynamics, sediment transport, and bank failure). As a result, it gives more control to the modeler and potentially generates more accurate results. However, it requires more data and the modeler should have a clear understanding of the physical process. In the demonstration examples for the sited selected in Texas, the model has to consider the floodplain heterogeneity, which includes soil type difference, vegetation variation, and the hardening effect due to the bridge and the adjacent road. Otherwise, the prediction cannot match the river course recorded in the historical maps. This can only be achieved in the RVR Meander model.

The newly updated section in the TxDOT Hydraulic Design Manual reflects the state-of-art knowledge in the field of channel stability and engineering countermeasures. The results permit an engineer to rapidly determine whether the regional geomorphic change in a channel could result in reduced safety and how engineering enhancement should be sought.

Chapter 1

Literature Review

1.1 Purpose and scope of the literature review

This technical memorandum is a literature review of documents the research team deemed relevant to the research project "Assessment of the Effects of Regional Channel Stability and Sediment Transport on Roadway Hydraulic Structures" funded by Texas Department of Transportation.

1.1.1 Purpose of literature review

Literature pertaining to various aspects of channel stability and fluvial geomorphology are abundant. It is impossible to explore all of them given the time constrain of this project. During the writing of this report, we have to constantly restrain from adding more details as it could easily make this review very lengthy. Instead, we strived to present the most relevant information in a concise fashion. When details have to be left out, references are given for furthering reading. Engineers or anyone in TxDOT who are interested can use this short report as a starting point.

The focus of the literature review was on the existing methods and approaches for assessing roadway hydraulic structures affected by regional channel stabilities. Specifically, the researchers synthesized existing knowledge in the literature on the following questions:

1. What are the geomorphological processes that affect the channel stabilities? How do they depend on hydraulic conditions and sediment parameters such as stage, discharge, slope, vegetation, bed and bank materials? Do perennial, intermittent, and ephemeral streams behave differently with regard to their channel stability?

2. How does channel stability affect bridges, culverts, and other roadway crossing structures, and what are the mechanisms of impairment?

3. Are there existing theoretical or statistical frameworks to provide methods to evaluate the potential of regional channel stabilities, including methods for both vertical degradation/aggradation and planform migrations? How well do they work in reality?

4. List and discuss the available mathematical models, statistical formulas, physical modeling datasets and field measurements on channel stability and erosion, in particular those developed for Texas.

5. How does a transportation structure (such as bridge and culvert) affect the stream water and sediment regimes? Could these local disturbances trigger regional geomorphic regime change? What are the common practices in the field to alleviate the possible negative impacts of transportation structures on river system?

6. If regional channel instability is inevitable, what engineering countermeasures are available to protect the structures?

1.1.2 Literature Reviewed

The researchers have conducted a thorough literature review on the subjects of river hydraulics, fluvial geomorphology, sediment transport, aggradation and degradation, bank erosion, channel stability, countermeasures, and regulations. All pertinent research papers, conference proceedings, manuals, guideline documents, and textbooks have been assembled to the extend possible.

Rivers are connected topographic low points that transport water and sediment through the fluvial system. Schumm (1985) differentiates three primary types of river channels: (1) bedrock channels, (2) semi-controlled channels, and (3) alluvial channels. For our purposes, both bedrock and semi-controlled channels can be considered as stable channels. Hence, the review of channel stability will focus on alluvial river channels. Alluvial rivers are defined as, "channels formed by a river in its own sediments, which it has transported and deposited, and is capable of remobilizing" (Church, 2006). We focused on river stability and basic fluvial geomorphology concepts that will be helpful for developing general stability assessment methods.

We note that TxDOT has supported numerous research projects in the past to deal with channel instability and related problems. Reports from past relevant TxDOT projects have been gathered and reviewed (see Table 1.1). In particular, methods to predict bend migration has been reviewed in detail in Briaud et al. (2001), and an analysis for Texas streams using their new method is given in Yeh et al. (2011). Another important source of references is the guideline documents by Federal Highway Administration (FHWA, see Table 1.2). In particular, HEC-18, HEC-20, and HEC-23 have been thoroughly examined and synthesized. These TxDOT and FHWA reports serve as the major part of the literature reviewed. The researchers have also relied on the comprehensive ASCE Manuals and Reports on Engineering Practices No. 110: Sedimentation Engineering (García, 2008), which is a good collection of references. Its chapters, ranging from basic theories of hydraulic and sediment transport to practical problems such as erosion protection and river training works were written by prominent researchers and engineers with extensive experiences.

1.2 Overview of channel instability

River channel stability has been a topic of research in engineering and geology for many years. Several good reviews of much of the fundamental work and concepts related to river dynamics have been made over the years. One of the many key review papers of note, dealing with alluvial rivers in particular, is that of Schumm (1985). In addition, there are two key Federal Highway Administration (FHWA) reports (Richardson et al., 2001; Lagasse et al., 2001) and one Texas Department of Transportation (TXDOT) report (Briaud et al., 2001) that came out in 2001 which summarize many of the issues related to river stability and roadway crossings up until the year 2001. Much of the information found in these reports can also be found in the ASCE Sedimentation Engineering manual number 110 (García, 2008) in chapters 6, 9, and 10. This section of the literature review does not attempt to repeat the reviews found in these documents. Some of the fundamental concepts of river stability will first be introduced to provide context, but the bulk of the review aims to synthesize information that is most pertinent to this project. In particular, we added new development in this field since 2001.

The review will focus on the concept of a graded river equilibrium state, the relative stability of various channel patterns at their dynamic equilibrium state, and methods to quantify channel stability as it related roadway structures. We will summarize existing knowledge on channel instabilities, including instability types, causes, and controlling factors. We then discuss the evaluation and countermeasure methods in practice, including those suggested by FHWA and used by TxDOT.

1.2.1 Definition of Channel stability

It should first be said that defining what is meant by the term channel "stability" is difficult and varies based on the context of the problem. Rivers, no matter what type of material they are flowing through, will deform their boundaries at some rate. S. A. Schumm expresses this sentiment in the following statement:

> No alluvial channel is actually stable in the sense that no change occurs. Rather there are degrees of stability depending upon the rate and type of channel change. For example, aggradation or degradation, caused by changes of baselevel or hydrologic conditions, will change the channel cross-section shape and dimensions. Although this is certainly an instability, the channel pattern may not be affected. On the other hand, local but dramatic changes of pattern such as cutoffs and meander shift may be considered to be normal river behavior. Therefore, meander growth and shift alone is not a criterion of instability. However, a riparian landowner whose property is being destroyed by the meander change will not be convinced that such a river is relatively stable (Schumm, 1985, , pp. 13,14).

For the purposes of this review, the term stability will be defined without regard to roadway structures simply as,

> *the rate at which a river deforms its boundary.*

In this definition, deformation includes both laterally and vertical change. Lateral deformations can include bend migration, bend cut-off , avulsion, or channel widening; and vertical deformation includes both degradation and aggradation. These various types of deformation are the result of several physical process, some of which will be discussed below. Based on this definition, a "stable" stream would be one which deforms its boundary at a very slow rate, with significant deformation only over decades. A stream that is "unstable" would be one which has a high deformation rate, with significant deformation possibly occurring on the order of a year or less. The terms used above in the definition of stability are relative, and what exactly constitutes significant change over a given time period is not well defined. In fact, coming up with a quantitative measure and a discrete, continuous, or probabilistic threshold for what is stable and unstable is one of the tasks that this project aims to address. Nonetheless, the definition above is helpful for developing a common language, and it is essentially equivalent to that used by Church (2006), who states that channel stability is, "*the propensity for aggradation or degradation and the style and rate of lateral* *movement.*"

A definition of stability without regard to roadway structures is general and has been used in the majority of the literature. However, the roadway structures are human imposed disturbances and will impact river deformations and evolutions. Engineers should keep this in their minds when deal with channel stability problems. In this regard, two relevant definitions of channel stability as it relates to roadways are given by Lagasse et al. (2001) and Johnson (2006). These definitions should be kept in mind during the review of these two studies (section 1.4.2) since they differ slightly from the more general definition used in the bulk of this review. With regard to channel stability, Lagasse et al. (2001) defines the following:

> *For highway engineering purposes, a stream channel can be considered unstable if the rate or magnitude of change is great enough that the planning, location, design, or maintenance considerations for a highway encroachment are significantly affected.*

Johnson (2006) has a slightly different definition of a stable channel:

> *A stable channel in the vicinity of a bridge is one in which the relationship between geomorphic process and form is stationary and the morphology of the system remains relatively constant over the short-term (one to two years), over a short distance upstream and downstream from bridge, and with minimal lateral movement.*

Regardless the exact definition, a channel can be generally defined as "stable" when erosion and deposition are in balance. The geometry and overall planform morphology of a stable channel do not significantly change. However, no channel is absolutely stable in the sense of being completely immobile. Therefore, stability should only be defined relative to a particular time frame. For example, a given channel alignment might not be prone to changes during the service life of a bridge built over it. But at longer time scale, disturbances could eventually trigger the transition to instability.

Transportation infrastructures at river crossings are built over a small portion of the river. When designing these structures, local scours are given most of the considerations. However, regional channel stability also affects safety. For example, regional degradations can reduce safety margins by further exposing the bridge piers in addition to local scour, while aggradations can cause structural burial and gravel choking. River meandering could endanger the structures by lateral expansion and down-valley translation of meander bend. Additionally, construction and maintenance activities can modify water/sediment regimes and impact channel stability. This is further complicated by the fact that the response in the channel system is nonlinear. Relatively small external disturbance at some critical locations could trigger abrupt channel changes. Therefore, engineers need to have a holistic view of the whole system.

1.2.2 Channel classification

Channel classification is the first step toward accurate assessment of its stability. Though diverse, there exist some distinctive channel forms or morphologies which are linked to relative stabilities among the various forms and are the basis for channel classification. Several classification systems have been proposed in the past. Leopold and Wolman (1957) classified fluvial channel planforms as being straight, meandering, or braided. Planform refers to the channel shape in the horizontal plane. Brice (1975) proposed another classification scheme for alluvial river channels. His scheme uses the following criteria: the degree of sinuosity, braiding and anabranching, and the character of each of them. Based on the relationships between planform and sediment load, Schumm (1981) proposed several basic patterns (Figure 1.1). He also ranked the relative stability for each pattern. Very recently, Rosgen (1996) proposed another channel classification scheme with a four-level hierarchy (see Figure 1.2). This scheme assess the channels based on different levels which range form broad geomorphic characterization to very detailed quantifications. Rosgen (1996) also noted an important point that though all classification schemes try to label channels as discrete categories, stream morphology displays a continuum of form. Among all the classification methods reviewed, Rosgen's classification is the most extensive and complicated.

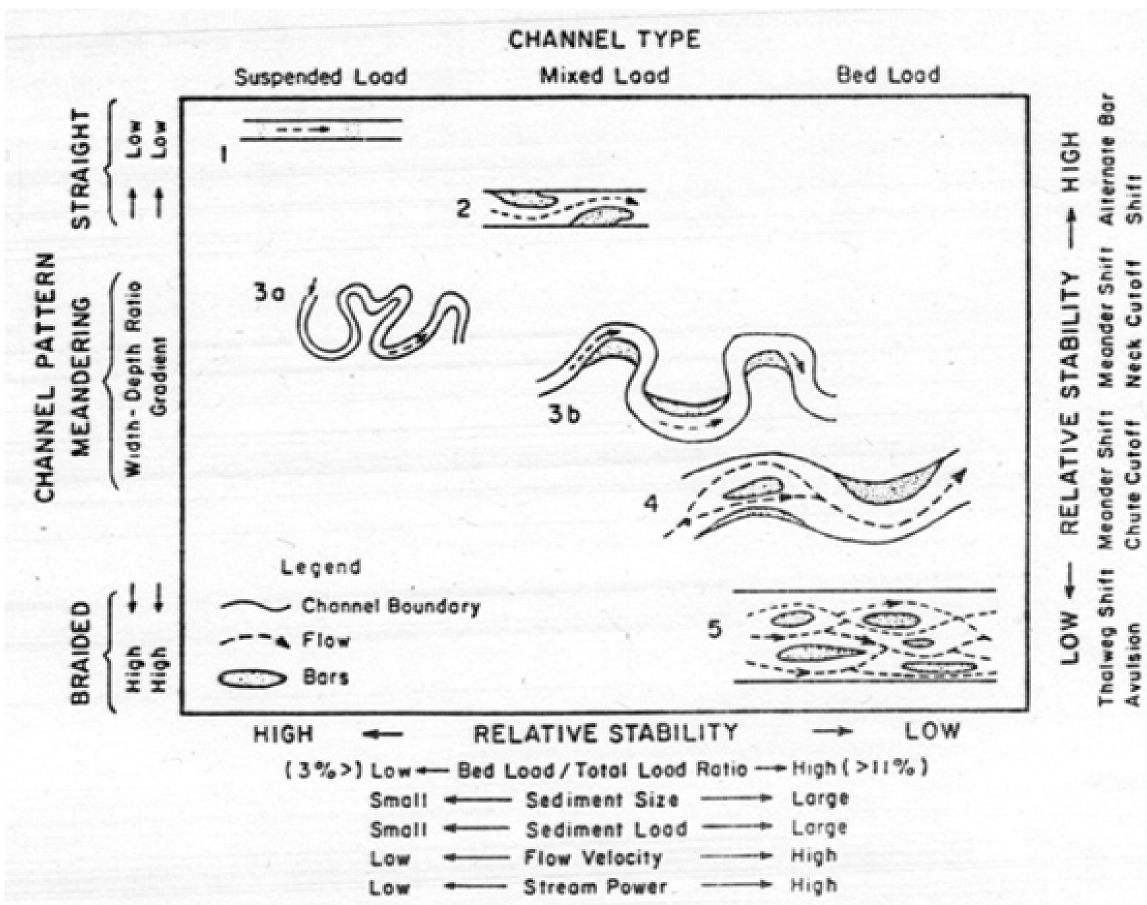


Figure 1.1: Channel classification based on pattern and type of sediment load (Schumm, 1981)

Channels can also be classified as either degrading or aggrading according to the vertical change of bottom. It should be noted that any given river may take on several different planform shapes

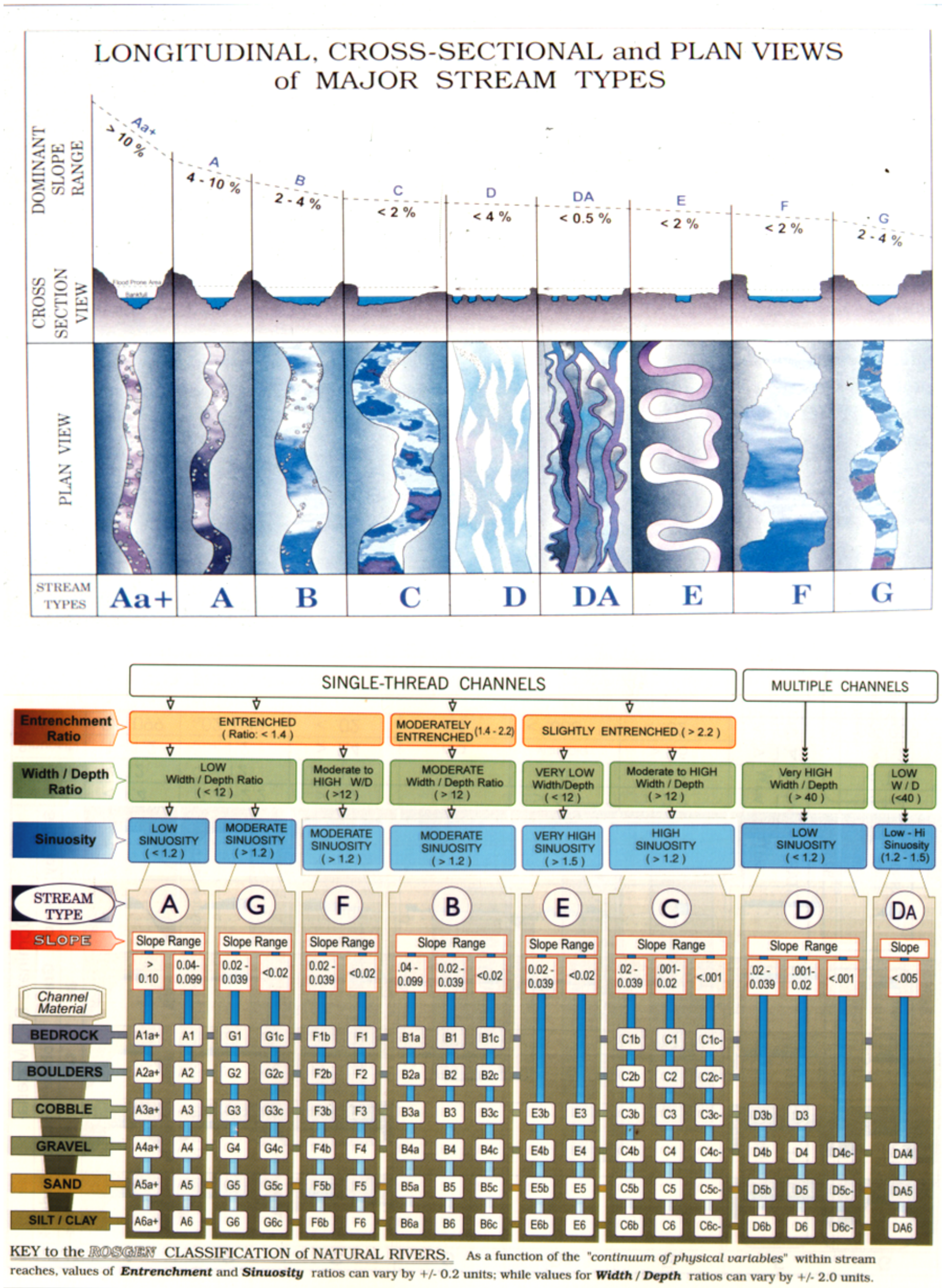


Figure 1.2: Rosgen channel classification (Rosgen, 1996)

and experience both degradation and aggradation at various reaches along its length.

1.2.3 Causes of channel instability

Fluvial streams continuously adjust their channels in response to changes in discharge, sediment load, and boundary conditions. The causes of channel instability can be grouped into three broad categories: downstream factors, upstream factors, and basin-wide factors García (2008).

- Downstream factors: Base level at downstream controls the backwater curve and defines the datum for the potential energy in the whole system. Engineering interventions such as meander cutoffs could trigger channel response of locally steepening the slope and increasing sediment transport capacity.
- Upstream factors: Examples of upstream factors include river regulations by a dam or diversion structure. These factors will change the input of water and sediment into the system which could drive the transition to instability.
- Basin-wide factors: Channel stability in a fluvial system depends on the characteristics of the watershed, including climate, soil type, vegetation, land use, rainfall-runoff relationship, and water resources management practices. Any change could cause a series of reactions affecting runoff from the watershed to the channel, sediment delivery to the channel, water and sediment transport within the channel, and response of the channel. One frequently cited example is urbanization, which increases the peak flows and reduce sediment delivery to the channel network. As a consequence, remarkable degradations have been observed in channels draining urbanized areas.

In HEC-20 (Lagasse et al., 2001), the factors affecting stream stability are grouped into two broad categories, namely geomorphic factors and hydraulic factors. Geomorphic factors include stream size, flow habit (ephemeral or perennial), and characteristics of channel boundaries. Hydraulic factors include the characteristics for stream flow and channel conditions which need to be analyzed using basic hydraulic principles.

As the affecting factors play over a spectrum of spatial and temporal scales. The stability assessment needs to consider whether these factors could impose a threat at the scale of interest. Small scale river engineering projects may work well for some erosion problem if the cause is local. However, if the problem is caused by larger scale mechanisms such as drastic land use change in the watershed, local bank protection projects will sometime prove to be futile.

1.2.4 Sediment transport and river mechanics

Channel instability is the result of the co-evolution between river flow and the sediment channel. From the physical processes point of view, a set of parameters and characteristics for sediment transport and river mechanics are very important. One can find more information in some classic textbooks such as Julien (2002, 2010). The following is a summary of the most important ones.

- Flow characteristics: In a straight open channel, vertical velocity distribution follows the log-law. In meandering bends, the centrifugal acceleration drives the faster-moving surface current toward the outer bank and the flow near the bed toward the inner bank, resulting in a secondary flow perpendicular to the primary flow direction. The net effect is the spiraling flow in the bend, which determines how the bend migrates.

- Sediment: The geotechnical community prefers the use of "soil" rather than sediment. So we will use sediment and soil interchangeably. Sediment is the material that shapes the landscape in the river system and is the foundation for most roadway hydraulic structures. It acts as the movable boundary for the channel. The mobility of sediment directly affects the channel stability. The sediment parameters include particle sizes and their distribution, density, shape, cohesivity, porosity, and fall velocity in water.

- Sediment in streams can be transported in two different modes, i.e. bedload and suspended load. In bedload, particles move by rolling, sliding and saltating within close proximity of the bed. For suspended load, sediment is distributed throughout the water column and only comes in contact with the bed for short durations of time.

- Shear stress: The shear stress exerted by the flowing water is the driving force for bedload transport. It is also a good indicator for energetic eruptions of vortices from the bed, which entrains the sediment particles and feeds then into the suspended load. So both modes of sediment transport are directly or indirectly relate to the bottom shear stress.

The weight of the particles in non-cohesive sediment, along with the inter-grain contact and the grain exposure within the bed, are the primary factors that counteract the driving drag force exerted on the particles by the flow (represented in an averaged way by the bed shear stress). The threshold of motion is, therefore, defined when these resisting forces are in balance with the drag force. When the grains just start to move, this shear stress is called the critical shear stress. The critical shear stress for cohesive sediment is generally higher than those for non-cohesive sediment due to the added inter-particle electrochemical bonding forces which give the sediment its sticky nature. The mobility of non-cohesive sediment can be estimated by use of the Shields diagram.

Channel stability in tide-affected waterways are not required in this research. However, it is worth to note that the laws governing the water flow and sediment transport in coastal channels are the same as in riverine channels. The difference is that in coastal regions, channels are subjected to the effects of tides and storm surges. In addition, the bed materials close to the coastal area are in general fine sands and cohesive silts/clays. Nevertheless, the outcomes of this project could benefit future researches targeted to coastal channels.

1.2.5 Interactions between river channels and highway constructions

Human activities such as construction of highways have great impact on the river channels. On the other hand, river channel changes (either naturally or induced by human activities) affect the stability and safety of roadway hydraulic structures. There exists a feedback loop between river channels and highway structures. Before detailed assessment and quantification for the interactions are introduced, it is beneficial to qualitatively analyze this two-way coupling. Sections 1.3 and 1.4 in HDS-6 (Richardson et al., 2001) have detailed discussions on some of scenarios out of numerous possibilities. The following is a summary of the two sections.

Effects of highway construction on river channels

The effects of highway construction on river channels can be grouped into two phases. One is the immediate response of rivers during the construction or shortly afterwards. The other one is the long term response.

The construction of bridges, channel stabilization, and countermeasures change the geometry or the hydraulic properties of the river. The local impact of the changes on the river system will be immediate. For example, contraction and local scour due to the construction of encroachments will start to develop. Scour holes will form around the construction site. Sediment removed from the site will be transported downstream until the river capacity is reduced. The contraction will also affect the backwater curve upstream of the site. For the same discharge, the water surface profile will be higher due the contraction. The disturbance due to construction will also induce erosion and increase the sediment load to receiving water channels. The sudden jump in sediment load will in turn cause local aggradation and steepen the channel. As a result, instabilities at the site could happen.

The long term impact on river channels due to highway construction will show over a long period of time. For example, the river training works will generally straighten the channel, shorten the flow path, and increase the flow velocity. Consequently, the potential for scour is increased and degradation of the river bottom will happen. If the degradation starts in main channel, it tributaries will also be subject to erosion due to the drop of water surface and bed elevation at the junctions.

Effects of river channel evolution to highway

Responding to any change in hydraulic or geomorphic factors, river channel changes its shape, dimension, and slope. To evaluate the effect of channel evolution on highways, one needs to have a holistic view. Highway is one of the possible human activities which interact with river channels. Other activities, such as water diversion, reservoir construction and operation, flood control works, cutoffs, levees, navigation works, and mining of gravel and sand also need to be considered. The river response to these activities along the river and in the watershed could propagate to highway crossings.

For example, a bridge might be far away from a reservoir. However, the impact of the reservoir and the river channel adaption could propagate way beyond the vicinity of the dam site. In general, due the sediment trap effect, the reservoir will create aggradation in the upstream and degradation downstream. Accordingly, any design of a new bridge or retrofitting of an existing one needs to thoroughly review the change made on different reach of the river. Some specific examples have been given and discussed in HDS-6.

1.2.6 What is special in Texas

The state of Texas has a dozen of major rivers and thousands of named streams flowing through its vast land. The rivers and streams, which play an important role in carving out their surrounding landscapes, transport tremendous amount of water and sediments. On the other hand, Texas ranks first among the 50 states in total highway mileage, railroad mileage, and number of airports. The transportation infrastructures, roadways in particular, built upon the land shaped by the rivers and streams are greatly impacted during their design, construction, operation, and maintenance phases. To assess these impacts, it is important to have an overview of the physiographic provinces, precipitations and the major river basins in Texas. It will help the engineers have an overview of the characteristics of Texas river channels and possible instability problems.

Texas is typically divided into seven physiographic provinces. Each province or landscape is the result of its geological history of depositional and erosional processes (Wermund, 1996a). They are distinguished by geologic structure, soil and rock types, vegetation, and climate. These seven physiographic provinces are plotted in Figure 1.3. The following is a brief description of each of them.

- **Gulf Coastal Plains**: It has three subdivisions, namely the Coastal Prairies, the Interior Coastal Plains, and the Blackland Prairies. In the Coastal Prairies, young deltaic sands, silts, and clays forms nearly flat grassland. The Interior Coastal Plains comprise alternating belts of resistant uncemented sands with weaker shales. This region is characterized by pine and hardwood forests and numerous permanent streams. The inner most part of the Gulf Coastal Plains is the Blackland Prairies which have chalks and marls weathered to deep, black, fertile clay soils. This region is largely cultivated for crops.

- **The Grand Prairie**: This region is in the west part of Eastern Texas. The east part of this region sits on limestones. The weathering and erosion have left thin rocky soils. On the west margin of the Grand Prairie underlies sandstones.

- **Edwards Plateau**: This region includes the Hill Country and a broad plateau. Streams erode into the fault escarpment and entrench the plateau. Sinkholes are common on the limestone terrain and connected with underground caverns. Alternating hard and soft marly limestones forms a stairstep topography in the central part of this region. On the west part, the Pecos River erodes a canyon with nearly vertical sides and very sparse vegetation.

- **Central Texas Uplift**: It is a central basin with rolling floor dotted with rounded granite hills such as the Enchanted Rock. Part of the Colorado River flow through this region.

- **North-Central Plains**:This region is an erosional surface with shale bedrocks and harder bedrocks. Meandering rivers develop where shale bedrocks prevail. Hills and rolling plains dominate in harder bedrock areas.

- **High Plains**:The high plains are nearly flat. Sand and gravel deposits from streams are extensive. Windblown sands and silts form thick, rich soils. Headwaters of major rivers deeply notch the caprock. Widespread small and intermittent streams dominate the drainage. The Canadian River separates the Central High Plains from the Southern High Plains.

- **Basin and Range**: This province contains eight major mountain peaks with the Guadalupe Peak the highest point in Texas. Mountains ranges are generally in the north-south direction and rise abruptly from barren rock plains.

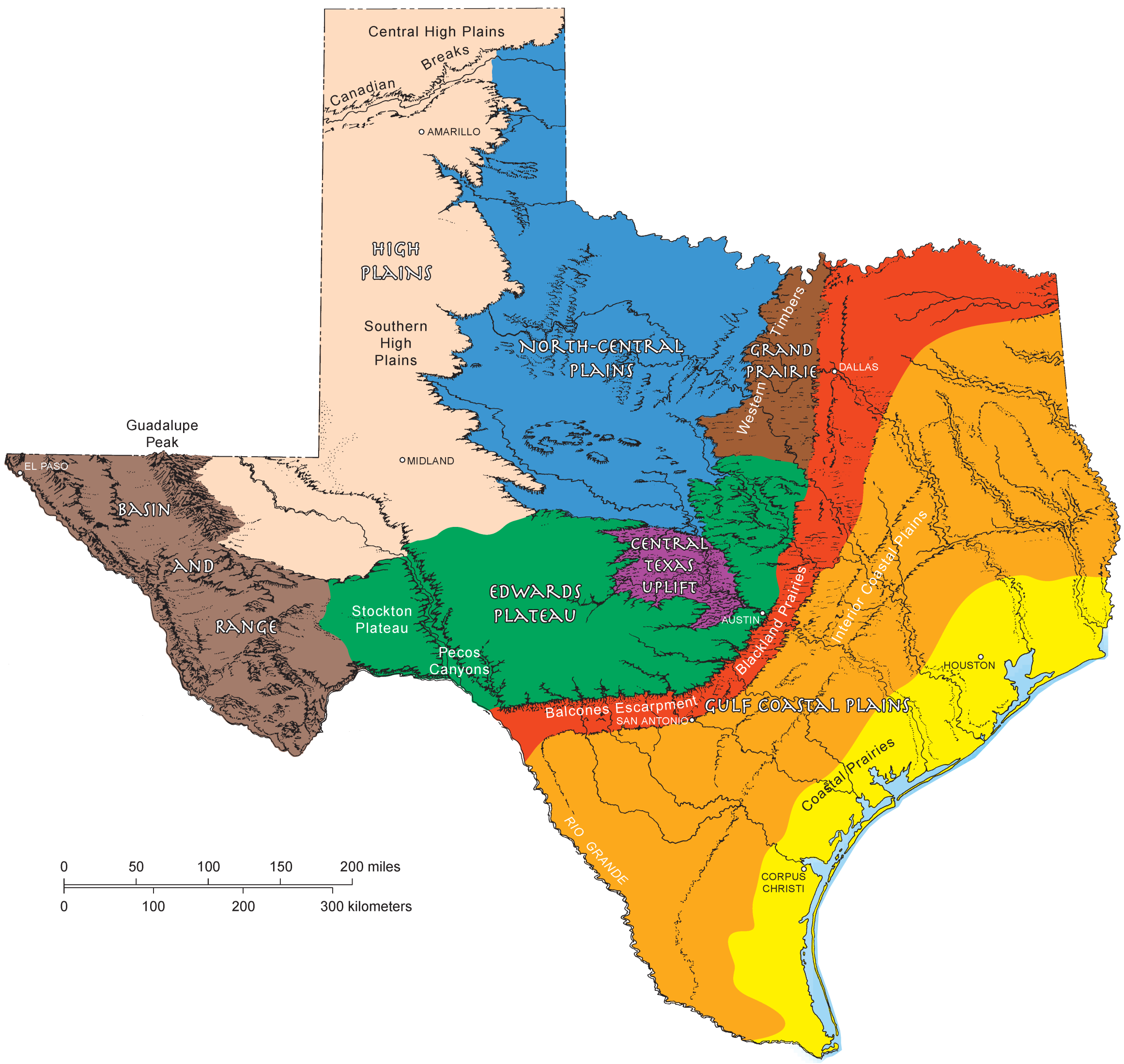


Figure 1.3: Seven physiographic provinces of Texas. Adapted from Wermund (1996a)

The rivers and their drainage watersheds overlaying on top of these seven different physiographic provinces vary greatly in size, shape, and patterns. The watersheds reflect the climate, geology, topography, and vegetation of the area (see Figure 1.4). There are 13 major river basins in Texas, with five of them originating from outside Texas and eight from inside. Two of them, the Canadian and the Red Rivers discharge beyond Texas. The remaining eleven flow into the Gulf of Mexico.

Precipitations strongly influence the flows of the rivers and streams in Texas. To the east in the Sabine River basin, the mean annual precipitation is about 60 inches and annual evaporation is less than 70 inches. However to the west in the Rio Grande River basin, mean annual precipitation is the range of 8 to 20 inches and annual evaporation is more than 100 inches. As a result, the rivers in the east part of Texas flow year round, while the west Texas streams only flow intermittently.

Sediment transported by the rivers originate from their watersheds and are controlled by the available rocks and soils in their physiographic provinces. East of the Trinity and south of the Red Rivers, streams are generally dark and murky because of high organic content. However, west of Austin, streams usually run clear when not in flood.

The geology influences the dimension and shape of rivers. In the wetter East Texas, where the sediments are general sands and muds, the river valleys contain wider and meandering streams with large amount of suspended load. Eastern rivers also have low gradient in the range of 1-2 feet drop per mile. In comparison, the dry West Texas sees more streams cutting deep gorges with nearly vertical sidewalls incising into hard limestones and sandstones. The river water is usually quite clear and free of suspended sediment. The majority of sediment transported is bedload with gravels and coarse sands. These rivers have steeper gradient in the range of 7-13 feet drop per mile.

Human activities have already had and will continue to have great impact on the rivers. Dams, levees, and other hydraulic control works have been built which changes the flow characteristics and channel evolution. Irrigations, flood control, waterwater treatment effluent discharge, and many other aspects have also contributed to the change. In the context of this project, large scale construction of transportation infrastructures imposes another layer of stress on the river systems.

1.2.7 Past and ongoing relevant TxDOT research projects

A preliminary survey of past and ongoing TxDOT research projects revealed that tremendous efforts have been spent on this problem, though each project focused on different aspect. A synthesis of these projects will give some historical perspectives and is very beneficial to this project. The benefits include:

- Finding out what has been studied and reducing duplicative efforts,
- Collecting existing data which can be used for this project,
- Summarizing the conclusions and recommendations from previous studies.

Figure 1.4: Thirteen Major River Basins of Texas. Adapted from Wermund (1996b)

Table 1.1 is a list of past and ongoing relevant TxDOT research projects. We have summarized what has been done and what information is useful. Research Supervisor and PIs of this proposal have actively participated in most of these past and ongoing efforts.

Project #	Project Title	PI	Leading Institution	Report(s)	Pages	Useful Information
0-1836	Regional applications for biotechnical methods of streambank stabilization in Texas	Ming-Han Li	TAMU (TTI)	1836-3: Regional applications for biotechnical methods for streambank stabilization in Texas: A literature review	46	It identified bioengineering and biotechnical streambank stabilization technologies appropriate to the climatic and resource regions of Texas with an evaluation of the potential cost effectiveness of various methods.
0-1914	The performance of flexible erosion control materials	H.C. Landphair, J.A. McFalls, et al.	TAMU (TTI)	0-1914-1: Performance of Flexible Erosion Control Materials; 0-1914-2: Performance of Flexible Erosion Control Materials and Hydraulic Mulches; 0-1914-4: 1994 Performance Results for Erosion-Control Blankets, Mulches, and Channel Liners; 0-1914-5: The 1995 Performance Results for Slope Protection Products, Hydraulic Mulches, and Flexible Channel Liners	646	It evaluated the performance of flexible erosion control materials and hydraulic mulchs. Though not directly related to channel stability, some of the information is useful for the design of countermeasures. In addition, the erosion control at the roadside and drainage channel reduces the load of sediment in the streams.
0-2105	Develop Guidance for Design of New Bridges and Mitigation of Existing Sites in Severely Degrading and Migrating Streams	Jean-Louis Briaud	TAMU (TTI)	2105-1: Predicting meandering migration: evaluation of some existing techniques	50	It is most relevant for this project. It evaluated two approaches of evaluation: empirical approach and time-sequences maps and extrapolation approach. It has data for 6 historic cases on meander migration for 4 rivers in Texas.
				2105-2: Guidelines for bridges over degrading and migrating streams. Part 1: Synthesis of existing knowledge	104	
0-3970	Remote Bridge Scour Monitoring: A Prioritization and Implementation Guideline	Carl Haas	UT Austin	1904-1: (the same as project title)	194	It developed an algorithm based on code contained in the BRINSAP database to prioritize bridge sites for further consideration of scour countermeasure implementation. It also evaluated remote mechanical monitoring for detecting and tracking bridge scour.
0-4378	Establish Guidance for Soil Properties-Based Prediction of Meander Migration Rate	Jean-Louis Briaud	TAMU (TTI)	4378-1: (the same as project title)	338	It considered soil erodibility as an independent parameter, in addition to conventional parameters, to predict migration. It has experimental data and numerical modeling results. A program with GUI is developed for prediction.
0-4695	Guidance for Design in Areas of Extreme Bed-Load Mobility	David Thompson	TTU	4695-1:Literature Review	38	It provides principles to avoid damages to low water crossings within Edwards Plateau region. Some of the guidelines should be considered in this project. It has field and laboratory data.
				4695-2: Design guidance for low-water crossings in areas of extreme bed mobility, Edwards Plateau, Texas	184	
0-5505	Simplified Method for Estimating Scour at Bridges	Jean-Louis Briaud	TAMU (TTI)	5505-1: (the same as project title)	482	It provides a new three-level method to evaluate scour at bridges. 16 bridges over different streams in Texas were tested using the economical and simple method. Valuable data for bridge scours are available. A program called TAMU_FLOW is a product of this project.
0-6549	Hydraulic Performance of Staggered-Barrel Culverts for Stream Crossings	Theodore Cleveland	TTU	Ongoing	N/A	It will develop design guidelines for culvert systems that adequately pass large quantities of sediments at stream crossings. Its literature review and experimental data is beneficial.
0-6654	Empirical Flow Parameters - A Tool for Hydraulic Model Validity Assessment	Theodore Cleveland	TTU	Ongoing	N/A	It will develop an empirical prediction tool for checking hydraulic modeling results, especially whether stage or velocity are reasonable. Massive USGS stream flow data is available.
0-6671	Synthesis of Hydrologic and Hydraulic Impacts	Hatim Sharif	UTSA	6671-1: (the same as project title)	168	This project synthesizes the impact of design, construction, and maintenance activities on drainage in both urban and rural areas. It can provide regulatory perspective to this project.

Table 1.1: Past relevant TxDOT research projects. Total pages of these documents are 2250. (TAMU-Texas A&M University; TTI-Texas Transportation Institute; TTU-Texas Tech. University; UTSA-University of Texas at San Antonio)

1.2.8 Relevant NCHRP research projects

At the national level, research projects over the past several decades have been done through the the National Cooperative Highway Research Program (NCHRP). NCHRP is administered by the Transportation Research Board (TRB) and sponsored by the member state departments, in cooperation with the Federal Highway Administration (FHWA). The most significant results of these research projects have been documented in their reports, some of which have been used as guidelines by individual state Department of Transportation. We have identified these projects and reviewed their reports, notably the three document series HEC-18, HEC-20, and HEC-23. A brief summary of these reports are listed in Table 1.2. It is clear that tremendous efforts have been devoted to this topic due to its significance. As a results, the volume of the literature keeps expanding. For the documents we reviewed, they have a total pages of 4852, which is probably overwhelming for engineers in practice.

1.3 Channel form and stability without regard to road crossings

1.3.1 The concepts of channel grade and river competence

Rivers are inherently dynamic entities that self organize in response to imposed tectonic and climatic forces. The concept of a river at "grade" formally put forward by (Mackin, 1948) is useful for building a framework to understand the trajectory of a river with time in response to the imposed boundary conditions. The grade concept simply states that a river reach will modify its slope, through vertical aggradation or degradation and/or lateral change, in such a way as to transport all of the imposed sediment at a given water discharge. This idea was built upon by Lane (1955) who parameterized the concept of a stream at grade as having,

$$QS \propto Q_b d \tag{1.1}$$

where Q is volumetric water discharge, S is the channel slope at grade, Q_b is the total bed material sediment load (bed load + suspended load), and d is the characteristic sediment grain size. Such a relationship would indicate that if, for example, slope increased due to tectonic uplift, then either or both the sediment load and size would need to increase at the given water discharge to produce a stream at an equilibrium grade. Or, if sediment load increases but discharge stays constant, the stream would respond by steepening its slope with time (Figure 1.5). In the transition from one

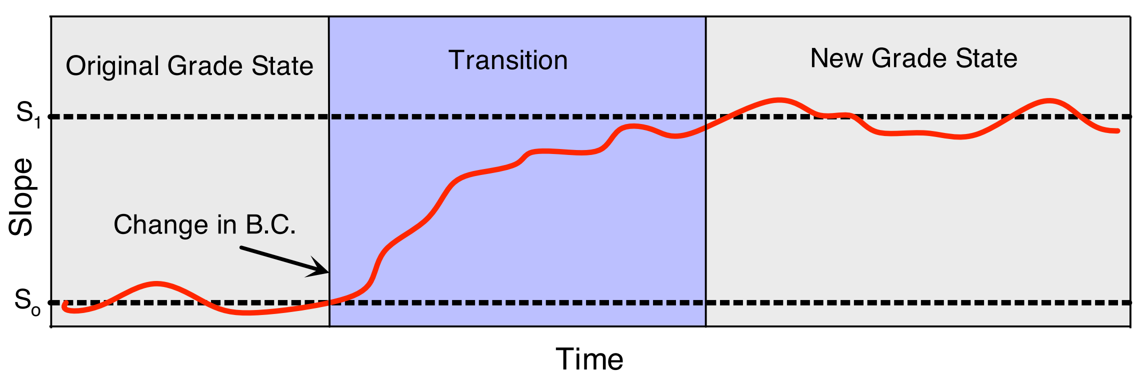


Figure 1.5: Schematic example of a channel adjusting its slope from S_o to S_1 in response to a change in bed material load, Q_b.

equilibrium state to another, a channel will adjust to the new conditions until the channel comes

Year	Project Title	PIs	Leading Institution	Report(s)	Pages	Major findings and Useful Information
1980	Methods for assessment of stream-related hazards to highways and bridges	H.W. Shen et al.	Colorado State University	FHWA-RD-80-160	252	It provided a procedure for the determination of stream-related hazards including evaluation techniques for geologic, geomorphic, and geographic stream characteristics.
1981	Stability of relocated stream channels	J.C. Brice	USGS	FHWA-RD-80-158	184	This report gathered data to documetn the stability of streams at 103 sites in different regions of the United States where stream channels were relocated for the purposes of highway construction indicate varied responses. It has only one site in Texas: Gills Branch at SR-21 at Bastrop, TX.
1984	Design of Spur-type Streambank Stabilization Structures	S.A. Brown	Sutron Corporation	FHWA-RD-84-101	106	It reported spur-type streambank stabilization structures and design guidelines. The recommendations and findings are based on a thorough review of pertinent literature, analysis of several hundred field sites, and on recent laboratory experiments.
1989	Design of riprap revetment	S.A. Brown and E.S. Clyde	Sutron Corporation	FHWA IP HEC-11	169	The revised manual includes discussions on recognizing erosion potential, erosion mechanisms and riprap failure modes, riprap types including rock riprap, rubble riprap, gabions, preformed blocks, grouted rock, and paved linings. Design concepts included are: design discharge, flow types, channel geometry, flow resistance, extent of protection, and toe depth.
1990	Highways in the River Environment	E.V. Richardson, et al.	N/A	FHWA-HI-90-016	683	This is a major revision of the 1975 manual. It incorporates technological advances since 1975 to 1989 related to lateral bank erosion, degradation and aggradation of river bed, and short time fluctuation of stream bed.
2001	Evaluating Scour At Bridges	E.V. Richardson and S.R. Davis	Ayres Associates	FHWA NHI HEC-18	378	It is a major documentation on the knowledge and practice for the design, evaluation and inspection of bridges for scour. We review the latest version (the fourth edition).
2001	Stream stability at Highway Structures	P.F. Lagasse et al.	Ayres Associates	FHWA NHI HEC-20	258	This document provides guidelines for identifying stream instability problems at highway stream crossings. It covers geomorphic and hydraulic factors that affect stream stability and provides a step-by-step analysis procedure for evaluation of stream stability problems. This is the most relevant document identified for the current project.
2001	River engineering for highway encroachments, Highways in the river environment	E.V. Richardson et al.	Ayres Associates	FHWA NHI HDS 6	644	This document is an authoritative document for hydraulics problems at stream crossings. Hydraulic principles of rigid and movable boundary channels are discussed.
2002	NCHRP 24-15: Complex Pier Scour and Contraction Scour in Cohesive Soils	Jean-Louis Briaud	Texas A&M University	NCHRP Report 516 Pier and Contraction Scour in Cohesive Soils	136	This is a research project undertaken by one of our co-PIs to investigate bridge scour in cohesive soils. It also recommended method (SRICOS) for predicting the extent of complex pier and contraction scour in cohesive soils.
2002	Development of Hydraulic Computer Models to Analyze Tidal and Coastal Stream Hydraulic Conditions at Highway Structures	L.W. Zevenbergen, et al.	Ayres Associates, Edge & Associates, Inc	FHWA-SC-02-03	39	This project focused on evaluating computer models to determine which models were well suited for simulating unsteady tidal flow conditions at bridges for the purpose of scour prediction.
2003	Bridge Scour in Nonuniform Sediment Mixtures and in Cohesive Materials: Synthesis Report	N/A	Colorado State University	FHWA-RD-03-083	121	It summarized the experimental study entitled "Effects of Gradation and Cohesion on Bridge Scour" conducted at Colorado State University between the dates 1991 through 1996. It collected new data sets for pier and abutment scour. It also considered the effect of cohesion.
2003	Methodology for Predicting Channel Migration	P.F. Lagasse et al.	Ayres Associates	NCHRP 24-16 Final Report: Methodology for Predicting Channel Migration; NCHRP Report 533	321	This study was to develop a practical methodology to predict the rate and extent of channel planform migration in proximity to transportation facilities. The principal product of this research was a stand-alone Handbook (NCHRP Report 533) for predicting stream meander migration using aerial photographs and maps. It also produced a 4-CD data set.
2004	Tidal Hydrology, Hydraulics, and Scour at Bridges	L.W. Zevenbergen et al.	Ayres Associates	FHWA NHI HEC-25	168	It provides guidance on hydraulic modeling for bridges over tidal waterways. Though it is not in the scope of our project, it provides some useful information, such as common physical features in coastal areas.
2005	Debris Control Structures Evaluation and Countermeasures	J.B. Bradley, et al.	WEST Consultants, Inc	FHWA NHI HEC-9	179	This report presents various problems associated with debris accumulation at culvert and bridge structures, provides a procedure for estimating the potential of debris accumulating, and provides general guidelines for analyzing and modeling. Various types of debris countermeasures for culvert and bridge structures are discussed.
2006	Assessing Stream Channel Stability At Bridges in Physiographic Regions	Peggy A. Johnson	Penn. State University	FHWA-HRT-05-072	157	This project expanded and improved a rapid channel stability assessment method developed previously by Johnson et al. to include additional factors, such as major physiographic units across the United States.
2009	Bridge scour and stream instability countermeasures	P.F. Lagasse et al.	Ayres Associates	FHWA NHI HEC-23 (two volumes)	632	HEC-23 identifies and provides design guidelines for bridge scour and stream instability countermeasures that have been implemented by various State departments of transportation (DOTs) in the United States.
2010	NCHRP 24-15 (2): Abutment Scour in Cohesive Materials	Jean-Louis Briaud	Texas A&M University	NCHRP REPORT 24-15 (2): Abutment scour in cohesive materials	425	It proposed a new approach for calculating the depth of the scour hole near an abutment and in the main channel constructed on a soil characterized by EFA curves or equivalent and subjected to a hydrograph.

Table 1.2: Major references, project reports, guidelines, and other documents reviewed. Total pages of these documents are 4852.

into a new dynamic equilibrium about the graded state where, on average, there is neither net degradation or aggradation in the channel (Figure 1.5).

Church (2006) proposed a very useful modification to Lane's balance (Eq. 1.1) by introducing the flow depth, h, to the set of parameters in the balance and recasting the relationship in dimensionless form as,

$$\frac{Q}{Q_b} \propto \frac{hS}{d} \tag{1.2}$$

In this form, both sides of the equation are dimensionless, and the right-hand side contains the core components of the well know dimensionless Shields parameter,

$$\tau^* = \frac{\tau_B}{\rho g R_s d} \tag{1.3}$$

where τ_B is the bed shear stress, equal to $\tau_B = \rho g h S$ for uniform flow in a wide channel, g is the acceleration of gravity, and $R_s = (\rho_s - \rho)/\rho$ is the submerged specific gravity of the sediment. The Shields parameter is a very useful dimensionless variable as it describes the competence of a flow to move a given size of sediment. For uniform flow in a wide channel, it is evident then that the right-hand side of equation 1.2 is $\tau^* R_s$. Therefore, the relation of Church (2006) says that the ratio of water to sediment discharge is proportional to τ^*, or in words, the competence of the flow to move sediment of grain size d.

$$\frac{Q}{Q_b} \propto \frac{hS}{d} \propto \tau^* \tag{1.4}$$

Eaton and Church (2011) built upon the rational form of Lane's relation (Eq. 1.4), by using a resistance equation and a bed load transport equation to show that the proportionality relation could be expressed functionally as,

$$\frac{Q}{Q_b} = a^{-1} \left[\frac{d}{h}\right]^{1+b} F(\tau^*) \tag{1.5}$$

where a and b are coefficients in the power-law resistance equation (Ferguson, 2007),

$$R_f = \frac{U}{u_*} = a \left[\frac{h}{d}\right]^b \tag{1.6}$$

and $F(\tau^*)$ is a dimensionless bed load equation expressed as a function of τ^* and the critical τ^* value, τ^*_{cr}, at which sediment starts to move ($\tau^*_{cr} = 0.045$). This new expression of the rational balance relation at grade shows that Q/Q_b is both a function of τ^* and the relative submergence, h/d.

Eaton and Church (2011) also examined the functionality of the ratio $Q_b/(QS)$, which they described as a sediment efficiency parameter, in describing the grade state. They found that the ratio was far less dependent on the relative submergence compared to equation 1.5 for a constant critical stress value, and they suggested that a physically meaningful grade relation based on resistance relations and measured sediment transport rate can is given by,

$$\frac{Q_b}{QS} \propto \left[\frac{hS}{d\tau^*_{cr}}\right]^{(3/2)x_1} \tag{1.7}$$

where x_1 is a coefficient obtained by a fit function to measured bed material transport data expressed in terms of a new dimensionless variable, E^*, and the dimensionless unit width stream power, $\omega^* = R_f \tau^{*3/2}$, in relation to a critical dimensionless unit width stream power, ω_o^*,

$$x_1 = 4.28/[\log(\omega^*/\omega_o^*) + 1.54]^{2.41} \tag{1.8}$$

From equation 1.8, it can be seen that x_1 will be large near threshold conditions ($\omega^* \sim \omega_o^*$) and will tend towards zero for high competence flows ($\omega^* \gg \omega_o^*$). In the Eaton and Church (2011) derivation, the dimensionless variable E^* is the sediment efficiency parameter, $E^* = R_s Q_b/(QS)$, and dimensionless stream power is used as a measure of stream competence over dimensionless bed shear stress so that a truly constant transport efficiency can be maintained. In equation 1.8, the critical stream power, ω_o^*, is related to the critical dimensionless shear stress and resistance factor R_f (Eq. 1.6), as $\omega_o^* = R_f \tau_{cr}^{*3/2}$.

Equation 1.7 represents the most physically grounded proportionality for defining the relationship between flow discharge, sediment load, slope, channel depth, grain size, and the Shields number for the bed. Such a relation can be used to estimate the response of a reach to changes in sediment load, Q_b, flow discharge, Q, or modifications in channel slope. Eaton and Church (2011) point out that the functionality in the grade relationship is different for near threshold streams (typically gravel bed rivers) than it is for streams whose competence is well beyond the threshold condition (typically sand bed rivers with cohesive banks an vegetation). This is due to the x_1 power (Eq. 1.8). For high competence streams ($\omega^* \gg \omega_o^*$), $x_1 \to 0$ and the grade relation becomes,

$$Q_b \propto QS \tag{1.9}$$

Therefore, a unit increase in discharge, say due to urbanization, would cause a unit increase in the bed material transport irrespective of the sediment grain size or the exact value of the threshold condition. However, in a near threshold channel, an increase in the grain size or threshold condition due to surface layer structuring (Church et al., 1998; Strom et al., 2004) could off set the increase in flow rate without much degradation or increase in sediment discharge. A much more thorough discussion on how streams near the threshold condition might respond is give in the discussion of Eaton and Church (2011).

1.3.2 Channel form and dynamics at equilibrium grade states

Based on the preceding discussion, it can be concluded that rivers far from their graded state are highly susceptible to change and will have higher rates of channel alteration, thereby making them more unstable. However, even at grade, rivers remain dynamic and can significantly migrate or alter their form without moving far from their graded slope. The propensity to do so is linked with the planform morphology of the river. This connection exists because the river morphology is an outcome of the frequency and mode of sediment erosion, transport, and deposition along with riparian vegetation dynamics.

Following this reasoning, the stability of a river near its graded state should be a strong function of the sediment delivered to the system and the competency of the river to move the sediment

(Schumm and Khan, 1972; Schumm, 1985; Church, 2006). Several figures depicting this concept have been developed. Schumm (1985) presented channel pattern type and the relative stability of a river as a function of bed material transport mode (bed, suspended, or mixed load), channel velocity, grain size, and slope. The most up-to-date and comprehensive figure relating channel stability and morphology with sediment load, grain size, and channel slope is that of Church (2006) which builds on much of the earlier work (Figure 1.6). In Figure 1.6, gravel bed channels along with the classic sand bed states are shown. While figures such as these are relative, they do help to give context for what river planform morphologies are more susceptible to higher rates of channel boundary deformation and how a system might respond if one of the variables such as slope, sediment loading, or grain size are altered.

Several authors have noted that channel morphology and bed state should be linked strongly to the competence of the flow, τ^*, and the bed material transport mode. To examine this link, the flow competence from a range of river morphology types have been plotted in Shields space (τ^* versus $Re_p = du_*/\nu$) by several authors such as Dade and Friend (1998), García (1999), Church (2006), as well as Gary Parker in unpublished work from the 1980's (García, 2008). Often a line demarcating suspended and bed load using the ratio of the settling and shear velocities is also plotted to aid in interpreting the data (García, 1999). The upshot of this analysis is that the data for most rivers clusters around three basic types of channels that correspond with the three basic modes of bed material movement at bankfull flow (Figure 1.7). The three channel types are referred to as Threshold channels ($\tau^* = O[0.1]$), Transitional channels ($O[0.1] < \tau^* < O[1]$), and Labile channels ($\tau^* > O[1]$) by Church (2006). The three channel types mostly correspond with the transport modes of bed, mixed, and suspended load respectively.

In the Church (2006) definitions, threshold channels are streams which only exceed the critical stress condition for sediment motion by a factor of 2 to 3 at bankfull flow, are dominated by partial bed load transport, and are associated with gravel bed streams. Labile channels are channels for which the flow rates at bankfull can easily suspend the bed material and re-work the river bed. Transitional channels live between the two and have a strong proportion of both bed and suspended load. Of the three types, Church (2006) identifies the transitional channels as being the most unstable, being able to nearly fully mobilize the bed material while still transporting a significant fraction as bed load. This leads to rapid change which can come in the form of bend migration, bar building, or braiding. Transition channels are often the main truck stream of a gravel bed river with moderate gradients and larger sediment supplies coming from steeper tributary streams (Church, 2006). In comparison, threshold channels do not often mobilize the majority of the bed material. This, along with variation in grain size and structural organization in the bed, often keep the beds for high rates of change. Labile channels can easily mobilize their bed sediments, but much of the fine clays and silts escape to the floodplain where vegetation colonizes and enforces the stability of the banks. Using these three channel definitions and then further discriminating alluvial form and stability by channel competence, τ^*, Church (2006) produced at table of alluvial river form, grain size, transport characteristics, and channel stability (Table 1.3). Figure 1.8 shows some examples of different channel types as they roughly correspond to the categories found in Table 1.3.

The spatial patterning of vegetation is largely controlled by hydrologic conditions (Gurnell et al., 2012), and as would be expected the vegetation plays a very important role in channel stability. Left

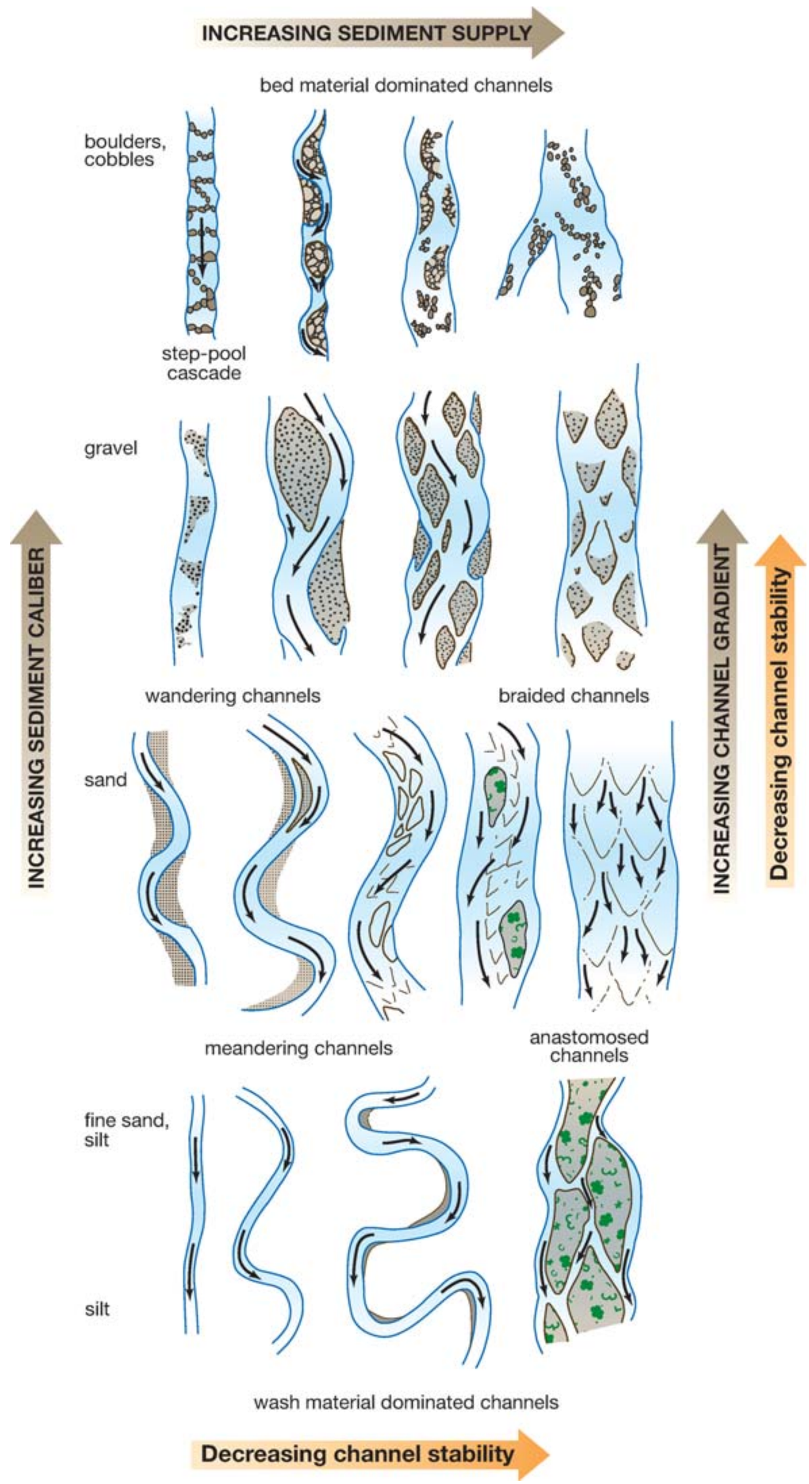


Figure 1.6: Alluvial river planform pattern diagram from Church (2006). Channel form is given as a function of sediment supply, sediment size, and channel slope. The relative stability of each channel type is also shown.

Type/characteristic Shields number	Sediment type	Sediment transport regime	Channel morphology	Channel stability
Jammed channel 0.04+	Cobble- or boulder-gravel	**Bed load dominated**; low total transport, but subject to debris flow	Step-pools or boulder cascades; width typically a low multiple of largest boulder size; $S > 3^{\circ}$	Stable for long periods with throughput of bed load finer than structure-forming clasts; subject to catastrophic destabilization in debris flows
Threshold channel 0.04+	Cobble-gravel	**Bed load dominated**; low total transport in partial transport regime; bed load may actually be less than 10% of total load	Cobble-gravel channel bed; single thread or wandering; highly structured bed; relatively steep; low sinuosity; w/d > 20, except in headwater boulder channels	Relatively stable for extended periods, but subject to major floods causing lateral channel instability and avulsion; may exhibit serially reoccupied secondary channels
Threshold channel up to 0.15	Sandy-gravel to cobble-gravel	**Bed load dominated**, but **possibly high suspension load**; partial transport to full mobility; bed load typically 1%–10% of total load	Gravel to sandy-gravel; single thread to braided; limited, local bed structure; complex bar development by lateral accretion; moderately steep; low sinuosity; w/d very high (>40)	Subject to avulsion and frequent channel shifting; braid-form channels may be highly unstable, both laterally and vertically; single-thread channels subject to chute cutoffs at bends; deep scour possible at sharp bends
Transitional channel 0.15–1.0	Sand to fine-gravel	**Mixed load**; high proportion moves in suspension; full mobility with sandy bedforms	Mainly single-thread, irregularly sinuous to meandered; lateral/point bar development by lateral and vertical accretion; levees present; moderate gradient; sinuosity <2; w/d < 40	Single-thread channels, irregular lateral instability or progressive meanders; braided channels laterally unstable; degrading channels exhibit both scour and channel widening
Labile channel >1.0	Sandy channel bed, fine-sand to silt banks	**Suspension dominated** with sandy bedforms, but possibly significant bedload moving in the bedforms	Single thread, meandered with point bar development; significant levees; low gradient; sinuosity >1.5; w/d < 20; serpentine meanders with cutoffs	Single-thread, highly sinuous channel; loop progression and extension with cutoffs; anastomosis possible, islands are defended by vegetation; vertical accretion in the floodplain; vertical degradation in channel
Labile channel up to 10	Silt to sandy channel bed, silty to clay-silt banks	**Suspension dominated**; minor bedform development; minor bed load	Single-thread or anastomosed channels; prominent levees; very low gradient; sinuosity > 1.5; w/d < 15 in individual channels	Single-thread or anastomosed channels; common in deltas and inland basins; extensive wetlands and floodplain lakes; vertical accretion in floodplain; slow or no lateral movement of individual channels

Table 1.3: Alluvial river classification scheme. Reproduced from Church (2006).

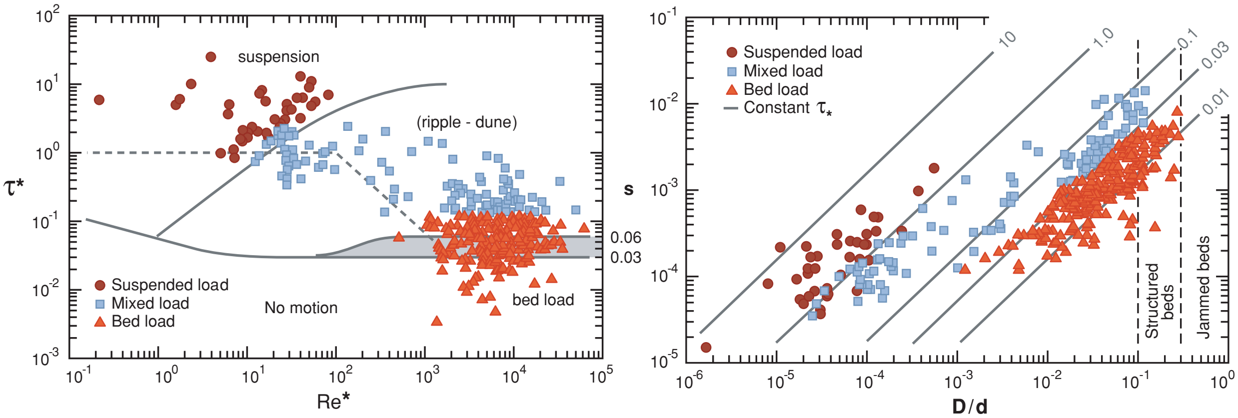


Figure 1.7: Figures from Church (2006) depicting transport mode and channel type as a function of key sediment transport variables.

unconfined, alluvial rivers will general tend towards a braided state (Gran and Paola, 2001; Tal and Paola, 2010; Gurnell et al., 2012). Therefore, without the presence of bedrock or highly consolidated and cohesive soils, vegetation is the main confining and stabilizing control acting on rivers and keeping them from widening and becoming braided. Vegetation plays three roles in stabilizing a river. First, it provides added cohesion through root stabilization of the soil. Second, it reduces shear felt on the river banks and floodplains by increasing resistance and reducing momentum transfer from the core of the flow to the boundary. And thirdly, the addition of plants reduces velocity on the floodplains during flood flow and enhances deposition of sediment in the separated wake regions around the plant stems. Gurnell et al. (2012) presents an excellent review of the interconnected nature of river dynamics and vegetation.

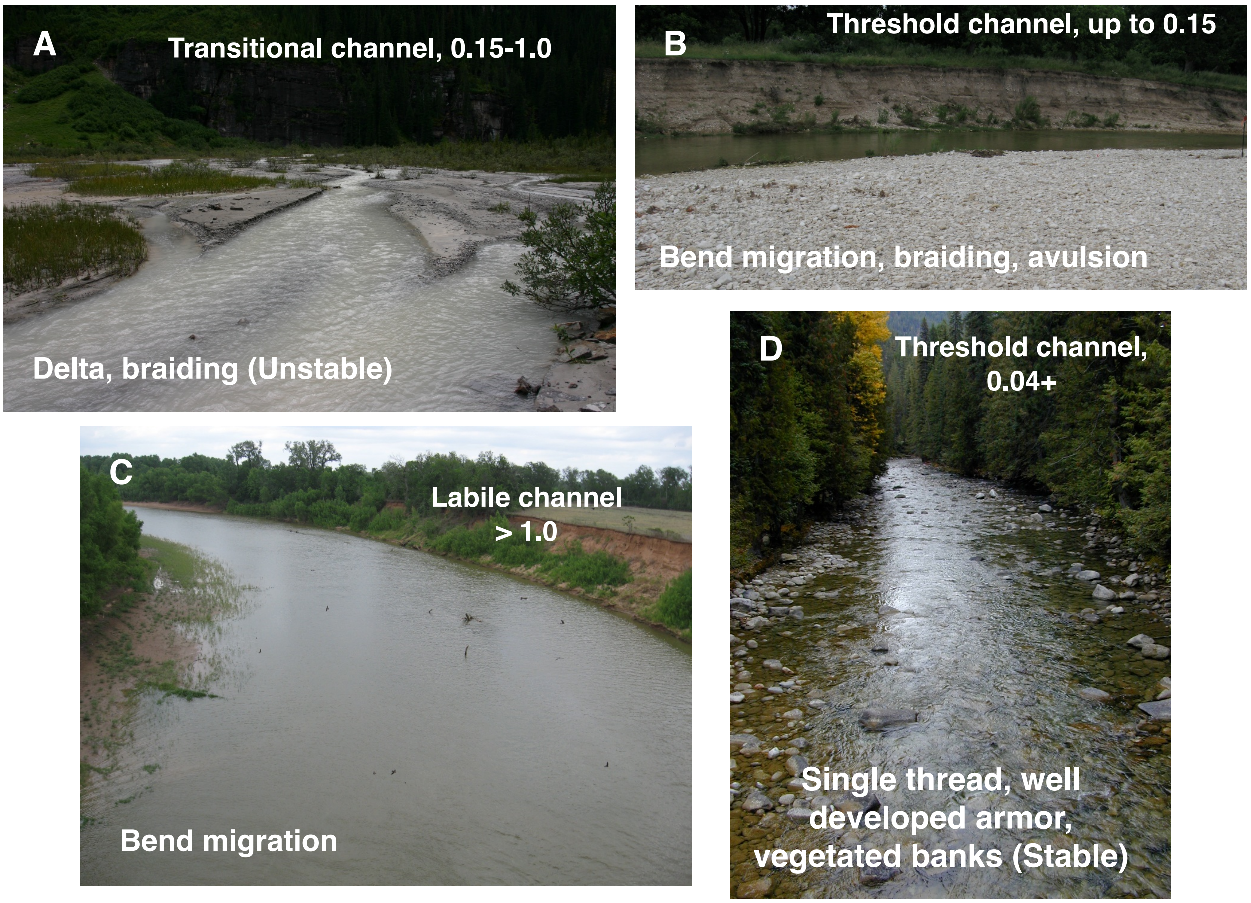


Figure 1.8: Examples of different channel types. (A) a glacial-fed alpine lake delta, Alberta, CA; (B) a high sediment yield flash-flood prone gravel-bed river, North Llano River, TX; (C) a single-thread lowland meandering river, Brazos River from Highway 290 near Hempstead, TX; (D) gravel to boulder plane-bed mountain reach, Entiat River, WA.

1.3.3 Changing boundary conditions

We now come to the question of how regional changes in land use, climate, or other boundary conditions may impact the stability of a reach.

Systematic changes in climate can affect river stability by changing the amount of flow delivered to a reach. According to equation 1.7, an increase in discharge would lead to channel erosion in an attempt to lower the slope in a labile or transitional channel, and could lead to a reduction in slope or coarsening of the surface layer in a threshold channel. Overall, these would lead towards a destabilization of the river, though there could, in some instances be a counteracting stabilizing force from increased vegetation if vegetation in the region was previously hampered by lack of water. Conversely, a decrease in rain could cause a reduction in flow but possible destabilization of banks due to increased sediment loading and decreases in vegetation. While these climate changes could be be important over long time periods, they are likely not to be of first-order importance when dealing with the stability of Texas streams in general at the present. However, a seasonal climate impact on stream stability could come from the role that reservoir levels play in setting the downstream boundary condition for upstream channels. Lack of rain and the resulting low-water levels in reservoirs could lead to a lowering of the downstream baselevel and an associated degradation in channels feeding the reservoir due to the effective steeping of the reach.

Human activities in a watershed can effect river stability in several ways (Leopold et al., 1964; Gregory and Brookes, 1983; Gregory, 2006; García, 2008). The majority of the human induced impacts on river systems essentially result in alterations to the amount of water or sediment delivered to stream. Although, some engineering measures also include direct reach alteration through channel straightening and/or lining of a reach with concrete.

Land use changes such as urbanization, deforestation, and agricultural development can alter the amount of water and sediment being delivered to the system (Bledsoe and Watson, 2001). Urbanization creates impervious surfaces that lead to increased runoff (discharge) while at the same time reducing sediment yield to a stream. The increase in flow and reduction in sediment yield combine to result in channel incision (Shields et al., 2010). Deforestation, or an increase in agricultural land use, can also lead to an increase in sediment load to streams, could result in deposition within affected downstream reaches and widening or shifting of morphologic states.

Dam construction can effectively shut off the upstream sediment supply and modify the flood frequency, duration, and magnitude to downstream reaches. This can result in channel degradation and coarsening of the surface layer with time downstream of the dam (Leopold et al., 1964). However, degradation does not always occur downstream of dams. In some cases, the attenuation of the flood peaks can lead to an overall reduction in the capacity of a stream to move the sediment already in the reach, essentially locking the coarse sediment in place (Kellerhals and Gill, 1973; García, 2008). Additional channel alterations due to dam installation and operation can occur on reaches upstream of dammed reservoirs. As channel baselevel increases, reaches impacted by backwater will aggrade (Leopold et al., 1964), and near the reservoir a unstable delta can develop.

Other human activities that may impact channel stability include gravel and sand mining, channel straightening, and channel bank lining. Gravel mining from rivers can have an effect similar to the installation of a dam by removing the sediment supplied to a reach. The resulting channel instability is one of degradation (Galay, 1983; García, 2008). Channel straightening is common in agricultural or urban settings (Shields et al., 2010). Straightening the channel results in a rapid increase in channel slope that pushes the channel far from its grade state and results in vertical incision, lateral widening, and an overall reduction in the channels geomorphic and ecologic health (Shields et al., 2010).

1.4 Channel stability assessment methods

1.4.1 Overview of federal and state Guidelines

Guidelines suggested by FHWA

FHWA currently has a series of publications dealing with stream instability and bridge scour problems: (1) HEC-18 "Evaluating scour at bridges", (2) HEC-20 "Stream stability at highway structures", (3) HDS-6 "Highways in the river environment", (4) HEC-11 "Design of riprap revetment", (5) HEC-23 "Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance". The three-document set, HEC-18, HEC-20 and HEC-23, has been recommended to be used in combination to do a comprehensive stability evaluation. A flow chart for scour and stream stability analysis has been provided and is plotted in Figure 1.9.

For channel stability assessment, the most notable guidelines are located in HEC-20, where a three-level analysis procedure is suggested: (1) Level 1-simple geomorphic concepts and other qualitative analysis; (2) Level 2-application of basic hydrologic, hydraulic and sediment transport engineering concepts; (3) Level 3-application of mathematical or physical modeling studies. It also outlines what data is needed for each level of analysis. In Chapter 10 of HDS-6, several examples for highway designs using the three-level assessment method are demonstrated.

For most of the channel stability evaluations, detailed hydrologic and hydraulic analysis needs to be developed. The procedures and data requirement have been documented in HEC-18. In this guideline, there is a special part named "Scour Analysis" which presents a seven-step specific design approach where each component of total scour is evaluated.

These FHWA documents also have detailed guidelines and design procedures for many standard countermeasures such as impermeable and permeable spur dikes, guide banks, and riprap for abutments, piers, and revetment. In HEC-23, a countermeasure matrix summarizing a variety of countermeasures used by different state Department of Transportation is provided. This matrix lists the distinctive characteristics of each countermeasure and groups them based on their functional applicability to a particular instability problem.

Over the years, the federal highway administration has accumulated dozens of documents on erosion and channel stability problems. Though very lengthy, they provide a good source of informa-

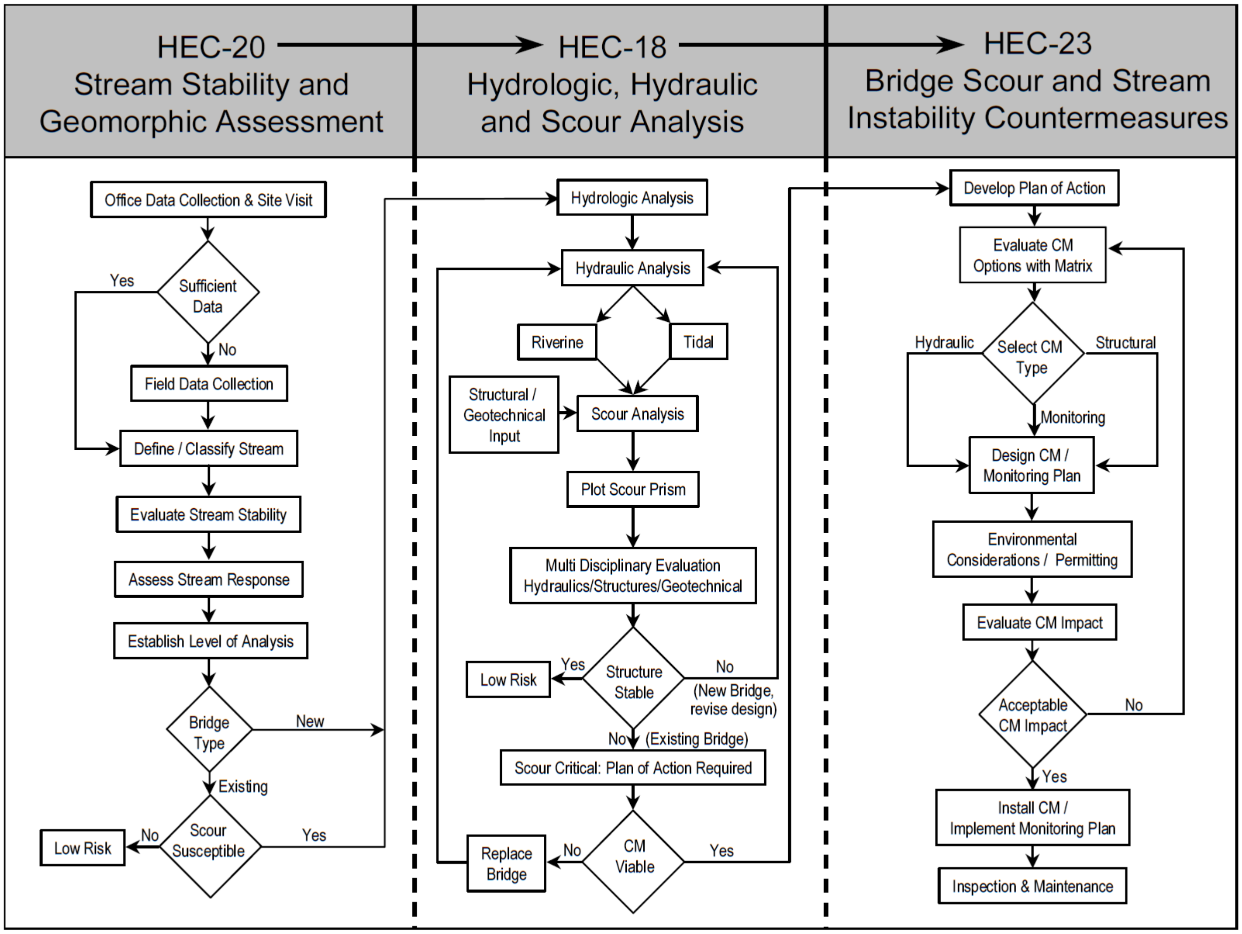


Figure 1.9: Flow chart for scour and stream stability analysis using HEC-18, HEC-20, and HEC-23

tion.

Current evaluation guidelines used by TxDOT

The research team also examined current TxDOT Hydraulic Design Manual (March 2009 edition) and found that relevant parts on channel stability are scattered over several sections. Most of them are very brief and descriptive in nature. In some cases, critical steps for evaluation are missing.

In Chapter 7-"Channels", the manual has one section focusing on channel stability:

- In Section 4 for "Stream Stability Issues", it states "An analysis of the tolerance to change may reveal that necessary channel modifications will not have detrimental results. If you recognize detrimental effects, develop plans to mitigate the effects ." As for how to recognize and determine the detrimental effects, the manual is very brief by providing a three-step procedure (see page 7-20 of the Hydraulic Design Manual). Each step is described in just one sentence. For instance, the second step is "Determine thresholds for changes in the various regime parameters". The details of how to determine the thresholds are missing. No further reference is given.

- On pages 7-23 to 7-24 of the manual, to countermeasure the threats on approach roadways and bridge foundations by meandering rivers, the manual gives the following recommendations on countermeasures: bridge lengthening, bridge relocation, river training (erosion control), linear structures such as spur dikes to alter flow direction and protect the bank. Readers are directed to FHWA/RD-84/101 and HEC-20 for the detailed design considerations, guidelines, and procedures for channel stabilization and meander countermeasures.

In Chapter 9-"Bridges", the manual has two dedicated sections:

- In Section 6 for "Bridge Scour", the three major scour components are outlined: natural scour (due to regional channel stability and degradation), contraction scour, and local scour. For the latter two, it suggested detailed formulas and procedures to calculate the scour depth. But that is not the case for natural scour. The statement in the manual, "Generally, projections based an evaluation of the history of the site or ones similar to the site may suffice", turns out to not sufficient for TxDOT engineers.
- In Section 7 for "Flood Damage Prevention", the potential response of alluvial streams to floods, including scour and regional channel change, is discussed. This section also gives general suggestions on how to protect roadway structures, such as bridge pier, embankment and abutment. However, for bank stabilization and river training devices, the manual only gives general guidelines and refers the engineers to HEC-20 and HEC-23 for details.

Based on the current status of the Hydraulic Design Manual, there is a need to enrich some relevant parts and make additions if necessary. That is the main objective of this project.

1.4.2 Current state of knowledge on river stability assessment with respect to road crossings

HEC-20 and Johnson et al. (1999)

Because rivers change with time, both at their dynamic equilibrium condition and when responding to boundary conditions changes that have pushed the system from a graded state, some method for assessing the stability of the river at roadway crossings is need for planning and maintenance purposes. The goal of Hydraulic Engineering Circular (HEC) number 20 (Lagasse et al., 2001) was to provide a set of guidelines for doing just that. Lagasse et al. (2001) states that, "The purpose of this document is to provide guidelines for identifying stream instability problems at highway-stream crossings. Techniques for stream channel classification and reconnaissance, as well as rapid assessment methods for channel instability are summarized." Below, a brief review of what is presented in HEC-20 as it pertains to assessing channel stability is given.

Based on the U.S. Army Corps of Engineers (1994) recommendations, Lagasse et al. (2001) (HEC-20) adopted the following three level approach for assessing channel stability:

Level 1: Application of Simple Geomorphic Concepts and other Qualitative Analyses.

Step 1: Stream characterization

Step 2: Land use changes

Step 3: Overall stability

Step 4: Lateral stability

Step 5: Vertical stability

Step 6: Stream response

Level 2: Application of Basic Hydrologic, Hydraulic and Sediment Transport Engineering Concepts.

Level 3: Application of Mathematical or Physical Modeling Studies.

Note that the intermediate steps in the Level 1 analysis have been included; a flow chart for the Level 1 analysis is shown in Figure 1.10. The Level 1 analysis deals with the more regionalized factors impacting stream stability. Details on the Level 1 analysis are found in chapter 4 of Lagasse et al. (2001).

The first step of the Level 1 analysis is to characterize the stream using geomorphic classifications based on a field visit, maps, and satellite data. Many charts and tables are presented throughout the manual to aid with this classification, and the stream reconnaissance forms developed by Thorne (1998) are advocated for use during field reconnaissance trips. Step-by-step forms along with additional information following the Thorne (1998) methodology of characterization are given in section 4.2.1 of the Lagasse et al. (2001) to help with the classification.

The second step of the Level 1 analysis is to assess the land use and land use changes by gathering data from Federal, State and Local government documents and again examining remotely sensed data such as aerial photos. Items outlined to look for include urbanization and changes in vegetation cover due to urbanization, logging, fire, etc..

Step 3 is the assessment of the overall stream stability by classifying it using geomorphic qualitative relationships such as those found in figure 1.6 and table 1.3. The actual figures presented in Lagasse et al. (2001) predate those found in Church (2006), but the concepts are similar.

Step 4 includes an assessment of lateral channel stability. The manual outlines various bank failure modes in the text and in appendix B. A site visit is deemed necessary for this step of the analysis and it is suggested that present day information at the site should be used in conjunction with historic river bank positions to help assess where or not the banks are stable. A designation of stable or unstable as it relates to Step 4 in the flow chart (Figure 1.10) is given in Lagasse et al. (2001) and cited below directly from the manual on pages 2.12 and 2.13, as follows:

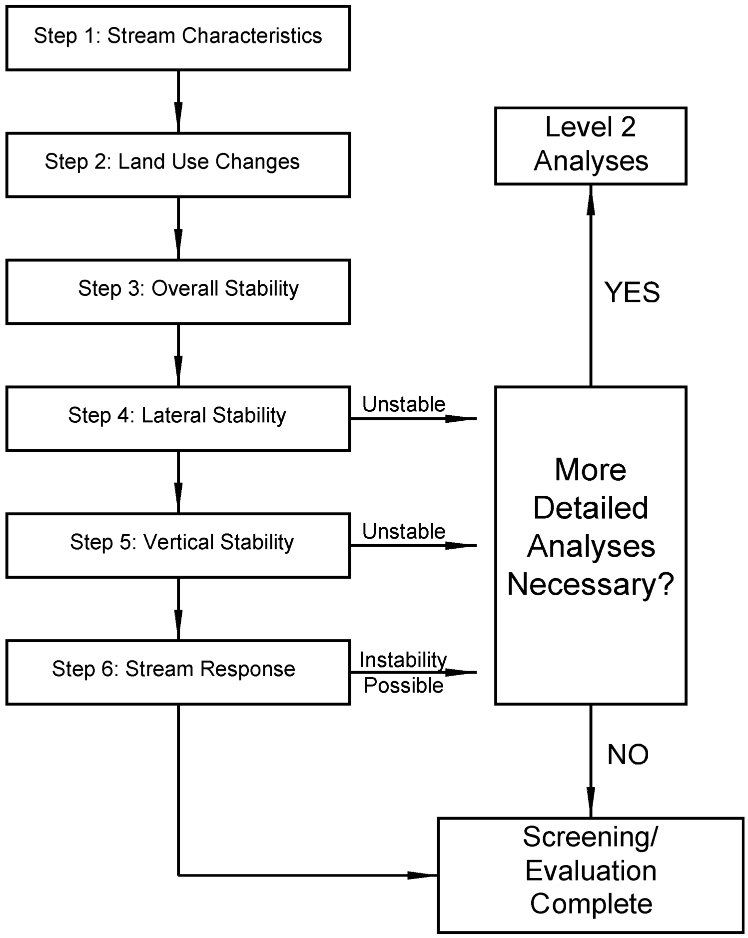


Figure 1.10: Flow chart for the Level 1 analysis from Lagasse et al. (2001).

- **Unstable** banks with moderate to high erosion rates usually have slopes which exceed 30 percent, and a cover of woody vegetation is rarely present. At a bend, the point bar opposite an unstable cut bank is likely to be bare at normal stage, but it may be covered with annual vegetation and low woody vegetation, especially willows. Where very rapid erosion is occurring, the bank may have irregular indentations. Fissures, which represent the boundaries of actual or potential slump blocks along the bank line indicate the potential for very rapid bank erosion.

- **Unstable** banks with slow to moderate erosion rates may be partly reshaped to a stable slope. The degree of instability is difficult to assess, and reliance is placed mainly on vegetation. The reshaping of a bank typically begins with the accumulation of slumped material at the base such that a slope is formed, and progresses by smoothing of the slope and the establishment of vegetation.

- **Eroding** banks are a source of debris when trees fall as they are undermined. Therefore, debris can be a sign of unstable banks and of great concern due to potential blockage of bridge openings.

- **Stable** banks with very slow erosion rates tend to be graded to a smooth slope of less than about 30 percent. Mature trees on a graded bank slope are convincing evidence of bank stability. In most regions of the United States, the upper parts of stable banks are vegetated, but the lower part may be bare at normal stage, depending on bank height and flow regime of the stream. Where banks are low, dense vegetation may extend to the water0s edge at normal stage. Where banks are high, occasional slumps may occur on even the most stable graded banks. Shallow mountain streams that transport coarse bed sediment tend to have stable banks.

The purpose of Step 5 is to assess vertical stability of the channel. The HEC-20 manual states that there can be problems associated with either degradation or aggradation, but the manual does not state explicitly how to assess whether or not a stream is degrading or aggrading other than stating that one should examine historic data on stream bed elevation profiles with time and examine long-term trends in the stage discharge relationships. This information is likely very limited for most streams.

The goal of Step 6 in the assessment is to take the information gained from Steps 1 through 5 and then consider how the stream might respond to changes using reason and geomorphic principles. The use of relationships such as Lane's balance (Eq. 1.1) are also suggested. Section 4.4 of the HEC-20 manual gives some examples of ways in which a qualitative evaluation of the channel system to changing boundary conditions can be made using Lane's relationship and a general knowledge of channel form and stability similar to what was presented above in section 1.3 of this review.

All of the above steps in the Level 1 analysis are qualitative and subjective. At the end of the analysis, one still has to make a judgement as to whether or not the stability of the channel warrants further Level-2 type quantitative analysis. To aid in making this assessment, the *Rapid Assessment Of Channel Stability* technique developed by Johnson et al. (1999) is included in HEC-20 (Lagasse et al., 2001). The method assesses general geomorphic instability rather than local scour, but stability is judged and defined in relation to roadway structures. Using previous developed metrics, Johnson et al. (1999) decided on a method for assessing stability that makes use of 13 morphologic and hydraulic process indicators that are both quantitative and qualitative. Numerical values are then given to each rating indicator, r_i, based on channel conditions and the indicators is scaled with a weighting factor, w_i, and summed to give an overall, channel integrated stability factor, R.

$$R = \sum_{i=1}^{13} r_i w_i \tag{1.10}$$

Table 1.4 listed the indicators used along with the associated weighting factors. A table is given in Johnson et al. (1999) listing each of the indicator factors and the conditions corresponding to various numeric, r_i, values ranging from 1 to 12 for each, with 1 being very stable 12 being unstable [see table 1 of Johnson et al. (1999)]. From table 1.4, the relative importance of each indicator as a predictor of overall stream stability can be inferred. An overall ranking of Poor ($R \geq 78$), Fair ($55 \leq R < 78$), Good ($32 \leq R < 55$), or Excellent ($R < 32$) channel stability is given to the reach based on the R value.

From the weights (Table 1.4), the most important indicator of stream stability in the Johnson et al. (1999) method is the relative shear stress ratio, τ^*/τ^*_{cr}, which is a measure of how mobile the sediment is at flood flow. This is followed in importance by vegetative bank protection, a bank failure index, bed material consolidation and armoring, angle of flood flow relative to the bridge, distance to meander impact point, and percentage of channel constriction (Johnson et al., 1999).

Stability Indicator, r_i	Weighting factor, w_i
- Shear stress ratios	1.0
- Vegetative bank protection	0.8
- Mass wasting or bank failure	0.8
- Bed material consolidation and armoring	0.8
- High flow angle of approach to bridge	0.8
- Distance from meander impact point	0.8
- Percentage of channel constriction	0.8
- Bank soil texture and coherence	0.6
- Average bank slope angle	0.6
- Bar development	0.6
- Bank cutting	0.4
- Debris jam potential	0.2
- Obstructions, deflectors, and sediment traps	0.2

Table 1.4: The 13 stability indicators of Johnson et al. (1999) ordered by weight.

The advantages of this method as listed by (Johnson et al., 1999) in their conclusions are, (1) that appropriate weight is given to each stability indicator so that parameters such as the relative stress and mass wasting indexes carry more weight than debris jam potential; (2) that all factors, both lateral and vertical stability factors, are integrated together in the stability rating. In this way, no single process dominates the ranking; (3) it is based on quantifiable physical process indicators such as the relative stress ratio and not solely ambiguous descriptors that are hard to quantify and rank; and (4) it uses bridge and culvert variables.

Details on how to use the method can be found in Johnson et al. (1999) and appendix D of Lagasse et al. (2001). Johnson et al. (1999) tested the method for gravel and cobble bed river crossings in Pennsylvania and Maryland. One further benefit of the method is that it can discriminate between likely lateral and vertical instabilities by looking at the subtotaled R value for r_i and w_i values pertaining to lateral or vertical stability. Indicators that relate to lateral stability include: Bank soil texture and coherence, Average bank slope angle, Vegetative bank protection, Bank cutting, Mass wasting or bank failure, Bar development, and Debris jam potential. Indicators over vertical instability include: Bar development, Debris jam potential, Obstructions, deflectors, and sediment traps, Bed material consolidation and armoring, and Shear stress ratios (Johnson et al., 1999).

Since 2001

HEC-20 has not been updated in full since 2001. However, moderate advances over the 2001 methods could be made by incorporating the updated channel classification work summarized in Church (2006) and the newly modified Lane relationship (Eaton and Church, 2011) into the Level 1 analysis. Both of these are summarized in section 1.3 of this review. In addition, the *Rapid Assessment Of Channel Stability* technique of Johnson et al. (1999) included in HEC-20 has been updated to expand the regional application of the method to 13 major physiographic regions in the United States (Johnson, 2005, 2006). Highlights of the modifications made to the method are summarized below.

The main idea of the updated model is similar to that of Johnson et al. (1999) in that it seeks to identify key channel stability indicator parameters that can then be assigned a numeric value and summed to produce an index of channel stability. While the basic premise of the new method is the same as the 1999 method, there are three key differences between the updated and old methods.

The first key difference is that some of the indicator parameters were changed in the updated version. Table 1.5 lists the new parameters used in the Johnson (2005, 2006) work. The parameter changes include, wrapping the *Debris jam potential* and *Obstructions, flow deflectors, and sediment trap* indicators into a single parameter, dropping four parameters (parameters 9, 10, 11, and 13 of Johnson et al. (1999)), and adding in five new parameters. The newly added parameters include indicators 1–5 listed in Table 1.5. Parameter 10 of the original Johnson et al. (1999) method, the shear stress ratio τ^*/τ^*_{cr}, was replaced in the updated method with a new indicator, parameter 5, related to the bed material and the proportion of sand in the bed. Johnson (2005) states that the development of the sand fraction parameter was based on the Wilcock and Crowe (2003) transport function, which predicts bed material transport as a function of sand fraction. While the two measures are not identical, the percentage of sand is likely a reasonable proxy for τ^* (section 1.3 of this review), and the two parameters are both indicators for bed material transport regime. This change in bed material transport parameterization was motivated by the fact that making estimates of τ^* and τ^*_{cr} can be quite difficult and problematic. The other four new indicators were included based in part on the work of Shields (1996), Thorne (1998), and Montgomery and MacDonald (2002). These new indicators are, *Watershed and floodplain activity and characteristics*, *Flow habit*, *Channel pattern*, and *Entrenchment/channel confinement*. In general, the inclusion of these parameters yields a more holistic approach to stream stability by accounting for various watershed-scale properties. *Watershed and floodplain activity and characteristics* accounts for land-use activities that might mediate or alter the amount of sediment and water being delivered to the system. *Flow habit* accounts for differences in river stability as a function of the way in which water is delivered to the system, e.g., perennial or ephemeral and level of flashiness. The *Channel pattern* indicator accounts for the variation in stability that different river patterns have (section 1.3), and the *Entrenchment/channel confinement* parameter accounts for the way in which a river interacts with its floodplain. Inclusions of these four new parameters also helps with making the method applicable over a variety for physiographic and hydrologic regions.

The second key difference between the updated method and the 1999 method, is that the individual

	Stability indicator
1.	*Watershed and floodplain activity and characteristics*
2.	*Flow habit*
3.	*Channel pattern*
4.	*Entrenchment/channel confinement*
5.	*Bed material; Fs = approximate portion of sand in bed*
6.	Bar development
7.	Obstructions, including bedrock outcrops, armor layer, LWD jams, grade control, bridge bed paving, revetments, dikes or vanes, riprap
8.	Bank soil texture and coherence
9.	Bank slope angle (where 90 degrees is a vertical bank)
10.	Vegetative or engineered bank protection
11.	Bank cutting
12.	Mass wasting or bank failure
13.	Upstream distance to bridge from meander impact point and alignment

Table 1.5: New indicator parameters in Johnson (2005, 2006). Indicators listed in italic font are newly added parameters compared to those listed in Johnson et al. (1999) and Lagasse et al. (2001). Values for each indicator can range from 1 (most stable) to 12 (least stable).

factors are not weighted in the summation, i.e., $w_i = 1$ in equation 1.10 for all indicators. The switch to uniform weighting was decided upon after running a series of analysis both with and without the weighting. In doing so, Johnson (2005) concluded that the weights had no influence on the final stability outcome and where therefore dropped.

The third key difference with the original method is that the ultimate summed R index score is given differentiated breaks between Poor, Fair, Good, and Excellent as a function of reach-morphology type (Table 1.6). This was done after an original analysis showed that using total R values undifferentiated by reach type, "provided limited sensitivity to some stream channel classifications and physiographic regions" (Johnson, 2005). To increase the sensitivity of the method, Johnson (2005) broke the R rankings out by reach morphology type using the Montgomery and Buffington (1997) classifications of cascade, step-pool, plane-bed, pool-riffle, and dune-ripple with the addition of the braided state classification. Three reach groupings were then made based on their inherent stability and tendency to adjustment to water and sediment input (Table 1.6). The first grouping consists of pool-riffle, plane-bed, dune-ripple, and engineered channels, and represents the majority of reach types and moderate or normal stability conditions and response to water and sediment loading. The second category, cascades and step-pools reaches, represents high-gradient supply-limited reaches that tend to be very stable. The third category, which includes only braided streams, is for those reaches which are almost always unstable. Johnson notes that these relative stability categories roughly correspond with those of Rosgen (2001).

As with the original Johnson et al. (1999) method, the factors relating to lateral and vertical stability can be summed individually and divided by the total number of points to provide a sense of what channel instability type may be more dominant in the accordance with the HEC-20 recommendations (Figure 1.10). Vertical stability indicators are indicators 4-6 listed in Table 1.5,

	Score, R		
Category	PR, PB, DR, EC,	C, SP	Braided
Excellent	$R < 49$	$R < 41$	N/A
Good	$49 \leq R < 85$	$41 \leq R < 70$	$R < 94$
Fair	$85 \leq R < 120$	$70 \leq R < 98$	$94 \leq R < 129$
Poor	$120 \leq R$	$98 \leq R$	$129 \leq R$

Table 1.6: Integrated R channel stability score and stability designation by channel reach type (Johnson, 2005). PR: Pool-riffle, PB: Plane-bed, DR: Dune-ripple, EC: Engineered channels, C: Cascade, SP: Step-pool.

and lateral instability indicators are listed as 8-13.

Johnson (2005, 2006) used this stability analysis scheme to examine the stability of 57 bridge crossing in 14 states over 13 physiographic regions and subregions. Of interest to this review is the possible stability values of streams and rivers interacting with roadway structures in Texas. However, Johnson (2006) made no actual measurements in Texas. The states where measurements were made that are closest to the physiographic regions of Texas included, New Mexico (Trans Pecos), Oklahoma (Central Plains), Tennessee (Coastal Plain), and Florida (Coastal Plain) (Johnson, 2006). A summary of the stability R indexes and overall destinations from these sites is given in table 1.7.

State	Region	Characteristics	R Index Range	Stability Rating
New Mexico	Trans Pecos	Naturally Grazed, Channelized Meander	100-130	Fair-Poor
Oklahoma	Central Plains	Agricultural, Meandering	97-127	Fair-Poor
Tennessee	Coastal Plain	Agricultural, Meandering	87-112	Fair
Florida	Coastal Plain	Suburban, Meandering	57-77	Good

Table 1.7: Stability analysis outcomes from bridge crossing in physiographic regions similar to what might be found in Texas. Data taken from Johnson (2006).

As a byproduct in the development of the regionalized rapid stream stability assessment technique, Johnson (2006) also creating a simplified version of the Thorne (1998) river reconnaissance forms. The developed forms are less time consuming than the Thorne (1998) forms while still containing pertinent stream stability data with a focus on roadway structures. Johnson (2006) suggests that such forms could be filled out during routine bridge in inspections. The three-sheet form can be found in chapter 5 of Johnson (2006).

1.5 Prediction of channel evolution

1.5.1 Methods to predict meander migration

These methods are classified into three categories: empirical methods, time rate observations and extrapolation, and predictions through simplified modeling.

Empirical methods have been proposed by several authors. For a comprehensive review, see Briaud et al. (2001). The following is the four methods used in a previous TxDOT project 0-2105: (1) Keady and Priest (1977) consider the rate of downstream migration to be a function of the free surface slope of the river, the meander amplitude, and the specific weight of water; (2) Hooke (1980) proposed that the erosion rate is most closely related to the catchment area (as a surrogate of discharge and width); (3) Brice (1982) proposed that the rate of bank migration increases with increasing channel width; (4) Nanson and Hickin (1983) showed that the ratio of radius of curvature of a bend (R_c) to channel width (W) influences the lateral migration rate of a meandering river. The proposed the relationship between channel migration rate (MR) and the ratio of radius of curvature to channel width. These methods have been used in project TxDOT 0-2105 for the following four sites:

- Brazos River at SH 105,
- Nueces River at US 90,
- Trinity River at FM 781,
- Guadalupe River at US 59.

The values predicted by the empirical equations were compared with the measured values for the migration rate. The conclusion on the accuracy of these methods were given in Briaud et al. (2001).

The time rate observations and extrapolation method is based on aerial photos taken at different times. This method has been documented in detail in Lagasse et al. (2004). First, circles at two different times are fitted for a given bend. Then, the location of the center and the magnitude of the radius are linearly extrapolated with respect to time. The direction of new migration increment can be extrapolated based on the direction of the two previous increments. The process is shown in Figure 1.11. The drawback of this method is that it cannot incorporate a change in soil condition and a future hydrograph different from the past.

To take into account the soil properties, a prediction method through simplified modeling was developed in Briaud et al. (2007). It uses the *MEANDER* program funded by TxDOT (Figure 1.12). This method has the advantage of taking into account many of the factors influencing the meander migration process but it is more complicated to use than the empirical methods and historical extrapolation methods described above.

Another choice for predicting meander migration is the RVR Meander platform (`http://www.rvrmeander.org`). The new development merges the functionalities of the first version of RVR

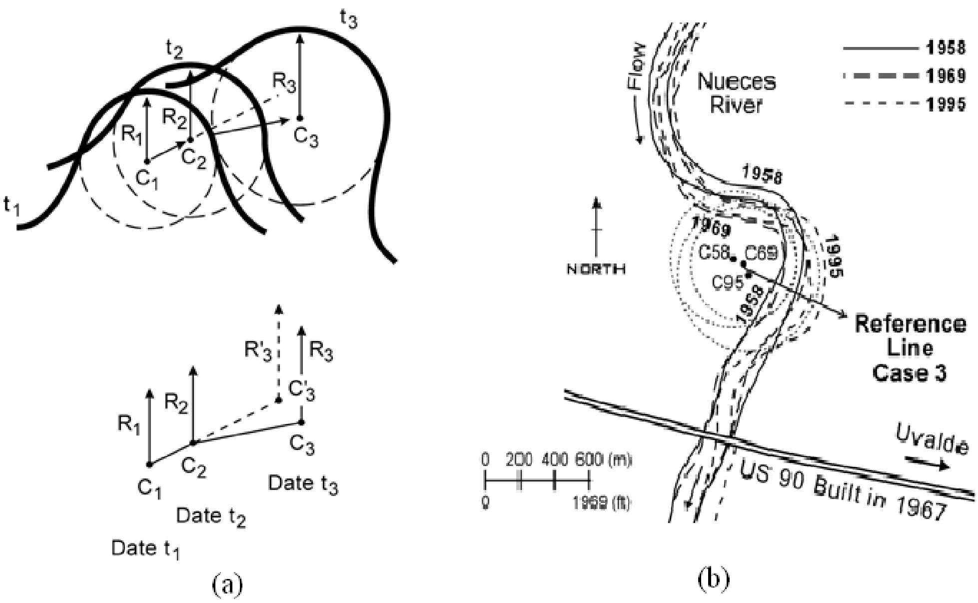


Figure 1.11: Time rate observation and extrapolation method (Briaud et al., 2001): (a) fitting of circles, (b) application example Meander for the meander migration of the Nueces River at US 90

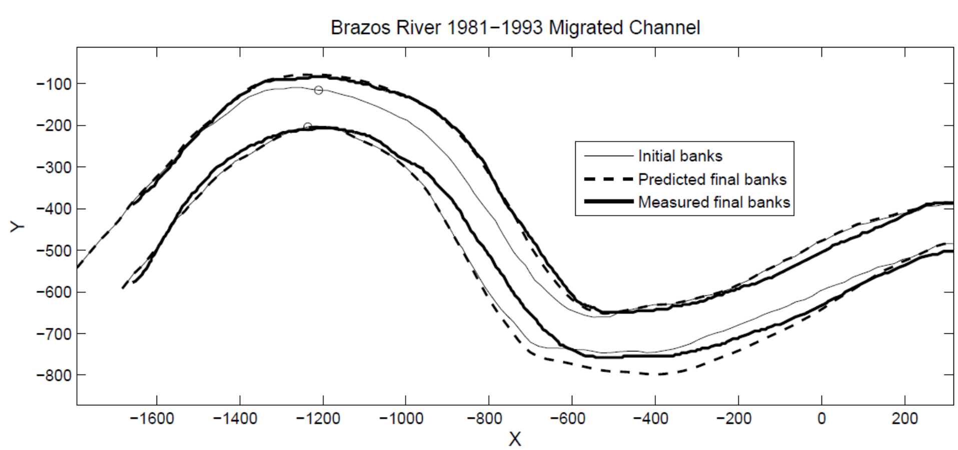


Figure 1.12: Example of results obtained with the MEANDER program (Briaud et al., 2007)

Meander (Abad and Garcia, 2006; Motta et al., 2012) and CONCEPTS model(Langendoen et al., 2001). CONCEPTS stands for CONservational Channel Evolution and Pollutant Transport System. The RVR Meander platform implements a physically- and process-based method that relates channel migration to the streambank erosion processes (both hydraulic erosion and mass failure). It has a stand-alone version for Windows and Linux operating systems and an intergraded version ArcGIS-ArcMap.

There are more advanced two- and three-dimensional numerical models which could be used to simulate the flow field and sediment transport processes. They will be introduced in a later section.

1.5.2 Methods to predict aggradation and degradation

Channel vertical stability, namely aggradation and degradation, is the result of imbalance between sediment transported into and out of a river reach. One can qualitatively and quantitatively analyze the channel vertical stability using the sediment continuity concept. Another useful tool for qualitative analysis is the Lane relationship introduced in Section 1.3.1. The essence of this relationship is that river channels respond to a change in flow discharge or sediment load and move from one equilibrium to another by changing its slope or sediment grading. However, it is not capable to predict the amount of aggradation and degradation and the time it needs to adjust.

In Section 6.3 of FHWA HEC-20 (Lagasse et al., 2001), a detailed discussion on predicting aggradation and degradation is given. In addition to the sediment continuity equation (termed as Exner equation in the sediment transport literature), analysis on incipient motion of sediment particles and armoring is needed. The resulting tool for degradation analysis is formulas to predict new equilibrium slope. Several typical scenarios which could cause channel slope adjustment are given, namely sediment supply cutoff (no sediment supply), reduced sediment supply, and base level control.

More advanced models can be used to predict the sediment transport in a river channel. These models route sediment down a channel and adjust the channel geometry to reflect the imbalance between sediment supply and river capacity. There is a variety of choices for such purpose, most notably the BRISTARS and HECRAS models, which will be introduced in Section 1.5.5.

1.5.3 Methods to measure soil resistance to erosion

Channel aggradation/degradation and migration occur through soil erosion and transport. Therefore, the erodibility of sediment is one of the key parameters. There are methods available to quantify soil resistance to erosion at the element level and to predict channel degradation and migration at the global level. The measurement of soil resistance to erosion at the element level provides information for global channel stability prediction.

In the literature, there are several methods to quantify erosion at the element level. In general, they apply artificially generated flows to the soils and observe the erosion process. We briefly discuss three of the methods, i.e., soil classification based method, the Erosion Function Apparatus, and the Pocket Erodometer. The soil classification approach consists of collecting samples of the soil, classifying it according to the Unified Soil Classification System and using Figure 1.13 (a) (Briaud et al., 2007). The Erosion Function Apparatus approach is well known and leads to an erosion curve as shown in Figure 1.13 (b) (Briaud et al., 2001). From this curve, an engineer can read the critical velocity and the erosion rate for a given river velocity.

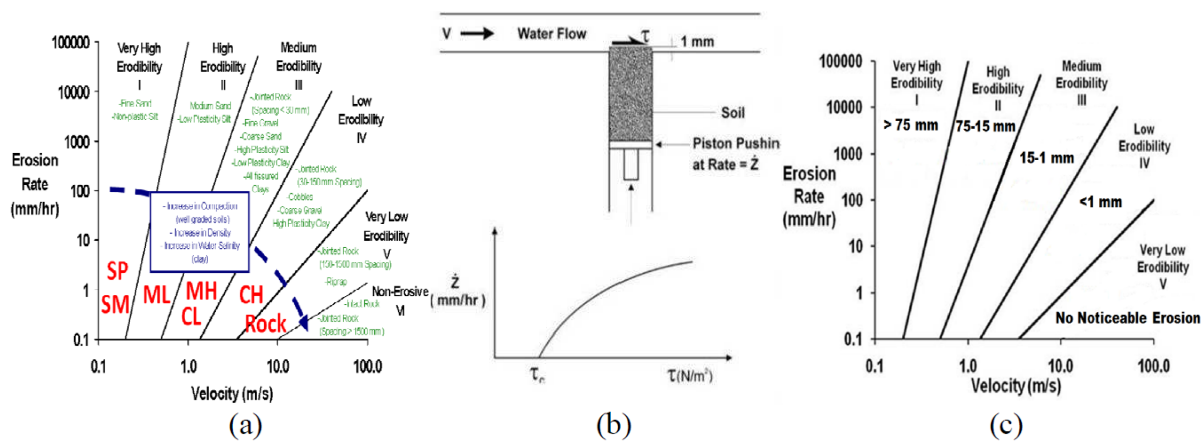


Figure 1.13: Methods to test soil erosion resistance: (a) Soil Classification Approach (b) Erosion Function Apparatus (c) Erosion chart for PET (Briaud et al., 2007)

The soil classification approach is too rudimentary and the EFA requires time and money. In order to simplify erosion testing, the Pocket Erodometer Test (PET) was developed (Figure 1.13 (c)). It consist of directing a jet to the surface of the soil sample and measuring the depth of the hole developing as a result of the test. The jet is at 8 m/s and is repeated 20 times from a distance of 50 mm from the sample face. Figure 1.14 shows a PET in progress.

Besides the methods mentioned in the previous sections, there are other techniques to predict channel stability. These techniques include physical modeling in the laboratory, computational modeling, and field measurements. They are not in the TxDOT Hydraulic Design Manual. FHWA suggested the usage of mathematical and physical model studies as the highest level of channel stability evaluation (Level 3). They are usually much expensive and time consuming. However, they are used for many important projects when there is excessive uncertainty associated with the simple methods in the previous sections. In the following, the physical model and numerical models are reviewed.

1.5.4 Physical modeling

Physical models have been used for the test of various river engineering structures. The purposes of physical modeling in the lab are to duplicate the complicated flow processes in a small scale

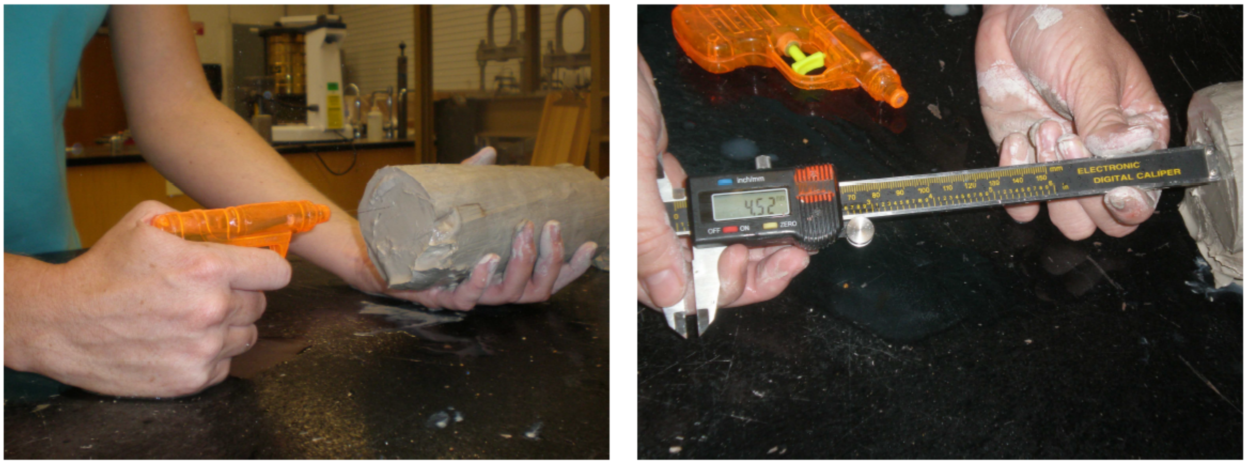


Figure 1.14: Pocket Erodometer Test (PET) in progress (Briaud et al., 2007)

laboratory, examine the effectiveness of countermeasures, investigate the hydraulic performance under different flow and sediment load conditions (Julien, 2002).

If properly designed, scaled physical modeling can provide valuable information about the physical process based on similarity principle. For a physical model to represent the reality, the geometric, kinematic, and dynamic similitude need to be considered. When not all of these similarities can be satisfied, an analysis needs to be done to take into account the critical physical processes. In Section 5.6.1 of HDS-6 (Richardson et al., 2001), a brief discussion of these similitude is provided. It also provides additional reports and documents on particular physical modeling projects for alluvial channel flows at highway crossings.

In general, there are two types of physical models for river channels: (1) fixed-bed, and (2) live-bed. For fixed-bed models, the interest is on the flow in the river and around hydraulic structures. The bed is fixed and no sediment motion is allowed. Usually the bed is paved with rigid surface or the bed shear stress is below the critical shear stress for sediment motion. On the other hand, live-bed models are useful when sediment transport is important, such as local scour and channel migration. Comparing to the fixed-bed models, one additional degree of freedom (sediment) is added to the problem. To ensure similarity between model and prototype, the dimensionless shear stress (Shields number) and the dimensionless sediment size should be similar. Figure 1.15 shows an artificial meandering river experiment conducted at Texas A&M University (Briaud et al., 2007).

1.5.5 Numerical modeling

Numerical models, also termed mathematical models in HEC-23 and computer models in HDS-6, solve the set of quantitative equations for the relevant physical processes involved in stream channel stability. There is a big pool of numerical models available for the evaluation of sediment transport, channel migration, and profile change. The use of these models can provide very detailed information for flow field and sediment motion.

Figure 1.15: Physical modeling of meandering channel development (Briaud et al., 2007)

A survey of 1D and 2D numerical models is provided in HDS-6. Examples of 1D models include the BRISTARS (BRIdge Stream Tube model for Alluvial River Simulation) model (Molinas, 2000), HEC-6 model (outdated, replaced by HEC-RAS software), and FLUVIAL-12 model (Chang, Chang). BRISTARS model is a generalized semi-two-dimensional water and sediment-routing computer model that includes an integrated graphical interface. It is capable of simulating the channel widening/narrowing phenomenon as well as local scour due to highway encroachments. It contains a subset of Federal Highway Administration's WSPRO subroutines for computing bridge hydraulics. HEC-6 and its replacement HEC-RAS are only suitable for aggradation/degradation simulations. The stream banks are fixed in space which makes it not suitable for simulating meanders. At bridge crossings, they calculate local scours which include contraction scour, pier scour, and abutment scour. The FLUVIAL-12 model has the capacity to simulate bank erosion and is described as an erodible-boundary model. HDS-6 also discussed two 2D models, i.e., SED2D (?)Letteretal1998) and Flo2DH (Froehlich, 1996). With the increasing of model dimensionality, the data requirement also increases.

In general, a basic numerical model of water flow and sediment transport in an alluvial river consists of three conservation principles: conservation of mass for water; conservation of mass for sediment, conservation of water momentum. The flow resistive force drives the motion of sediment which is usually described by a sediment transport rate formula. These equations form a nonlinear partial-differential system that in general cannot be solved analytically.

For channel stability problems, especially those involve large river reach and long term prediction, 1D model is probably the most reliable and affordable choice. However, the simplicity of 1D models come with the price of loosing too much physical information. To improve this situation, 2D models (usually depth-averaged in the water column) can provided more details about the flow field, particularly the cross-channel flow which is important for the channel cross section profile evolution. The limitations of most 2D models are: (1) they have no capability to describe the vertical flow distribution in a cross section, and (2) they usually assume hydrostatic pressure distribution in the vertical direction. As shown in Section 1.2, secondary flow is critical for meander migration. However, 2D models can not predict this secondary flow circulation in a bend. Special treatment has been developed to use 2D models for secondary flows, though their applicability is limited.

The state-of-art computational fluid dynamics (CFD) simulation technique can reveal the detailed turbulent flow field in the channel and indicate the trend of erosion and channel migration. For example, 3D CFD simulation has been done for the first two bends of the St. Clair River in the Great Lakes area to investigate the erosion problem (Figure 1.16 (a), Liu et al. (2012)). The simulated shear stresses were used to calculate the erosion rate. Corresponding field measurements using ADCP have also been done the in that area. Figure 1.16 (b) shows the velocities in the primary and secondary directions at the first bend. Field campaigns can also measure sediment transport rate (both bedload and suspended load) and survey geomorphological features of the site.

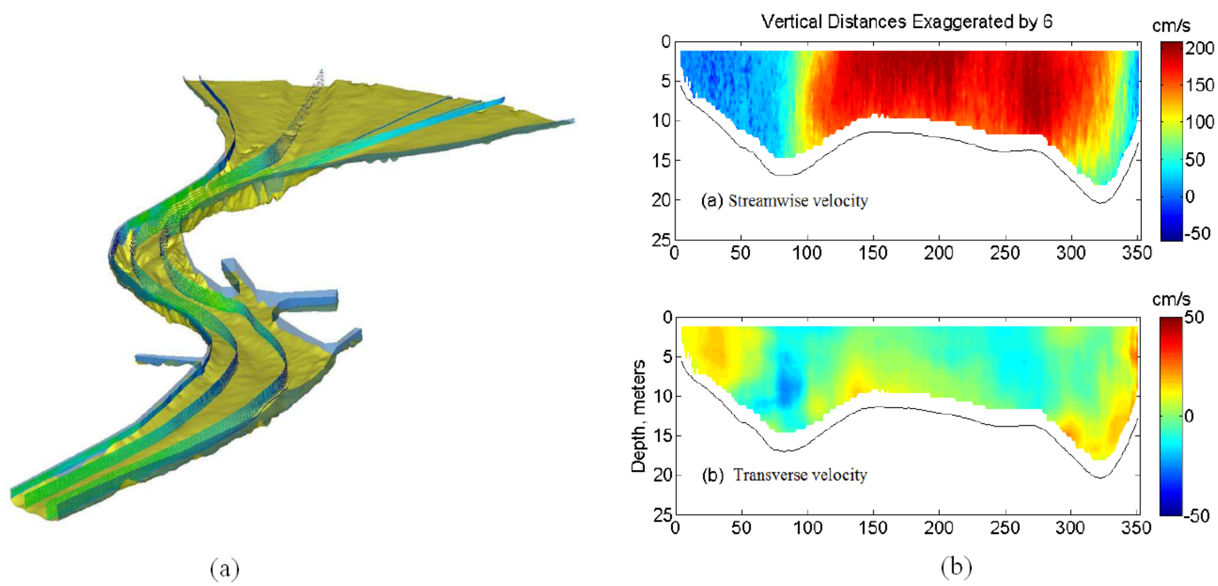


Figure 1.16: Modeling of meandering channel in the St. Clair River: (a) 3D numerical modeling (b) ADCP velocity measurement showing secondary flow in the first bend of the St. Clair River

The physical modeling and numerical modeling techniques can be used in combination to cross check and further reduce the uncertainties. They are used more frequently for large projects. In practice, since each project is unique, these techniques can only be used on a case-by-case basis.

1.6 Channel instability countermeasures

This section of the review is a summary of report FHWA HEC-23 (volume 1 and 2, Lagasse et al. (2009)). It is the most comprehensive guideline so far. There are certainly many other literatures documenting various types of countermeasures. However, they are most likely covered in HEC-23. In this document, a countermeasure is defined as a measure incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability problems.

1.6.1 Regulatory mandate

In item 113 of the National Bridge Inventory, if a bridge is identified as scour critical, a Plan of Action (POA) is required per the National Bridge Inspection Standards (NBIS) regulation 23 CFR 650.313(e). The POA needs to specify what should be done to address the scour problem. The actions include hydraulic countermeasures, structural countermeasures, biotechnical countermeasures, and/or monitoring program.

1.6.2 Countermeasure selection criteria

The selection criteria to determine whether a countermeasure is appropriate for a specific channel stability problem is dependent on the several controlling factors. They include the sediment erosion mechanism, stream characteristics, construction and maintenance requirements, potential for vandalism, and costs. Section 3.2 of HEC-23 has a very detailed discussion on each of these factors.

1.6.3 Countermeasure classifications (groups)

Countermeasures have been organized into groups based on their functionality with respect to scour and stream instability. The four main groups of countermeasures are: hydraulic countermeasures, structural countermeasures, biotechnical countermeasures, and monitoring. Here monitoring has been deemed as an important part of countermeasures. The following identifies the countermeasure groups:

- Group 1. Hydraulic Countermeasures. They are primarily designed either to modify the flow or resist erosive forces caused by the flow. Hydraulic countermeasures are organized into two groups: river training structures and armoring countermeasures. The performance of hydraulic countermeasures is dependent on design considerations such as edge treatment and filter requirements, which are discussed in Sections 5.2 and 5.4 of HEC-23 volume 1, respectively.
    - Group 1.A: River training structures. They are those structures which modify the flow. River training structures are distinctive in that they alter hydraulics to mitigate un-

desirable erosional and/or depositional conditions at a particular location or in a river reach. River training structures can be constructed of various material types. They can be distinguished by their orientation to flow. River training structures are described as transverse, longitudinal or areal depending on their orientation to the stream flow.

    * Transverse structures: They are countermeasures which project into the flow field at an angle or perpendicular to the direction of flow.
    * Longitudinal structures: They are countermeasures which are oriented parallel to the flow field or along a bankline.
    * Areal structures: They are countermeasures which cannot be described as transverse or longitudinal when acting as a system. This group also includes countermeasure "treatments" which have areal characteristics such as channelization, flow relief, and sediment detention.

  - Group 1.B: Armoring countermeasures. They are distinctive because they resist the erosive forces caused by a hydraulic condition. Armoring countermeasures do not necessarily alter the hydraulics of a reach, but act as a resistant layer to hydraulic shear stresses providing protection to the more erodible materials underneath. Armoring countermeasures generally do not vary by function, but vary more in material type. Armoring countermeasures are classified by two functional groups: (1) revetments and bed armoring, (2) local scour armoring.

    * Revetments and bed armor. Revetments and bed armoring are used to protect the channel bank and/or bed from erosive/hydraulic forces. They are usually applied in a blanket type fashion for areal coverage. Revetments and bed armoring can be classified as either *rigid* or *flexible/articulating*. Rigid revetments and bed armoring are typically impermeable and do not have the ability to conform to changes in the supporting surface. These are subject to failure due to undermining. Flexible/ articulating revetments and bed armoring can conform to changes in the supporting surface and adjust to settlement; however, these countermeasures can fail by removal and displacement of the armor material.
    * Local scour armoring. Local scour armoring is used specifically to protect individual substructure elements of a bridge from local scour. Generally, the same material used for revetments and bed armoring is used for local scour armoring, but these countermeasures are designed and placed to resist local vortices created by obstructions to the flow.

- Group 2. Structural Countermeasures: Structural countermeasures involve modification of the bridge structure (foundation) to prevent failure from scour. Typically, the substructure is modified to increase bridge stability after scour has occurred or when a bridge is assessed as scour critical. These modifications are classified as either foundation strengthening or pier geometry modifications.

  - Foundation strengthening. It includes additions to the original structure which will reinforce and/or extend the foundations of the bridge. These countermeasures are designed to prevent failure when the channel bed is lowered to an expected scour elevation, or to restore structural integrity after scour has occurred. Design and construction of bridges with continuous spans provide redundancy against catastrophic failure due to substructure displacement as a result of scour. Retrofitting a simple span bridge with continuous spans could also serve as a countermeasure after scour has occurred or when a bridge is assessed as scour critical.

  – Pier geometry modification. Pier geometry modifications are used to either reduce local scour at bridge piers or to transfer scour to another location. These modifications are used primarily to minimize local scour.

- Group 3. Biotechnical Countermeasures: Vegetation has been used increasingly over the past few decades to control streambank erosion or as a bank stabilizer. It has been used primarily in stream restoration and rehabilitation projects and can be applied independently or in combination with structural countermeasures. There are several terms that describe vegetative streambank stabilization and countermeasures. The use of 'soft' revetments (consisting solely of living plant materials or plant products) is often referred to as bioengineering. The techniques that combine the use of vegetation with structural (hard) elements include biotechnical engineering and biotechnical slope protection. Where riprap constitutes the "hard" component of biotechnical slope protection, the term vegetated riprap is also used (see Chapter 6 of HEC-23 volume 1). Representative categories for biotechnically engineered countermeasures (which incorporate rock) includes:

  – Vegetated geosynthetic products,
  – Facines/woody mats,
  – Vegetated riprap,
  – Root wads,
  – Live staking.

  Biotechnical engineering can be a useful and cost-effective tool in controlling bank or channel erosion, while increasing the aesthetics and habitat diversity of the site. However, where failure of the countermeasure could lead to failure of a bridge or highway structure, the only acceptable solution in the immediate vicinity of a structure is a traditional, "hard" engineering approach.

- Group 4. Monitoring: Monitoring describes activities used to facilitate early identification of potential scour problems. Monitoring could also serve as a continuous survey of the scour progress around the bridge foundations. While monitoring does not fix the scour problem at a scour critical bridge, it allows for action to be taken before the safety of the public is threatened by the potential failure of the bridge. Monitoring can be accomplished with instrumentation or visual inspection. A well designed monitoring program can be a very cost-effective countermeasure. Two types of instrumentation are used to monitor bridge scour:

fixed instruments and portable instruments.

- Fixed instrumentation: Fixed instrumentation describes monitoring devices which are attached to the bridge structure to detect scour at a particular location. Typically, fixed monitors are located at piers and abutments. The number and location of piers to be instrumented should be defined, as it may be impractical to place a fixed instrument at every pier and abutment on a bridge. Instruments such as sonar monitors can be used to provide a timeline of scour, whereas instruments such as magnetic sliding collars can only be used to monitor the maximum scour depth. Data from fixed instruments can be downloaded manually at the site or it can be telemetered to another location.

- Portable instrumentation: Portable instrumentation describes monitoring devices that can be manually carried and used along a bridge and transported from one bridge to another. Portable instruments are more cost effective in monitoring an entire bridge than fixed instruments; however, they do not offer a continuous watch over the structure. The allowable level of risk will affect the frequency of data collection using portable instruments.

- Visual monitoring: Visual inspection describes standard monitoring practices of inspecting the bridge on a regular interval and increasing monitoring efforts during high flow events (flood watch). Typically, bridges are inspected on a biennial schedule where channel bed elevations at each pier location are taken. The channel bed elevations should be compared with historical cross sections to identify changes due to scour. Channel elevations should also be taken during and after high flow events. If measurements cannot be safely collected during a high flow event, the bridge owner should determine if the bridge is at risk and if closure is necessary. Underwater inspections of the foundations could be used as part of the visual inspection after a flood.

1.6.4 Specific engineering countermeasures for channel instability problems

Countermeasures for meander migration

The best countermeasure against meander migration is to locate the bridge crossing on a relatively straight reach of stream between bends. At many such locations, countermeasures may not be required for several years because of the time required for the bend to move to a location where it becomes a threat. However, bend migration rates on other streams may be such that countermeasures will be required after a few years or a few flood events and, therefore, should be installed during initial construction. Countermeasures for meander migration include those that:

- Protect an existing bank line
- Establish a new flow line or alignment
- Control and constrict channel flow

The classes of countermeasures identified for bank stabilization and bend control are bank revetments, spurs, bendway weirs, longitudinal dikes, vane dikes, bulkheads, and channel relocations. Also, a carefully planned cutoff may be an effective way to counter problems created by meander migration. These measures may be used individually or in combination to combat meander migration at a site. Some of these countermeasures are also applicable to bank erosion from causes other than bend migration.

Countermeasures for braiding and anabranching

Countermeasures used on braided and anabranched streams are usually intended to confine the multiple channels to one channel. This tends to increase the sediment transport capacity in the principal channel and encourage deposition in secondary channels. These measures usually consist of dikes constructed from the margins of the braided zone to the channel over which the bridge is constructed. Guide banks at bridge abutments in combination with revetment on highway fill slopes, riprap on highway fill slopes only, and spurs arranged in the stream channels to constrict flow to one channel have also been used successfully.

Since anabranches are permanent channels that may convey substantial flow, diversion and confinement of an anabranched stream is likely to be more difficult than for a braided stream. The designer may be faced with a choice of either building more than one bridge, building a long bridge, or diverting anabranches into a single channel.

Countermeasures for aggradation and degradation

Countermeasures used to control bed degradation include check dams and channel linings. Check-dams and structures which perform functions similar to check-dams include drop structures, cutoff walls, and drop flumes. A check-dam is a low dam or weir constructed across a channel to prevent upstream degradation.

Channel linings of concrete and riprap have proved unsuccessful at stopping degradation. To protect the lining, a check-dam may have to be placed at the downstream end to key it to the channel bed. Such a scheme would provide no more protection than would a check dam alone, in which case the channel lining would be redundant. The USACE found that longitudinal stone dikes, or rock toe-dikes, provided the most effective toe protection of all bank stabilization measures studied for very dynamic and/or actively degrading channels.

The following is a condensed list of recommendations and guidelines for the application of countermeasures at bridge crossings experiencing degradation:

- Check-dams or drop structures are the most successful technique for halting degradation on small to medium streams.
- Channel lining alone may not be a successful countermeasure against degradation problems.

- Riprap on channel banks and spill slopes will fail if unanticipated channel degradation occurs.
- Successful pier protection involves providing deeper foundations at piers and pile bents.
- Jacketing piers with steel casings or sheet piles has also been successful where expected degradation extends only to the top of the original foundation.
- The most economical solution to degradation problems at new crossing sites on small to medium size streams is to provide adequate foundation depths. Adequate setback of abutments from slumping banks is also necessary.
- Rock-and-wire mattresses are recommended for use only on small (¡100 ft) channels experiencing lateral instability and little or no vertical instability.
- Longitudinal stone dikes placed at the toe of channel banks are effective countermeasures for bank caving in degrading streams. Precautions to prevent outflanking, such as tiebacks to the banks, may be necessary where installations are limited to the vicinity of the highway stream crossing.

Countermeasures to control aggradation at highways include channelization, debris basins, bridge modification, and/or continued maintenance, or combinations of these. Channelization may include dredging and clearing channels, constructing small dams to form debris basins, constructing cutoffs to increase the local slope, constructing flow control structures to reduce and control the local channel width, and constructing relief channels to improve flow capacity at the crossing. Except for debris basins and relief channels, these measures are intended to increase the sediment transport capacity of the channel, thus reducing or eliminating problems with aggradation. Cutoffs must be designed with considerable study as they can cause erosion and degradation upstream and deposition downstream. The most common bridge modifications are increasing the bridge length by adding spans and increasing the effective flow area beneath the structure by raising the bridge deck. A program of continuing maintenance has been successfully used to control problems at bridges on aggrading streams. In such a program, a monitoring system is set up to survey the affected crossing at regular intervals. When some pre-established deposition depth is reached, the bridge opening is dredged or cleared of the deposited material. A debris basin or a deeper channel upstream of the bridge may be easier to maintain. Continuing maintenance is not recommended if analysis shows that other countermeasures are practicable.

An alternative similar to a maintenance program which could be used on streams with persistent aggradation problems, such as those on alluvial fans, is the use of controlled sand and gravel mining from a debris basin constructed upstream of the bridge site.

The following is a list of guidelines regarding aggradation countermeasures:

- Extensive channelization projects have generally proven unsuccessful in alleviating general aggradation problems, although some successful cases have been documented. A sufficient increase in the sediment carrying capacity of the channel is usually not achieved to significantly reduce or eliminate the problem. Channelization should be considered only if analysis shows that the desired results will be achieved.

- Alteration or replacement of a bridge is often required to accommodate maximum aggradation depths.
- Maintenance programs have been unreliable, but they provide the most cost-effective solution where aggradation is from a temporary source or on small channels where the problem is limited in magnitude.
- At aggrading sites on wide, shallow streams, spurs or dikes with flexible revetment have been successful in several cases in confining the flow to narrower, deeper sections.
- A debris basin and controlled sand and gravel mining might be the best solution on alluvial fans (see HEC-20) and at other crossings with severe problems.

1.7 Summary

This technical memorandum summarizes the literature the research team has reviewed on the topic of channel stability and its impact on roadway hydraulic structures. Based on the review of the abundant technical literature, this report gives a relatively short overview of this problem. The aspects (corresponding to sections in this report) we considered are:

1. The background information on channel stability and river evolution,
2. Current channel stability assessment methods,
3. Prediction methods for channel evolution,
4. Countermeasures.

Chapter 2

Data Collection and Integration

2.1 Introduction

One of the outcomes of Task 1 is the identification of certain key parameters that need to be quantified, e.g., discharges, bed material sizes, and sediment transport rate. Gauge station records from the United State Geological Survey (USGS) have been used to calculate annual mean, maximum velocity, stage, and other hydraulic and hydrological quantities.

Historical data on channel planforms, especially in the form of printed maps and GIS shapefiles, are also collected for the sites identified in this project as examples. Understanding the historic changes to channel morphology is important in determining the expected future trajectory for channel evolution. In particular, determining how a channel has responded to watershed perturbations such as major storm events, changes in sediment and water input, and in-channel modifications can give insight into how the channel will continue to adjust to existing conditions and how it will subsequently respond to future perturbations. The data series can be used to validate and calibrate empirical formulas and models.

We have used the following data sources:

- Texas Natural Resources Information System (TNRIS, http://www.tnris.state.tx.us) is a central portal for downloading critical information for this project, such bathymetry, boundaries, geology, and land cover. It also provides aerial photography covering the entire state of Texas going back to the 1920s. Scales of the photography range from 1:62,500 to 1:15,840, with the most common scale being 1:24,000. In addition, it has satellite imagery for Landsat 5 and Landsat 7 (affiliated with USGS).
- Natural Resources Conservation Services, US Department of Agriculture: Soil erosion, land use, development, etc.
- USGS: Stream flow, stage, and sediment measurements
- National Weather Service: Hydrological data
- Past relevant TxDOT project reports: Various data for the state of Texas

This technical memorandum explains the database contents. This memorandum will not interpret results, but simply describe the database. It is noted that this task is closely related to Task 3: GIS Inventory. Some of information documented in this memo might a repetition of Technical Memo 3.

2.2 Sediment information

The sediment information collected in this project are divided into two parts. The first part of the information is collected by the research team for the sites selected for this project. The second part is a more compilation of sediment data (sizes, distribution, and load) for the major rivers in Texas.

2.2.1 Sediment data collected in this project

This section documents part of the sediment data we collected during the field trips to the five sites in the summer of 2012. We visited six sites and collected sediment samples from both the river bed and banks. These sites are:

- SH63 at Sabine River
- SH105 at Brazos River
- FM787 at Trinity River
- US90 at Nueces River
- SH34 at N. Sulphur River

The sampling efforts were divided into bed materials (undertaken by UTSA and UH) and bank materials (undertaken by TAMU). Figure 2.1 shows two pictures taken during the field visit in the summer of 2012. Sediment samples were tested in the lab for sizes and erodibility. The following will document the size distributions of bed and bank materials separately. The erodibility test results will be presented in another technical memo.

Bed materials

UTSA and UH took bed material samples and did sieve analysis on the samples with fine particles (sand and clay) and the sediment size distributions are stored in MS Excel spreadsheets. The GPS coordinates of the samples are also stored. The general procedure of the sieve analysis is the following:

1. Washing all grains.
2. Leaving in the oven for about 24 hours.
3. Selecting a set of sieves.
    (a) Coarse grains:
        - First a set of bigger sieves are selected.
        - Finer grains left on the pan are introduced to a set of finer sieves.

    (b) Fine grains:
        - A set of sieves from #4 to #200 are selected.
        - If the percentage remained on a sieve is greater than 50%, finer set of sieves in that range will be selected.
4. Cleaning the sieves with two coarse and fine brushes.

Figure 2.1: Sampling of the field sites: (a) Bed material sampling in the Brazos River at SH105, (b) Bank material sampling in the bank of the Sabine River at SH63.

5. Weighing the sieves.
6. Measuring the initial weight of a sample (around 100 gr for very fine grains, 500 gr for sands and 1000gr for coarser ones).
7. Introducing sediment to sieves and run shaker for 15 to 20 minutes.
8. Weigh the sieves with grains.
9. Repeating steps 4 to 8 for a new sample.
10. Analyzing the results and making the statistics.

For gravels, we did pebble count and a standard gravel meter was used. The sites with gravel samples are US90 at Nueces River and SH34 at North Sulphur River (which has gravel patches with the majority of the sand materials).

We also used GPS to record the coordinates of each samples,which are listed in Table 2.1. In Table 2.2, the summary of the bed material information is listed.

Site name	Sample number	GPS coordinates	Note
SH190 at Sabine River	1	N30°21.781', W096°09.239'	Multiple samples were taken. But they are more or less uniform.
SH105 at Brazos River	1	N30°21.788' W096°09.246'	
SH105 at Brazos River	2	N30°21.789' W096 °09.247'	
SH105 at Brazos River	3	N30°21.790' W096 °09.247'	
SH105 at Brazos River	4	N30°21.793' W096 °09.246'	
FM787 at Trinity River	1	N30°25.438', W094°50.954'	
FM787 at Trinity River	2	N30°25.451', W094°50.981'	
US90 at Nueces River	1 (gravel)	N29°12.397', W099 °54.163'	This sample was measured using gravelmeter.
SH34 at N. Sulphur River	1 (gravel)	N33°27.369', W095°56.536'	This sample was measured using gravelmeter.
SH34 at N. Sulphur River	2	N33°27.369', W095°56.536'	Extremely cohesive. No sand size material at all.
SH34 at N. Sulphur River	3	N33°27.368', W095°56.492'	
SH34 at N. Sulphur River	4	N33°27.388', W095°56.490'	

Table 2.1: GPS coordinates for the bed material samples

From Figure 2.2 to 2.12, the graphs for the size distributions using both sieve analysis and gravelmeter are plotted. More details can be found in the Excel data file.

Sample	d5	d16	d50	d84	d95	sg
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm/mm]
Brazos #1	0.23	0.46	1.58	3.61	5.56	2.79
Brazos #2	0.18	0.28	0.43	0.89	2.20	1.80
Brazos #3	0.21	0.30	0.43	0.59	0.82	1.39
Brazos #4	0.17	0.23	0.35	0.46	0.56	1.40
Trinity #1	0.31	1.09	4.04	16.52	30.50	3.89
Trinity #2	0.18	0.30	0.45	0.63	0.82	1.45
Sabine #1	0.19	0.22	0.35	0.60	1.08	1.63
Sulfur #1	Gravel sample					
Sulfur #2	-- Extremely cohesive. No sand size material at all. --					
Sulfur #3	0.26	1.14	3.33	7.92	13.80	2.63
Sulfur #4	0.02	0.08	0.01	1.06	1.98	3.69
Nueces #1	Gravel sample					

Table 2.2: Summary on the size information for bed material samples

Bank materials

The team from TAMU was in charge of the materials on the bank. Shelby tubes were driven into the soil and samples were carefully taken. Two standard tests to determine the size distribution of soils were performed in the laboratory according to the ASTM standard D 422-63 (2007). The first test is a sieve analysis, in which the soil is separated by a stack of sieves. Each of these sieves has a number that represents the amount of openings per linear inch. The second test is the hydrometer analysis, which is a test used for particles smaller than 0.075 mm (particles that pass sieve #200). In this test the soil is mixed with water and a dispersing agent, and the distribution is obtained by a process of sedimentation. The results from both tests are plotted and then used to obtain the classification of the soil, with the Atterberg limits of the soil.

For the sieve analysis, 5 sieves and a pan are put together and the soil is shaken in the sieves for a period of time to separate the coarse soil particles from the fines. The fines are those particles that have a diameter smaller than 0.075mm. The hydrometer was conducted for the soil samples after the sieve analysis test. The soil retained in the pan was analyzed with the hydrometer test. There are other different ways to perform the soil particle size analysis such as performing the hydrometer first and then the sieve or performing a wet sieve analysis. For the soils obtained at the sites, the soil was dried and then separated in the sieves. Only the particles that passed the #200 sieve were tested with the hydrometer test. It is desirable to perform a wet sieve analysis for soils containing

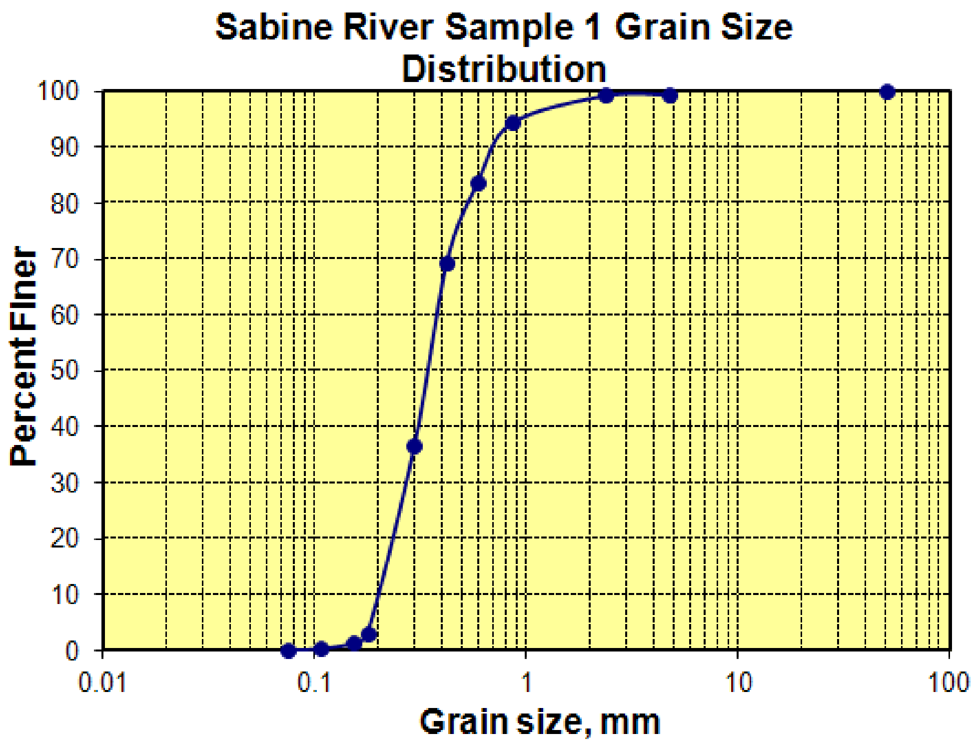


Figure 2.2: Bed material size distribution for SH190 at Sabine River (Sample #1)

large quantities of clay. Soil from the North Sulfur River contains clay and wet analyses have to be conducted to obtain the size distribution.

The following tables and figures show the results of the sieve analysis and hydrometer test for some samples of the selected rivers. Some of the samples may or may not correspond to locations where samples were obtained using the modified Shelby tubes for erosion testing.

The labeling of of the samples are the following. Each river has a different site number: Brazos River is S1, Trinity River is S2, Sabine River is S3, North Sulfur River is S4 and Nueces River is S5. Also, each sample has its own identification number. For example, the first sample collected at Brazos River is S1B1. Table 2.3 shows the locations where the bank materials were taken and a brief description. For each site, a map is shown with the locations of the samples. Samples from North Sulfur River are not included in this report.

2.2.2 Sediment data in the literature

Aside from the data we collected, the research team also complied sediment data for the major rivers in Texas from different sources. The resulted dataset is an important accomplishment since we found there was no effort to do this in the past. The research team deems this as a very useful

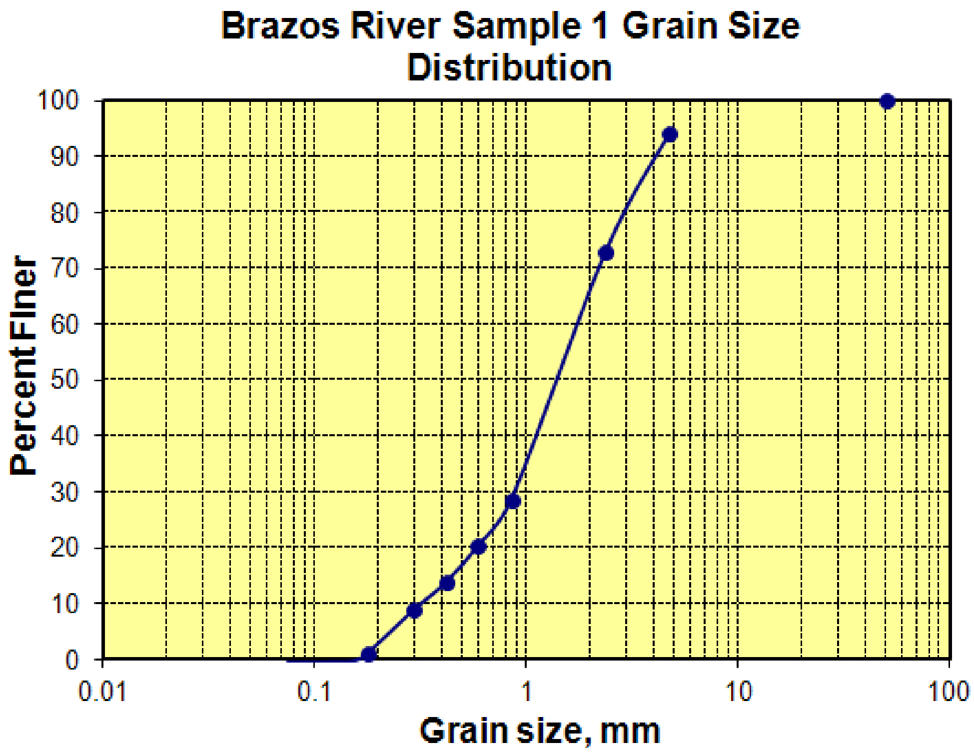


Figure 2.3: Bed material size distribution for SH105 at Brazos River (Sample #1)

work for TxDOT for future projects.

In this part of work, we identified and characterized the major rivers in the state of Texas. Then we assessed possible data sources for sediment in these rivers. Reports from different government agencies, journal and conference papers, web documents and other public information are considered for identifying the source of sediments. The collected sediment size data (bedload and sediment load), sediment load concentration, and sediment characteristics are compiled into Excel spreadsheets. The locations of data were also compiled in an easy-to-use format.

The amount of data is huge and it is impossible to present them (either in figures or tables) in this technical memo. The data have been organized into folders with the name of rivers. We only briefly present some representative data.

- Brazos River: The TWDB has collected periodic suspended-sediment samples from streams in Texas, including the Brazos River, since the early 1900s. These data have been published in several reports such as that by Dougherty (1979). The samples were collected using a device known as the "Texas sampler."

  The USGS has collected periodic and daily suspended-sediment data at the Brazos River at the Richmond gaging station since 1957. These data were collected using depth-integrating

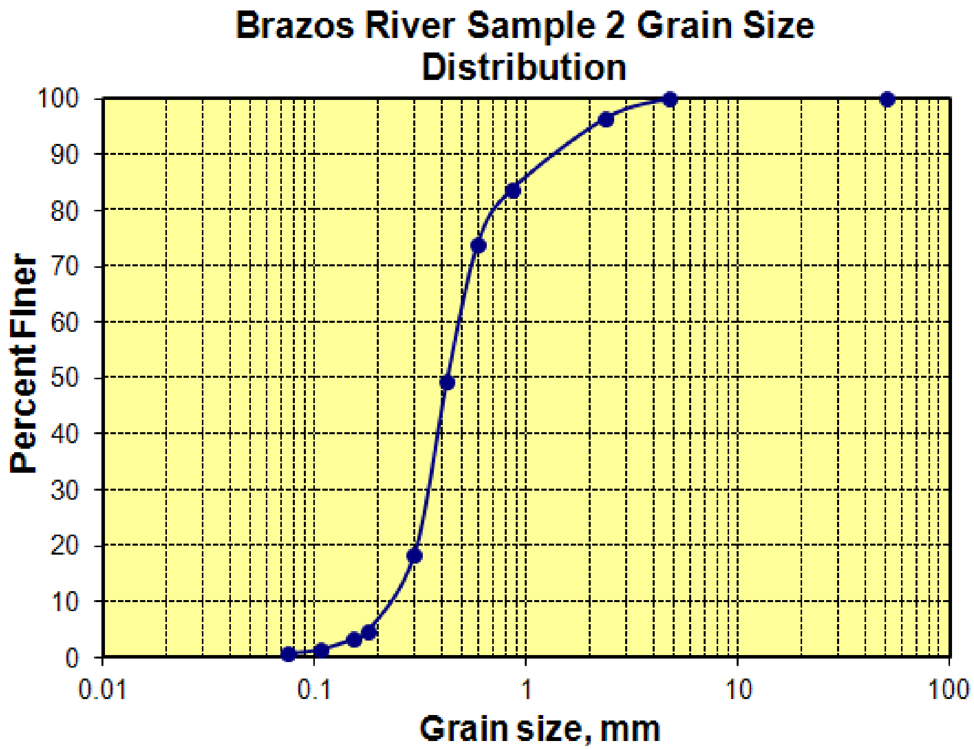


Figure 2.4: Bed material size distribution for SH105 at Brazos River (Sample #2)

samplers as described by Edwards and Glysson (1999) and developed through the Federal Interagency Sedimentation project.

Seelig and Sorenson (1973) analyzed sand loads computed from TWDB and USGS samples at the Richmond stream flow-gaging station for water years 1922-65. Using mean annual concentrations of sediment load, they identified three periods with distinctly different suspended-sediment concentrations: (1) 1922-40, concentrations averaged about 5,000 parts per million (ppm), (2) 1941-50, concentrations declined steadily from 5,000 to 2,000 ppm, and (3) 1951-65, concentrations declined slightly but remained in the 1,000 to 3,000 ppm range. They used methods developed by Colby (1957).

The median sediment size (D_{50}) represents the mesh size of a sieve through which 50 percent, by weight, of the material passes and is used as the representative size of bed material for tractive-force and bed-material transport computations (Stelczer, 1981).

Suspended-sediment concentration varies with depth. Generally, silts and clays are uniformly distributed with depth, but the larger sand-size particles are present in greater concentration near the streambed because greater turbulence and shear stress are required to suspend them.

- Llano River: The bed materials can be separated into low-flow channels and channel bars be-

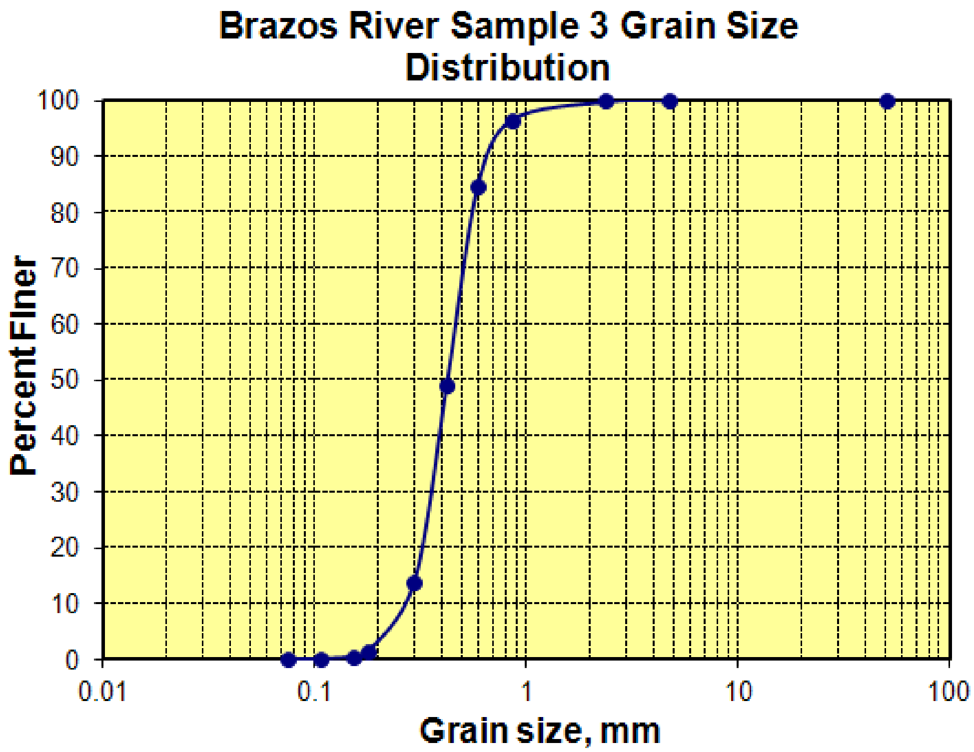


Figure 2.5: Bed material size distribution for SH105 at Brazos River (Sample #3)

cause constant hydraulic sorting processes in low-flow channels contrast with episodic sorting of bar deposits during high-flow conditions (Heitmuller, 2009).

Low-flow-channel (thalweg) deposits of the North Llano, South Llano, and Llano Rivers are characterized by cobbles, pebbles, and gravels with a range in median particle size from 25.3 to 60.0 mm (Heitmuller, 2009).Channel-bar deposits are characterized by cobble, pebble, and gravel-sized material upstream of an abrupt gravel-to-sand transition zone between Mason and Castell.

The Llano River valley becomes increasingly confined by bedrock with distance downstream of the Cretaceous-Paleozoic contact. Although ubiquitous exposures of bedrock in the river channel are often assumed to result in relatively coarse bed material (Tinkler and Wohl, 1998), channel-bar material of the Llano River decreases in size with distance downstream, which is due to the different weathering mechanisms of carbonate and igneous lithology.

- Nueces River: Extensive field sampling throughout 2002-2003 has been reported in Santschi and Yeager (2004), which focused primarily on the southernmost portion of the Nueces River watershed in southwest Texas. In their work, surface sediments and sediment cores were collected. Surface sediment samples consisted of channel alluvium from the Nueces River and associated tributaries, floodplain and delta sediments and prospective source area soils

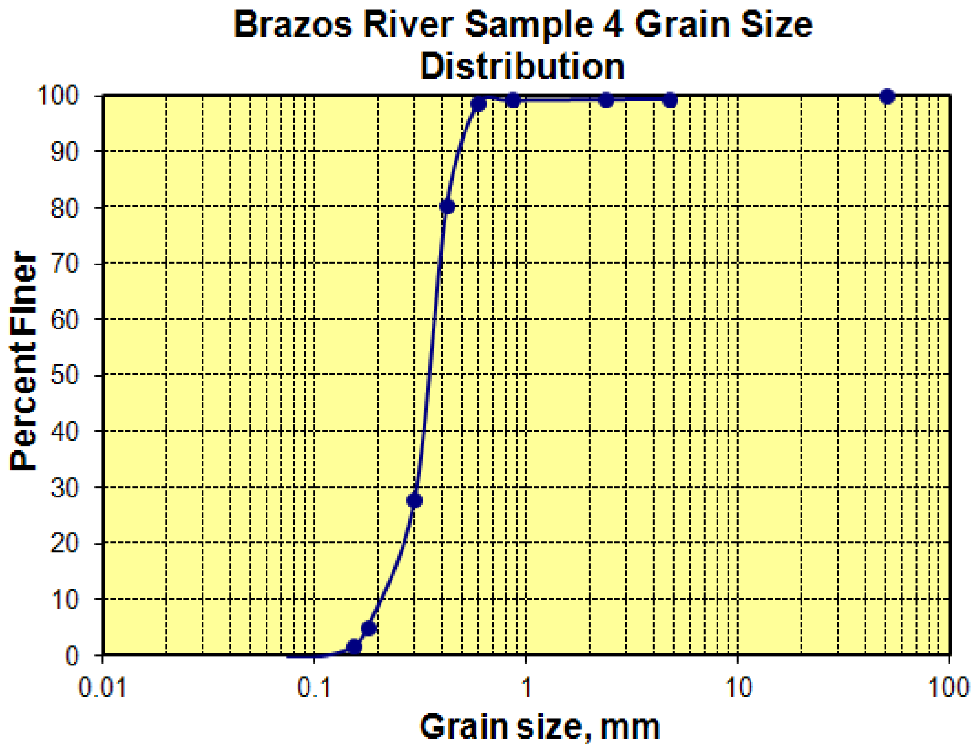


Figure 2.6: Bed material size distribution for SH105 at Brazos River (Sample #4)

predominantly throughout the lower watershed.

Large volumes of gravel and sandy muddy gravel are transported in the Nueces River. There are meander lobe sequences consisting predominately of coarse gravel. Mean grain size of Nueces River alluvium ranges from 1.2 to 3.4 cm. Its bed load consists almost entirely of gravels, which have been confirmed by the field measurement in this project. The predominant bed forms of the Nueces River are transverse gravel bars. They occur both along the channel and on the outer banks of the meander lobes. It is reported in the literature and verified by our field work that bars occur singly or in groups with amplitudes up to 2 m and lengths in excess of 100 m (Santschi and Yeager , 2004).

- Rio Grande River: Due to the reduced peak flows, incoming sediment loads and available flood plain, the Rio Grande is not in equilibrium and continues to evolve. The following geomorphological changes have been reported in the literature: active channel width and accompanying vegetation encroachment; channel incision and loss of flood plain connectivity in some reaches, aggrading in others; general bed material coarsening with an increasing amount of the river changing from sand-bedded to gravel-bedded; and a general reduction in slope (Lagasse, 1980; Reclamation, 2003).

Past geomorphic studies of the Rio Grande found that the sediment discharge and physical

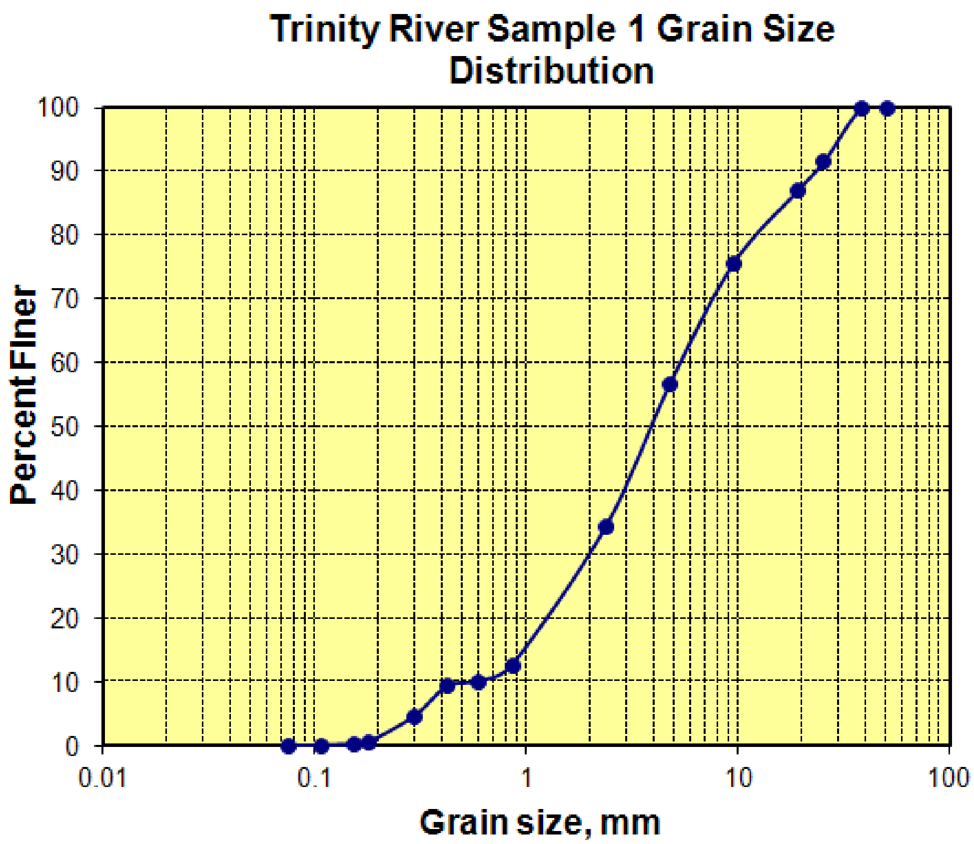


Figure 2.7: Bed material size distribution for FM787 at Trinity River (Sample #1)

channel features have changed significantly from historical conditions and that with current sediment supply the river channel will continue to narrow, incise, and move toward a gravel bed channel (Lagasse, 1980; Reclamation, 2003; Makar and Strand, 2003).

- Guadalupe River: Pleistocene fluvial deposits and Cretaceous limestones are the major underlying geologic units of the Guadalupe river channel. If one inspects the surficial geology of the Guadalupe River, five main geologic units appear. The Fluviatile Deposits Formation is made up of gravel, sand, silt, and clay and ranges from 9 to 15 m thick. Along the Guadalupe River, siliceous, coarse gravel is most prominent. This formation is composed of relict Pleistocene stream deposits (Brown et al. 1974). The special feature of the Guadalupe River in terms of sediment transport is that in the Guadalupe River the presence of very large sediment waves or gravel terraces provides an abundant source of sediment for transport. However, in most bedrock rivers the source is from the valley side slopes in constricted reaches where the erosion process will produce large amount of sediment (Cenderelli and Cluer 1998).

- Colorado River: On the lower Colorado River, stream flow and sediment transport dynamics

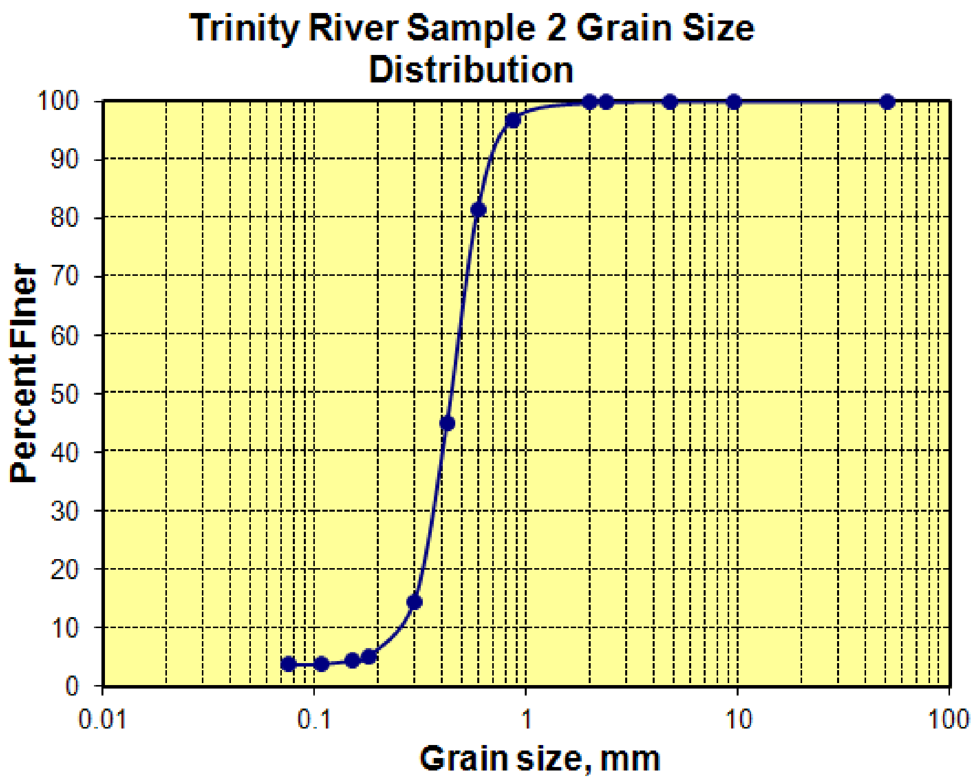


Figure 2.8: Bed material size distribution for FM787 at Trinity River (Sample #2)

produce unique geomorphological features, which include sand and gravel bars, side channels and backwaters, riffle and pool habitats, river banks, and floodplain and terrace features. Sediment data at USGS gauging stations from various source were compiled.

- San Antonio River: Surface geology directly impacts soil mineralogy as well as influences valley and channel morphology. We have collected sediment size data in the San Antonio River Basin as well as the data near the City of San Antonio.

- Trinity River: The Texas Water Development Board (TWDB) collected daily suspended sediment samples at several stations on the Trinity River (Liberty, Romayor, and Crockett, upstream of Lake Livingston) over the 1964-1989 periods. This period spans both before and after the construction of dams. The samples were taken with the "Texas Sampler".

  Due to the construction of the Livingston Dam, a clear decline in sediment transport rate can be observed from the sediment data at the Romayor station. On the other and, sediment data at Liberty does not show any clear evidence of a change in sediment transport rate.

- Red River: Total measured suspended sediment data were available between 1938-1978 (Blumer 1983). Between 1965 and 1977 size class analysis data were available at Arthur

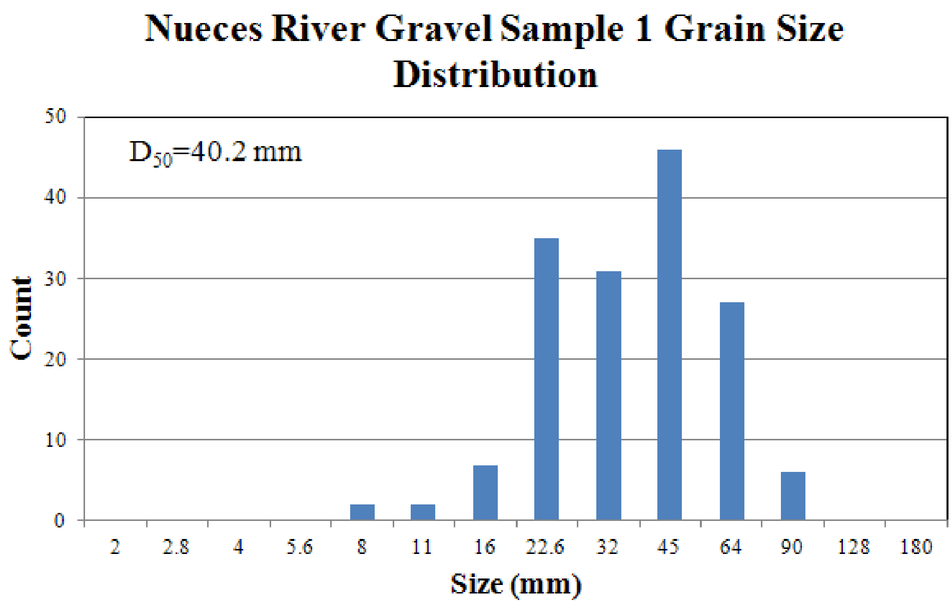


Figure 2.9: Gravel size distribution for sample taken for US90 at Nueces River (Sample #1)

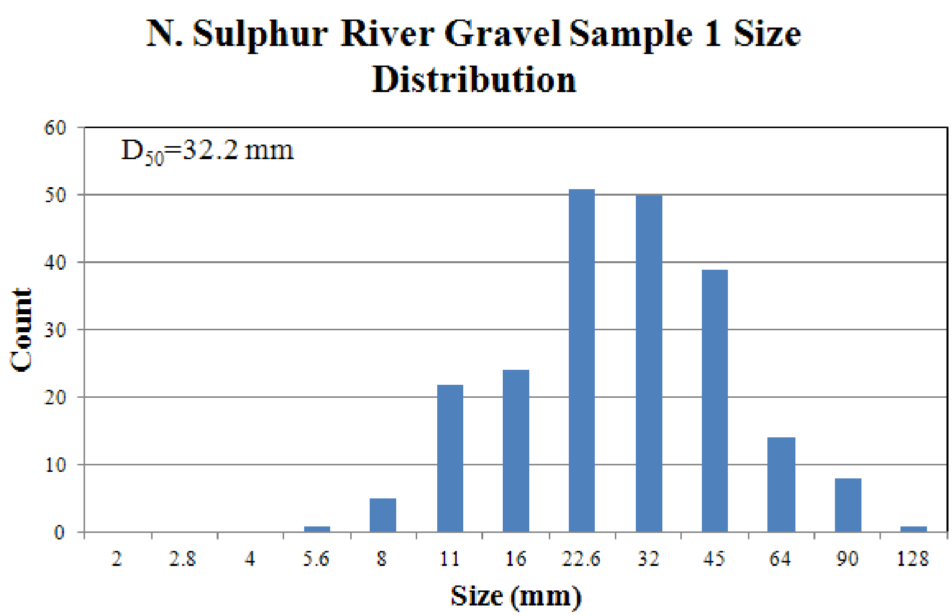


Figure 2.10: Gravel size distribution for SH34 at N. Sulphur River (Sample #1)

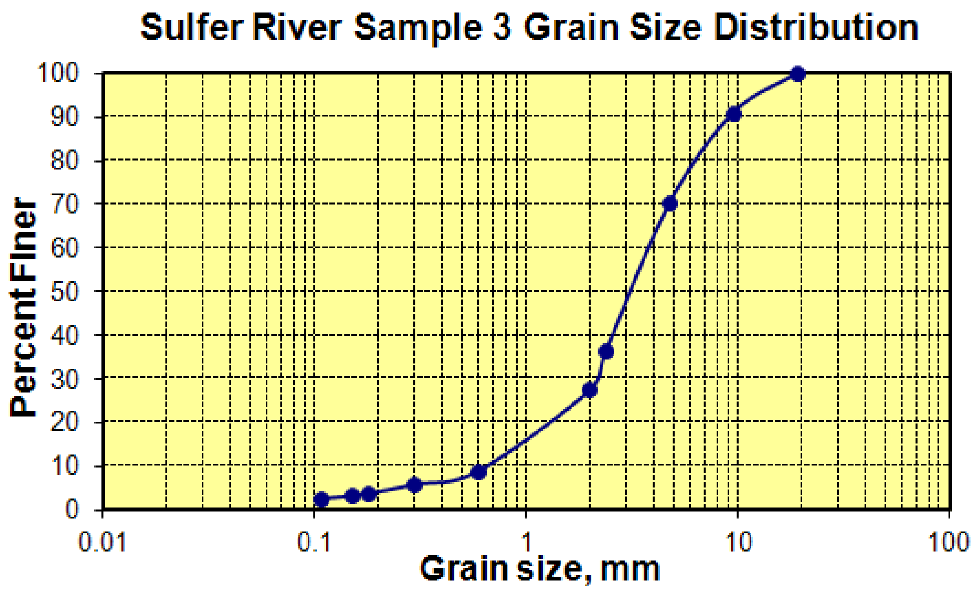


Figure 2.11: Bed material size distribution for SH34 at N. Sulphur River (Sample #3)

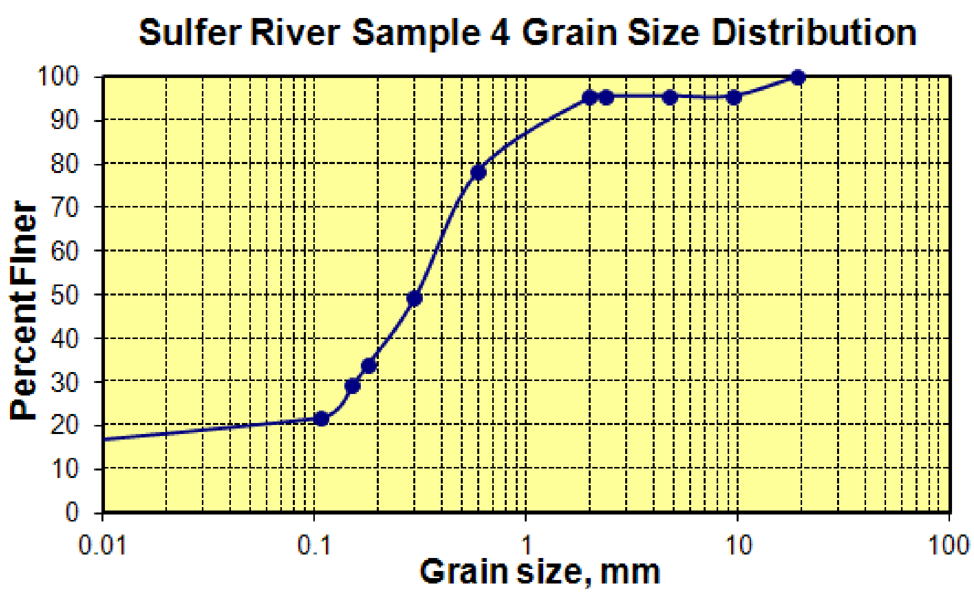


Figure 2.12: Bed material size distribution for SH34 at N. Sulphur River (Sample #4)

River	Sample	GPS Coordinates		Brief Description
SH 105 at Brazos River	S1B1	30°21'49.20"N	96° 9'8.50"W	sandy soil, fine grained, digged 1 foot, orange/brown color
	S1B2	30°21'49.20"N	96° 9'8.60"W	wet clay, 9 feet away from S1B1, halfway from river to top
	S1B3	30°21'52.10"N	96° 9'4.70"W	sand, looks like sediment from point bars, not representative
	S1B4	30°21'47.50"N	96° 9'12.10"W	same soil as in S1B1, not too much effort to drive
	S1B5	30°21'41.60"N	96° 9'18.90"W	10 feet away from water, beneath the bridge, dark color, muddy
	S1B6	30°21'41.80"N	96° 9'21.00"W	from west side of river, clayey, dark color, muddy
FM 787 at Trinity River	S2B1	30°25'42.70"N	94°50'50.30"W	sandy soil, has vegetation, 20 feet away from river, light brown
	S2B2	30°25'42.70"N	94°50'49.70"W	sandy soil, has vegetation, 25 feet away from river, light brown
	S2B3	30°25'42.40"N	94°50'49.60"W	sandy soil in bag, from cliff, has roots
	S2B4	30°25'29.61"N	94°51'4.69"W	dark soil from west side, clay and sand, has roots
	S2B5	30°25'30.00"N	94°51'4.60"W	dark soil from west side, sand
SH 63 at Sabine River	S3B1	31° 3'51.90"N	93°31'13.50"W	sandy soil, tube inserted horizontally, area looks eroded, light brown color
	S3B2	31° 3'52.14"N	93°31'13.02"W	sandy soil, tube inserted horizontally, area looks eroded, close to the river
	S3B3	31° 3'51.96"N	93°31'12.12"W	sandy soil, tube inserted horizontally, area looks eroded, 5 feet from water
	S3B4	31° 3'51.60"N	93°31'11.70"W	sand from under the bridge, layers of different colors, wet
SH 34 at North Sulfur River	S4B1	33°27'22.26"N	95°56'32.28"W	away from bridge, different sizes, wet, clay and sand
	S4B2	33°27'21.84"N	95°56'30.54"W	under the bridge, next to column, wet, sand with different sizes
	S$B3	33°27'22.02"N	95°56'30.36"W	under the bridge, next to column, wet, sand with different sizes
	S4B4	33°27'22.44"N	95°56'30.72"W	under the bridge at center, wet, sand with different sizes
	S4B5	33°27'21.54"N	95°56'30.18"W	at side of the river, wet clay, hard to drive, dark gray color
US 90 at Nueces River	S5B1	29°12'28.62"N	99°54'12.66"W	very fine grained with a few pebbles, light brown color, from west side of bend
	S5B2	29°12'29.10"N	99°54'12.54"W	very fine grained with a few pebbles, light brown color, from west side of bend
	S5B3	29°12'32.70"N	99°54'10.50"W	very fine grained with a few pebbles, light brown color, from west side of bend
	S5B4	29°12'23.76"N	99°54'12.18"W	from bottom of bridge, sand and small rocks, dry
	S5B5	29°12'23.70"N	99°54'12.18"W	from bottom of bridge, sand and small rocks, dry
	S5B6	29°12'23.82"N	99°54'12.24"W	from bottom of bridge, clayey, brown color, wet
	S5B7	29°12'39.30"N	99°53'53.34"W	from east side of bend to the north of bridge, light brown color, 3 bags

Table 2.3: Bank material sample locations and brief descriptions

City which varied between clay and coarse sand.

- Sabine River: From the Neches River mouth to the southeast Louisiana coast, there is an alternating narrow and wide belt of very fine sand. The mechanism that caused this belt might be a sediment-bearing current moving southward through the lake toward the Louisiana coast. Very fine sand is also found along the near shore areas.

2.3 Flow information

In another TxDOT research project 0-6654, an extensive database built upon USGS gauging station records has been used. Part of the research team also participated in that project. It gives us the access to that flow database, which contains the data for 437 gauging stations in Texas. The database is in the format of text file.

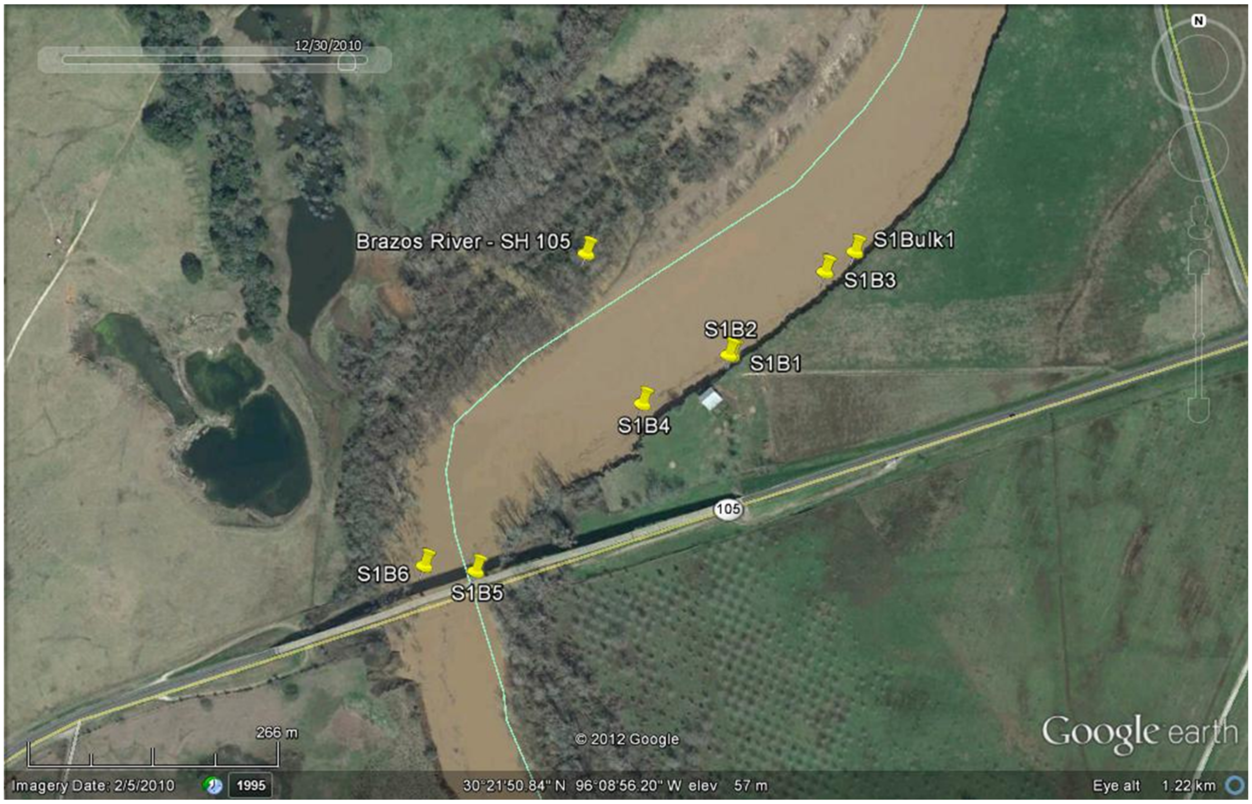


Figure 2.13: Locations of the bank material samples for the Brazos River at SH105

Dr. William Asquith from USGS used custom computer programs and internal access methods to the National Water Information System (NWIS), generated a text file titled *QVFAB.txt*. This file contains 89,874 records of selected entries from the measurement database for 437 selected Texas stations. This file provides the following attributes: discharge, velocity, area, top width, Froude number, and estimated streamflow probability.

For our project, from the point of view of fluvial hydraulics and geomorphology, one of the important parameters is the bankfull discharge. Alluvial rivers tend to construct their channel geometries and flood plains in consistent ways in terms of bankfull characteristics. Bankfull condition are attained when the river just starts to spill out of its channel banks and onto its flood plains. On the rating curves, the bankfull condition is clearly defined by a slope change. The associated geometrical characteristics of rivers are their bankfull width and depth. Due to the large variation of rivers in nature, these characteristics seems random. However, rivers establish their bankfull width and depth through the co-evolution of the river channel and the floodplain. Statistically, they follow some general rules. The bankfull cross-sections and floodplains of alluvial rivers are created by the coupled interactions of flows and sediment movements. The river bed and lower banks are constructed from bed material load. The middle and upper banks are usually constructed predominantly out of wash load. In some cases, some bed material load can also be found in the floodplains. As the river avulses and shifts, this wash load material is spread out across the

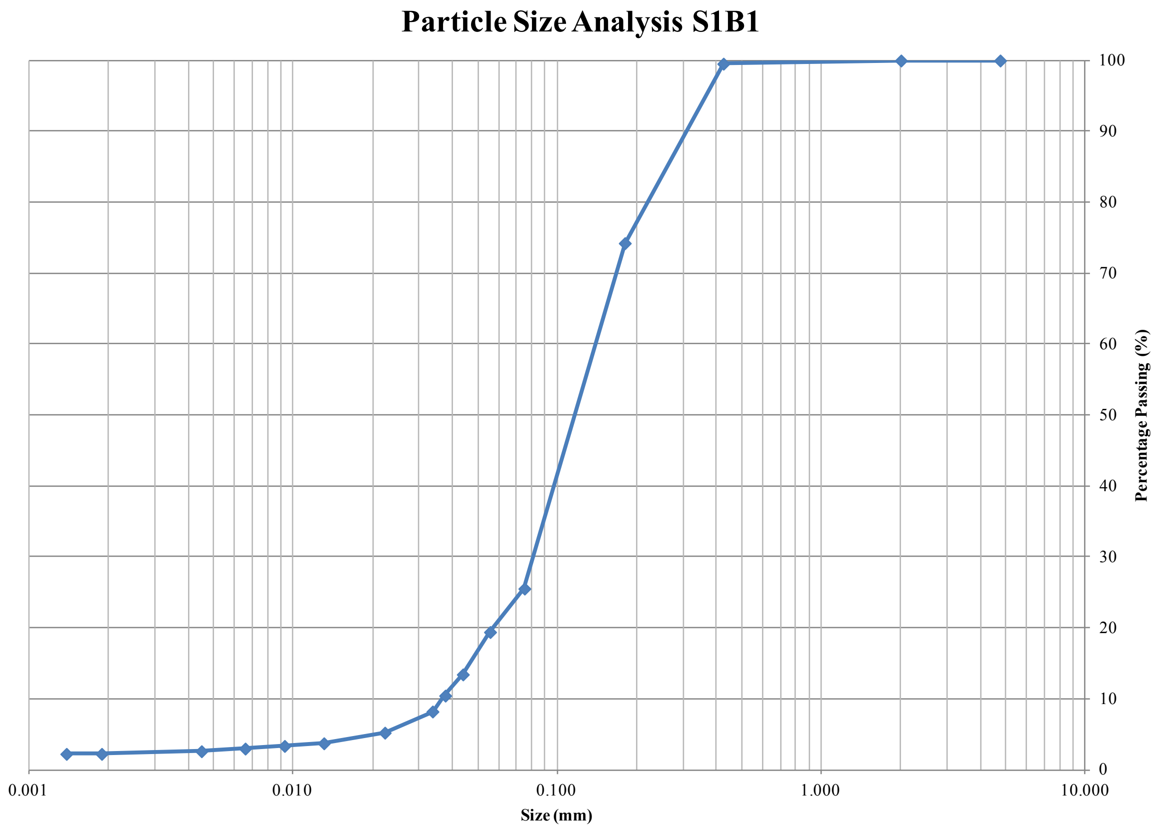


Figure 2.14: Bank material size distribution of sample 1 for the Brazos River at SH105

floodplain.

In our project, to predict the migration of meander channels, the bankfull discharge and cross section geometry are required by some predictive tools. To infer these information, we can use that database. As an example of using the flow database, the flow duration curve and the discharge-topwidth curve for USGS station 8195000 (Frio River at Concan, TX) are plotted in Figure 2.44. The bankfull discharge was determined to be around 50 cfs. This value was also confirmed by the discharge-topwidth curve. This bankfull discharge can be used as input parameter for RVRMeander, one of meander prediction models we used in this project.

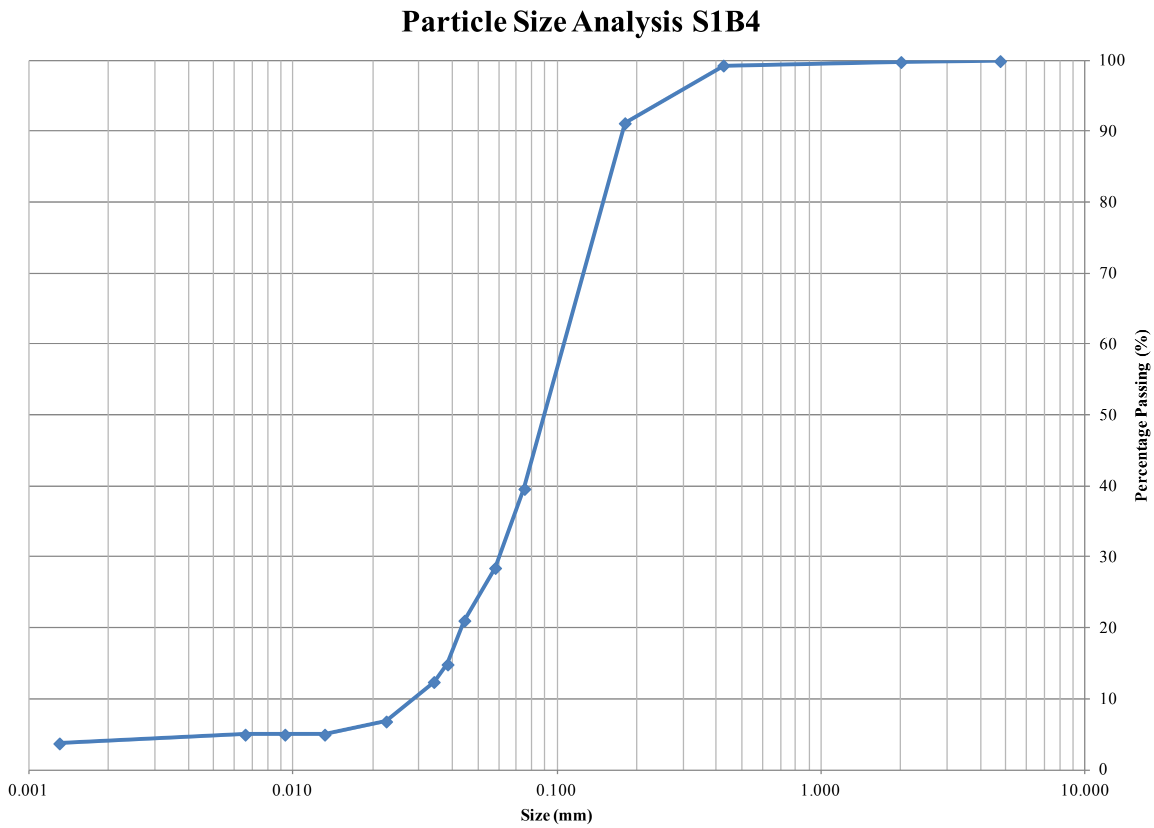


Figure 2.15: Bank material size distribution of sample 4 for the Brazos River at SH105

2.4 Historical maps

A database of historic maps was built up for the selected sites. Different formats of the maps are available including "KML", "JPG" and "PNG" file. Most of the historical maps were topographic maps. Digital copies of images are approximately 1800x1800 pixels. Images can also be imported into GIS applications using WORLD or KML files. KML files can be converted into Shape file by using free software DNRGarmin 5.4.1. Google Earth extracted polygons/lines/points can also be converted into shape files using this software. The following is a list of the historical maps collected for each site.

- SH190 at Sabine River
  - Source: historicaerials.com
    - Aerial map: 2004, 2007

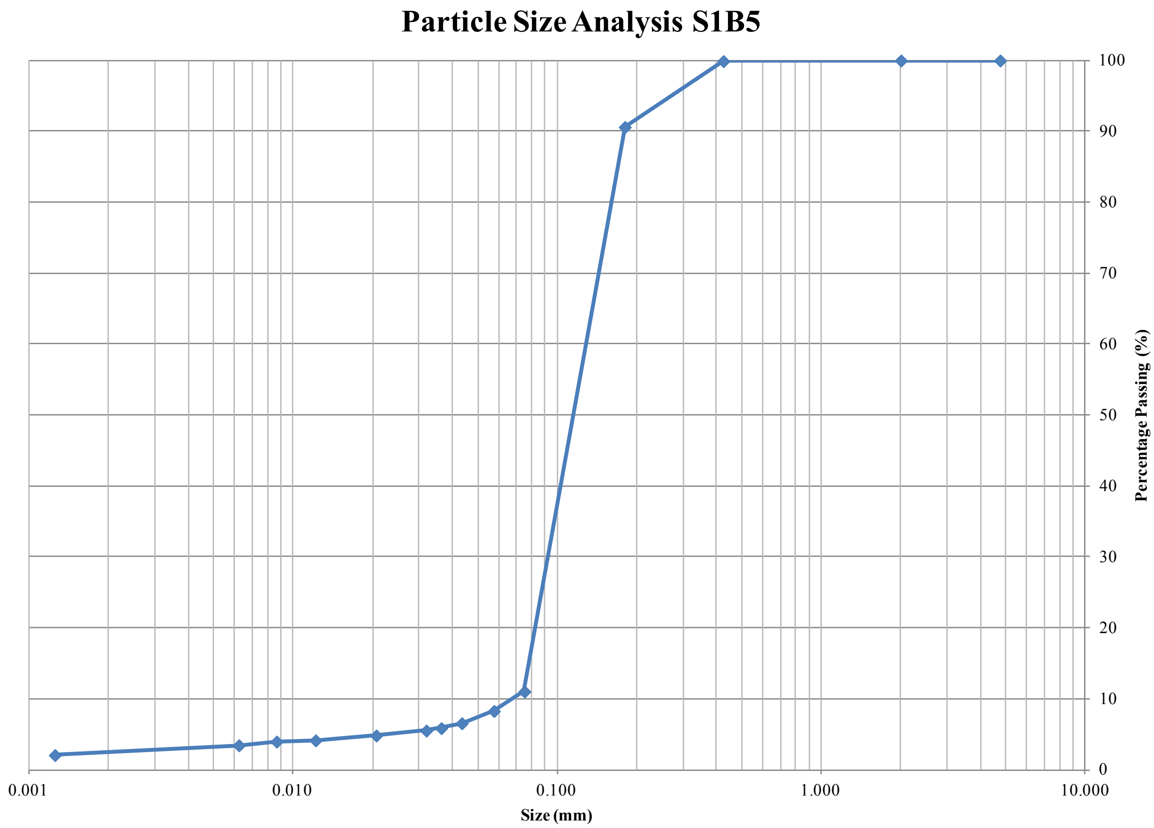


Figure 2.16: Bank material size distribution of sample 5 for the Brazos River at SH105

    * Topographic map: 1954, 1960, 1986, 1988
  - Source: Google Earth
    * 1996, 1998, 2003, 2004, 2005, 2006, 2007, 2009, 2010
- SH34 at North Sulphur River
  - Source: historicaerials.com
    * Aerial map: 1964, 2004
    * Topographic map: 1968, 1985, 1991
  - Source: Google Earth
    * 2005, 2008, 2012

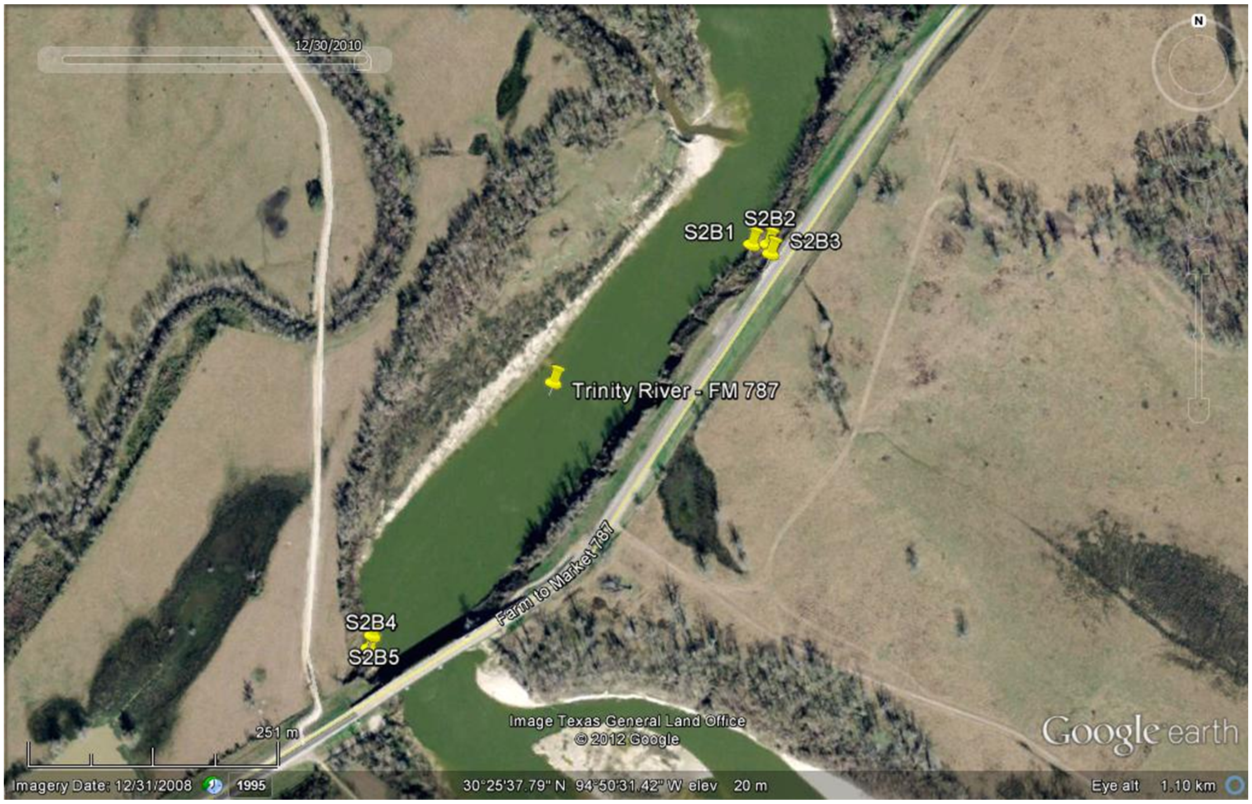


Figure 2.17: Locations of the bank material samples for the Trinity River at FM787

- FM787 at Trinity River:
  - Source: historicaerials.com
    - Aerial map: 2004
    - Topographic map: 1943, 1957, 1967, 1985, 1986
  - Source: Google Earth
    - 1995, 1996, 2005, 2006, 2008, 2009
- US90 at Nueces River:
  - Source: historicaerials.com
    - Aerial map: 2004
    - Topographic map: 1898, 1910, 1931, 1962, 1985, 1992
  - Source: Google Earth
    - 1996, 2005, 2008, 2012

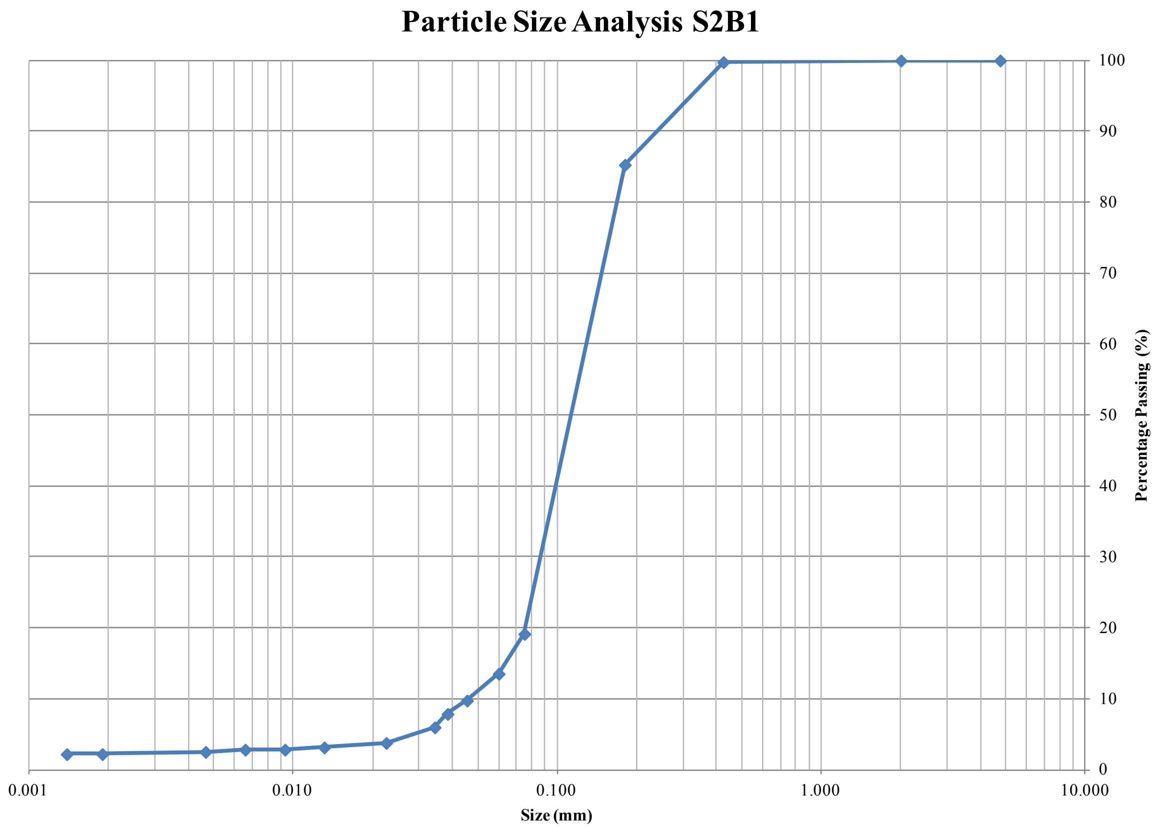


Figure 2.18: Bank material size distribution of sample 1 for the Trinity River at FM787

- SH105 at Brazos River
  - Source: historicaerials.com
    - Aerial map: 2004
    - Topographic map: 1914, 1942, 1960, 1989
  - Source: Google Earth
    - 1995, 2003, 2005, 2008, 2009, 2010, 2011

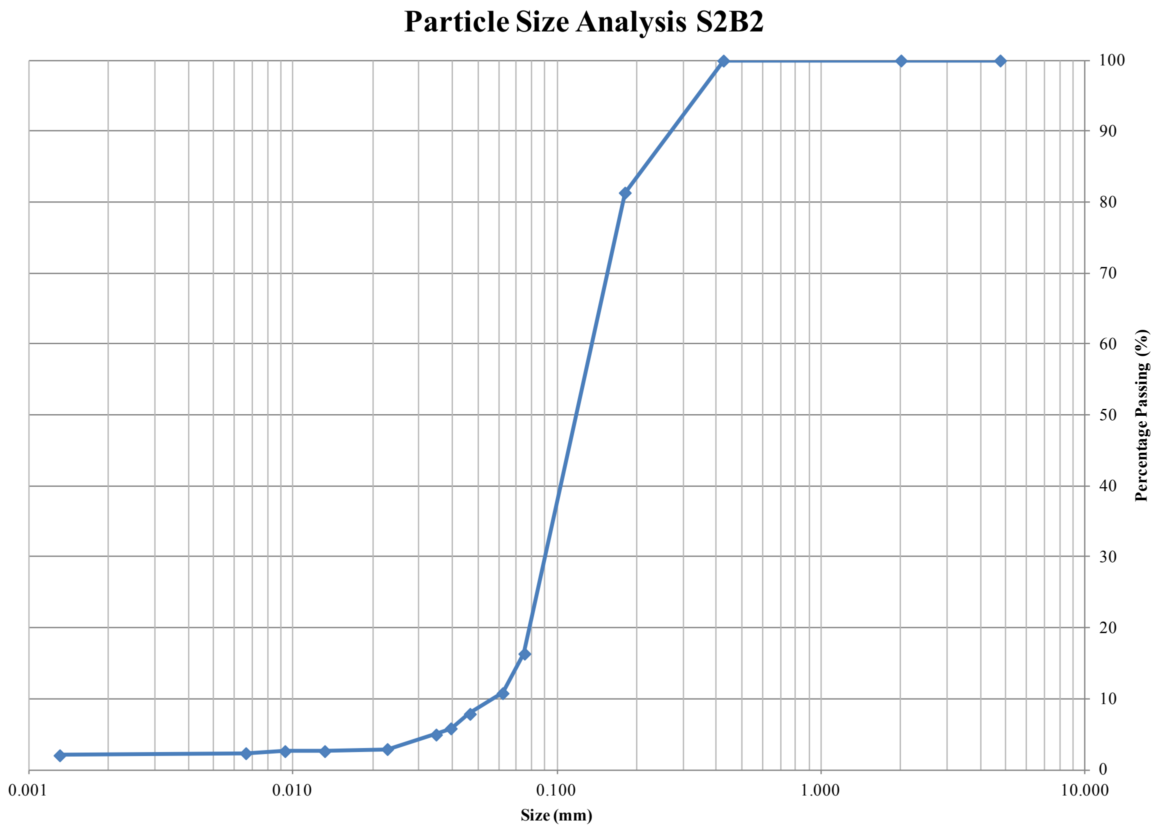


Figure 2.19: Bank material size distribution of sample 2 for the Trinity River at FM787

2.5 Summary

In this technical memo, the data collected for this project was documented. The data ranges from sediment data, flow data, to historical maps. The sediment data has two parts. The first part of the information is collected by the research team for the sites selected for this project. The second part is a compilation of sediment data (sizes, distribution, and load) for the major rivers in Texas from literature. The flow data was built upon an existing USGS gauging station database, which contains 9,874 measurement records for 437 selected Texas stations. A database of historic maps was also built for the selected sites. The data collect in this task will be used for channel stability predictions as model inputs.

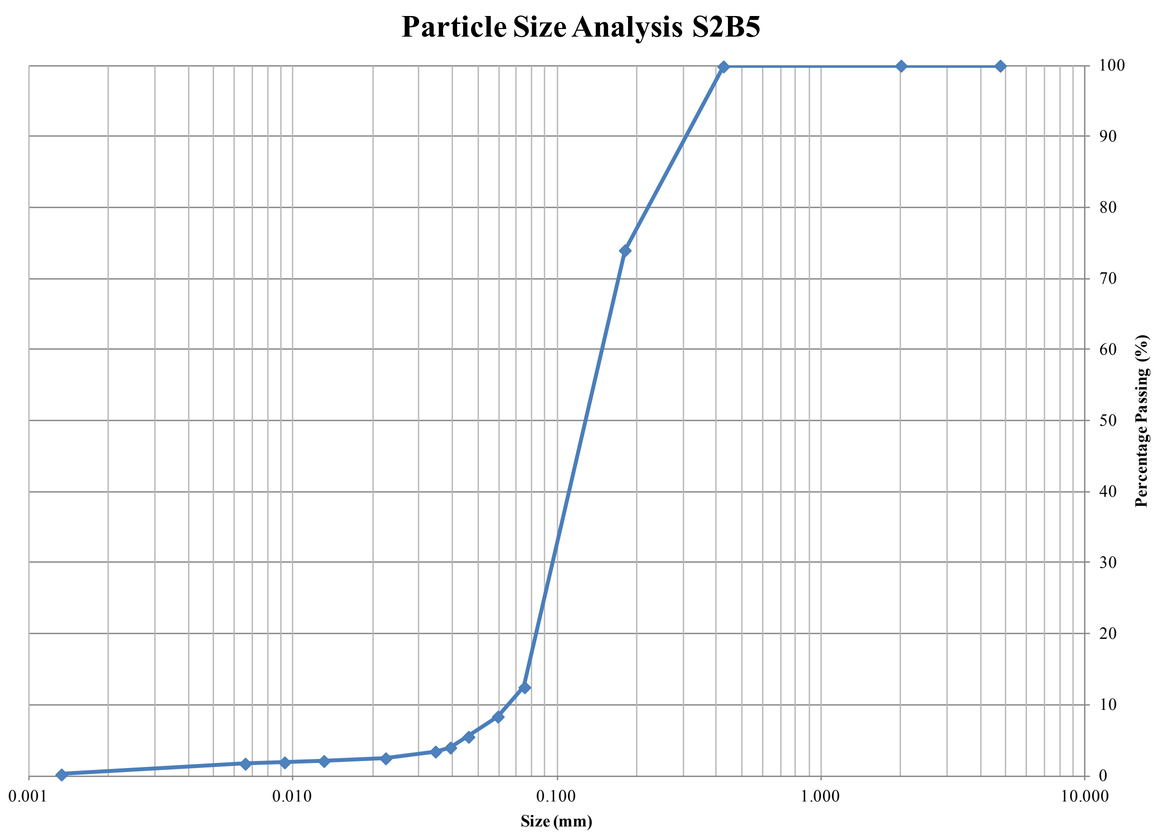


Figure 2.20: Bank material size distribution of sample 5 for the Trinity River at FM787

Figure 2.21: Locations of the bank material samples for the Sabine River at SH63

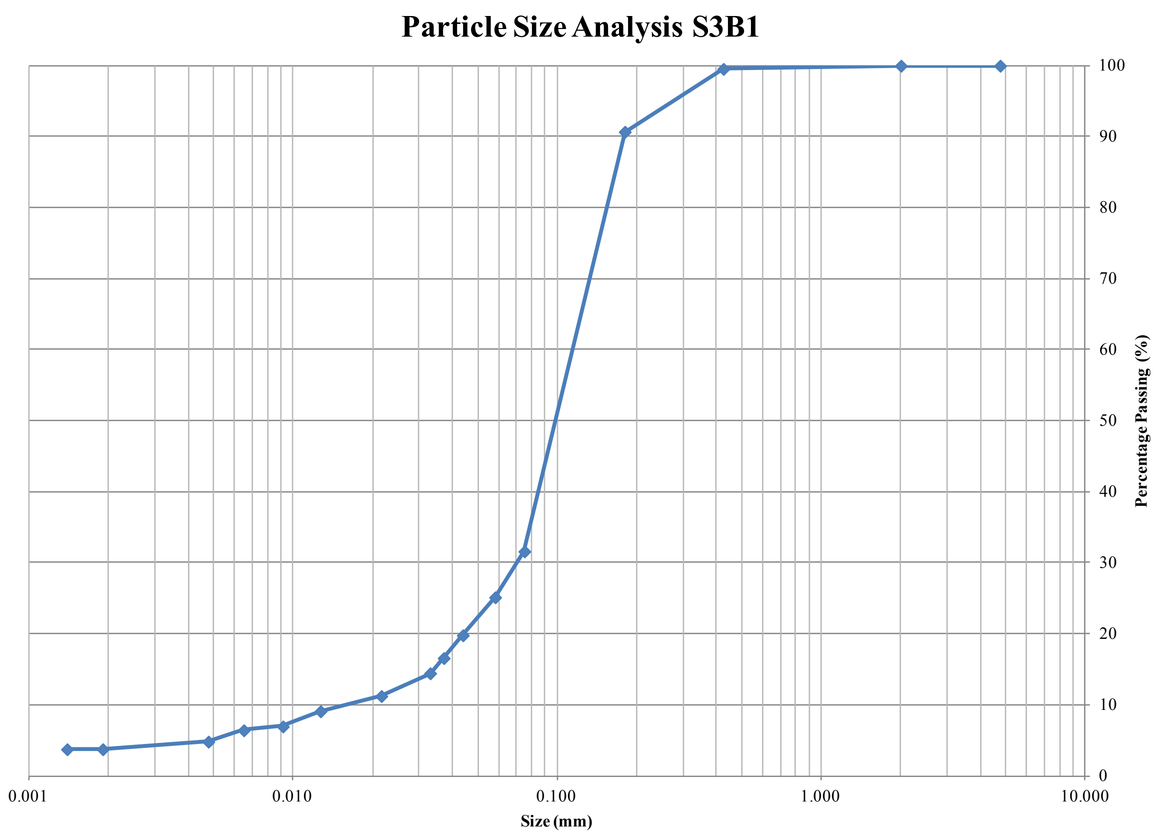


Figure 2.22: Bank material size distribution of sample 1 for the Sabine River at SH63

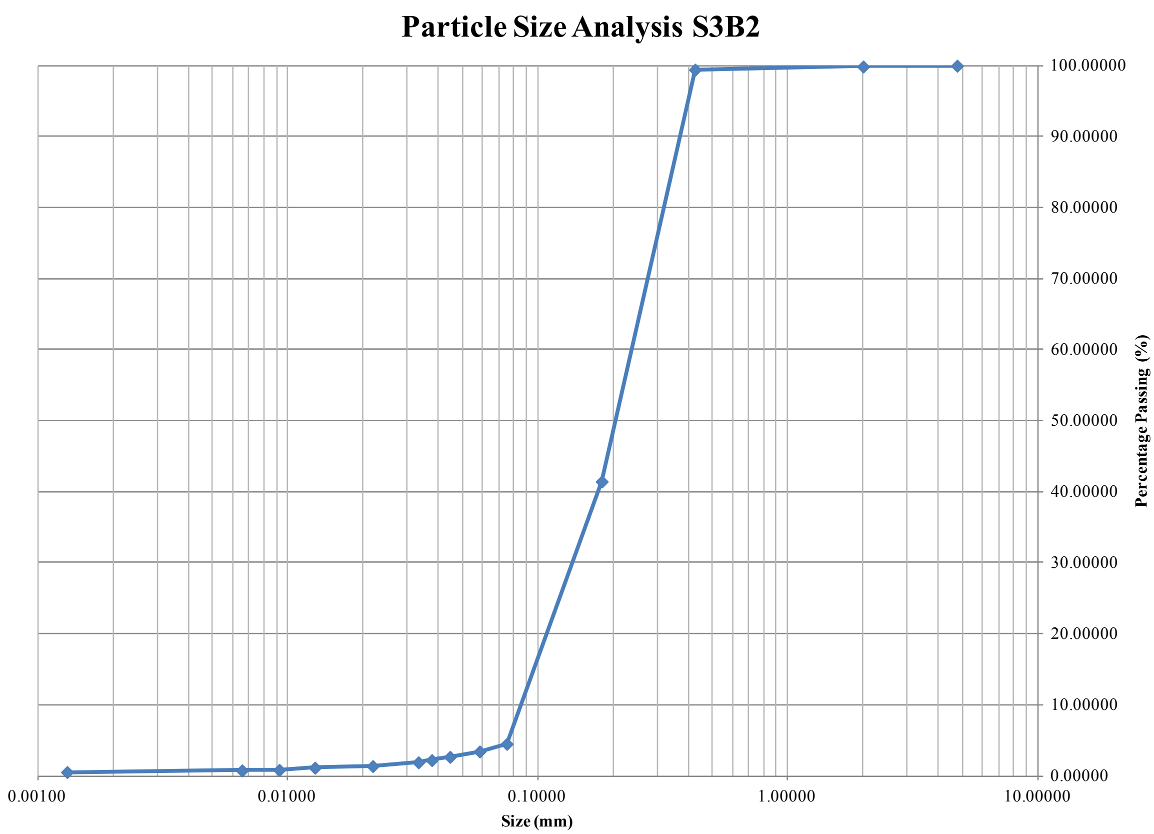


Figure 2.23: Bank material size distribution of sample 2 for the Sabine River at SH63

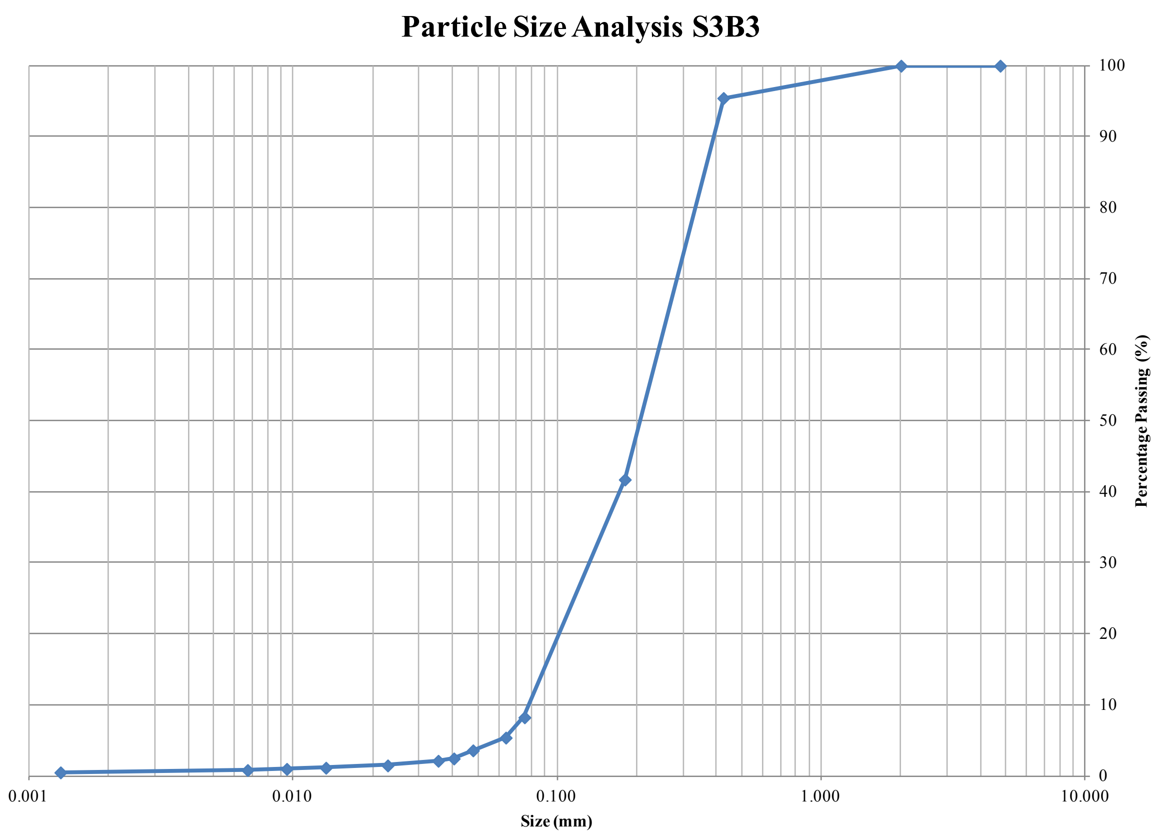


Figure 2.24: Bank material size distribution of sample 3 for the Sabine River at SH63

Figure 2.25: Locations of the bank material samples for the North Sulfur River at SH34

Figure 2.26: Locations of the bank material samples for the Nueces River at US90

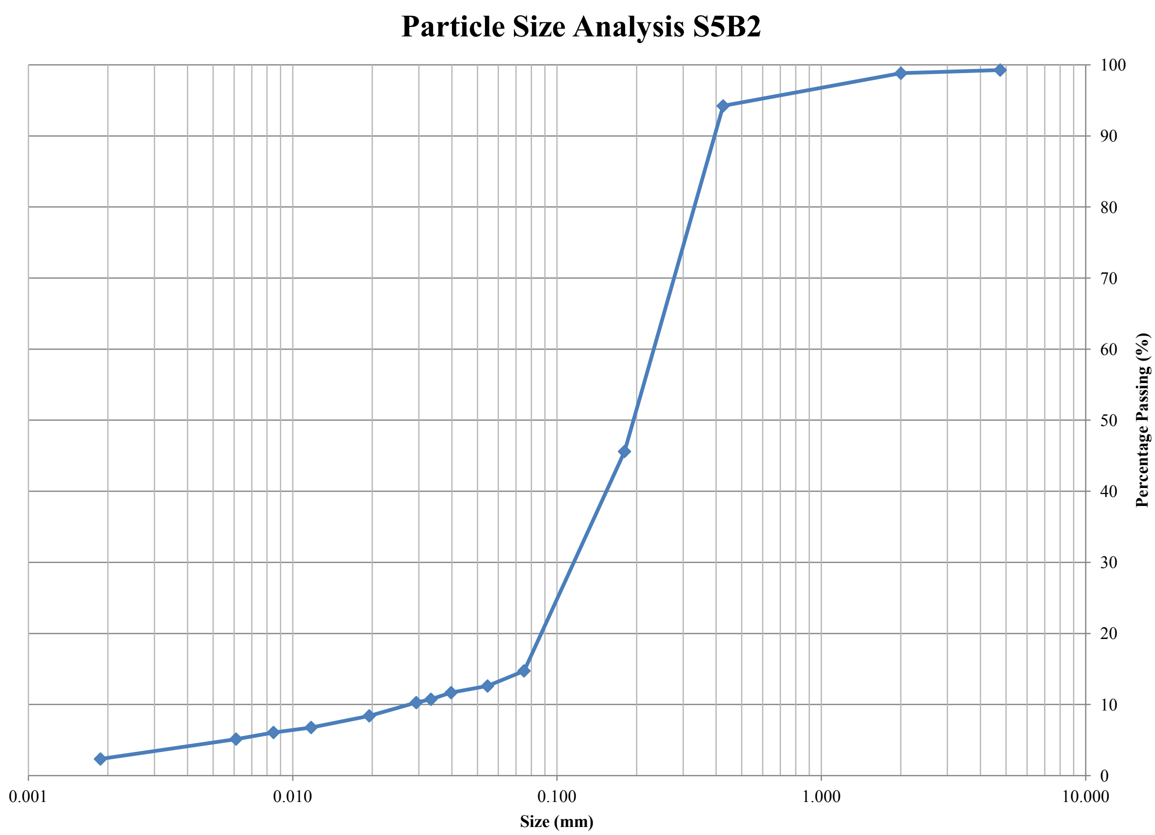


Figure 2.27: Bank material size distribution of sample 2 for the Nueces River at US90

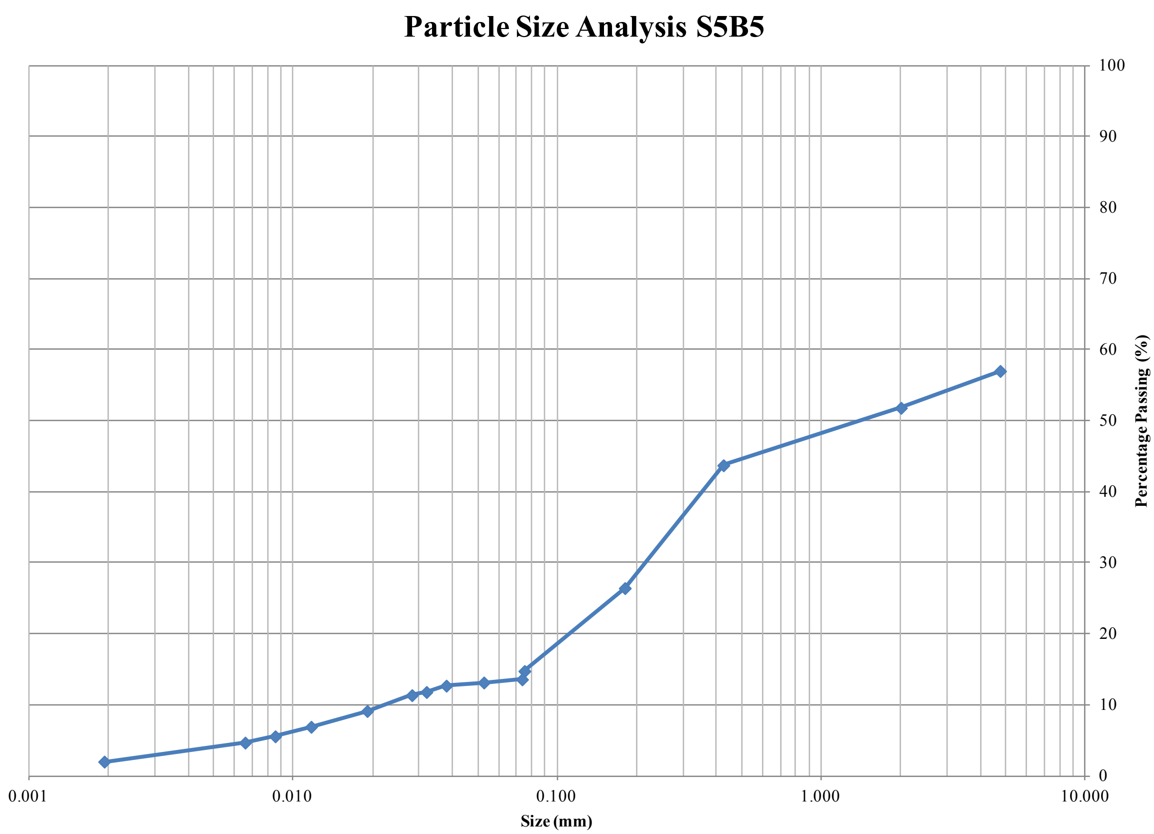


Figure 2.28: Bank material size distribution of sample 5 for the Nueces River at US90

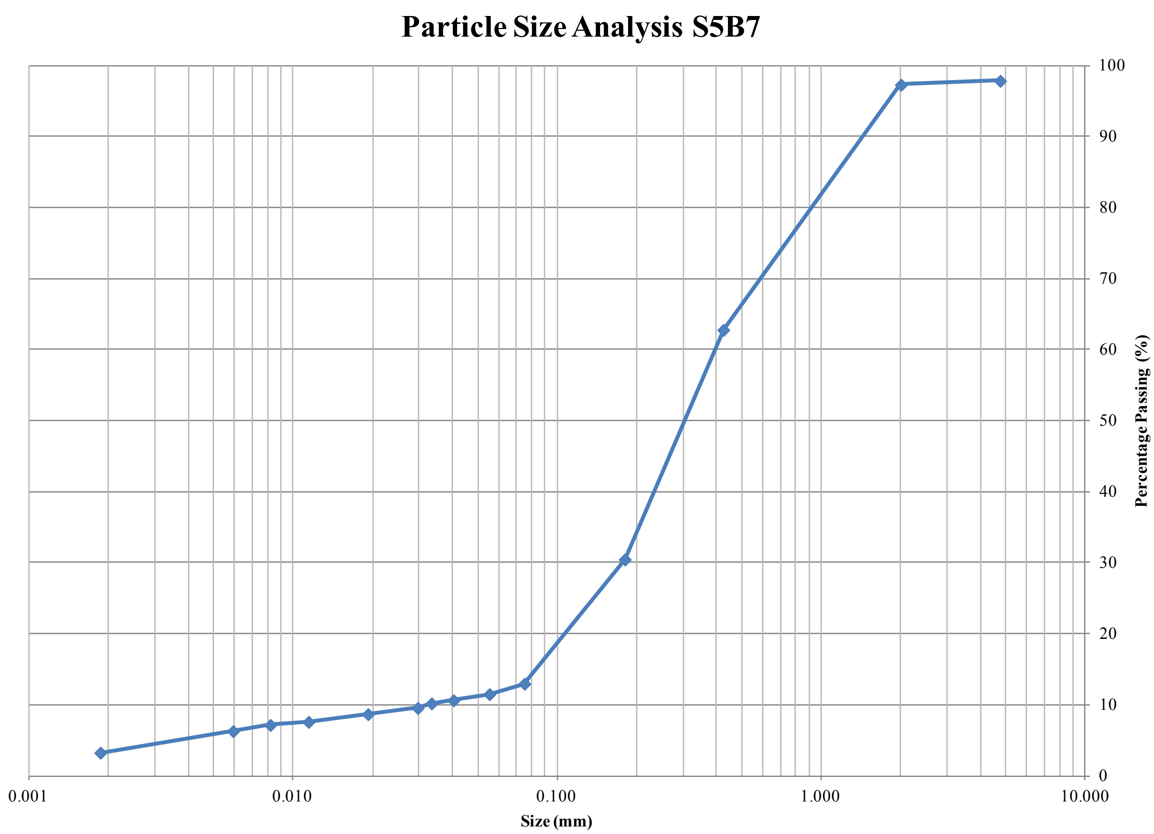


Figure 2.29: Bank material size distribution of sample 7 for the Nueces River at US90

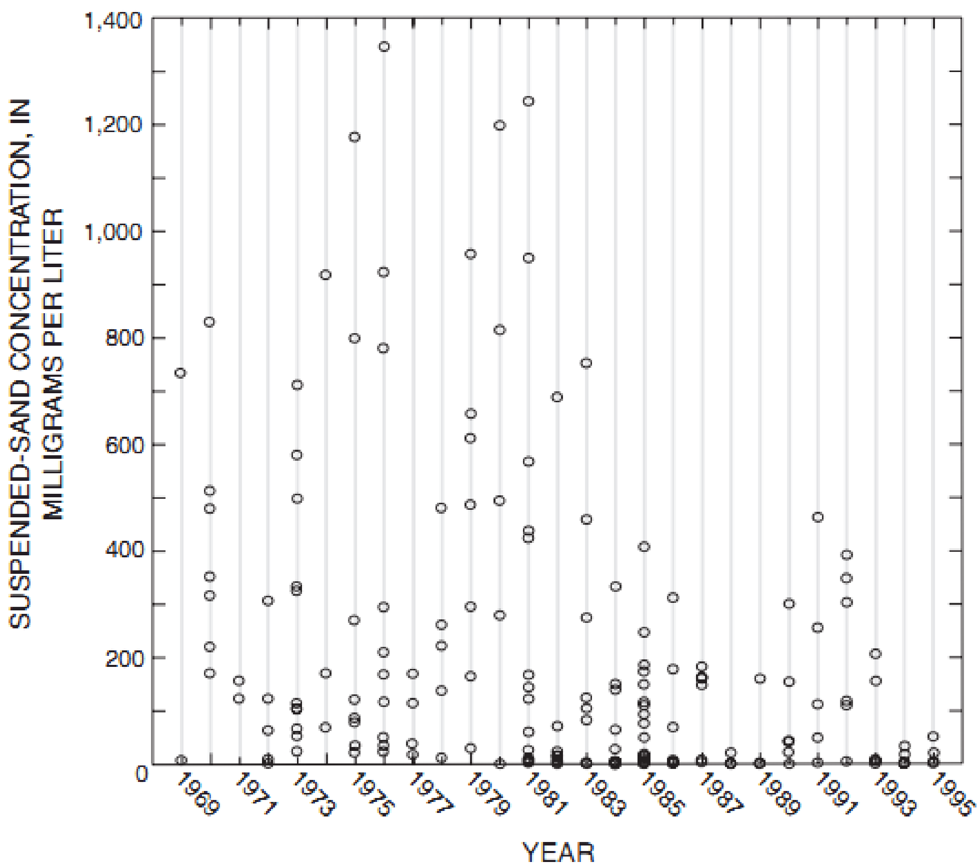


Figure 2.30: Suspended-sand concentrations in samples at stream flow gaging station 08114000 Brazos River at Richmond, Texas, 1969-95 (Water Resources Investigations Report 01-4057, USGS)

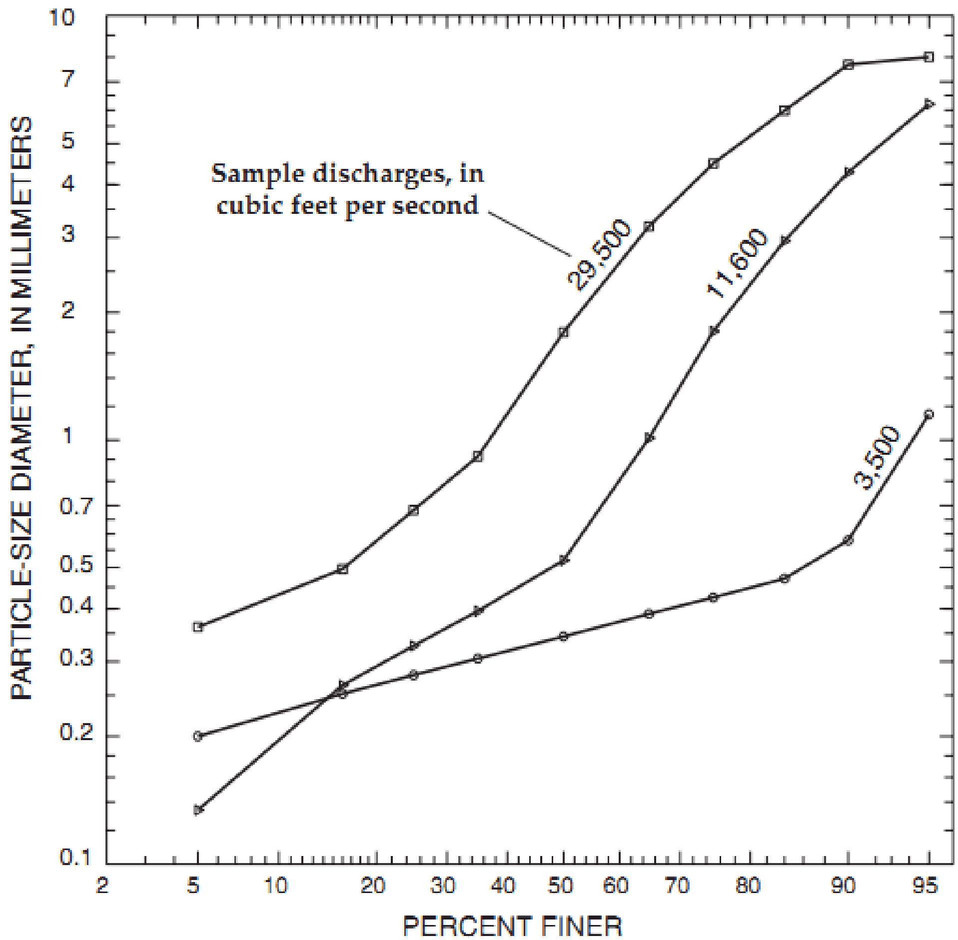


Figure 2.31: Particle-size distributions of bed material samples near stream flow-gaging station 08114000 Brazos River at Richmond, Texas (Water Resources Investigations Report 01-4057, USGS)

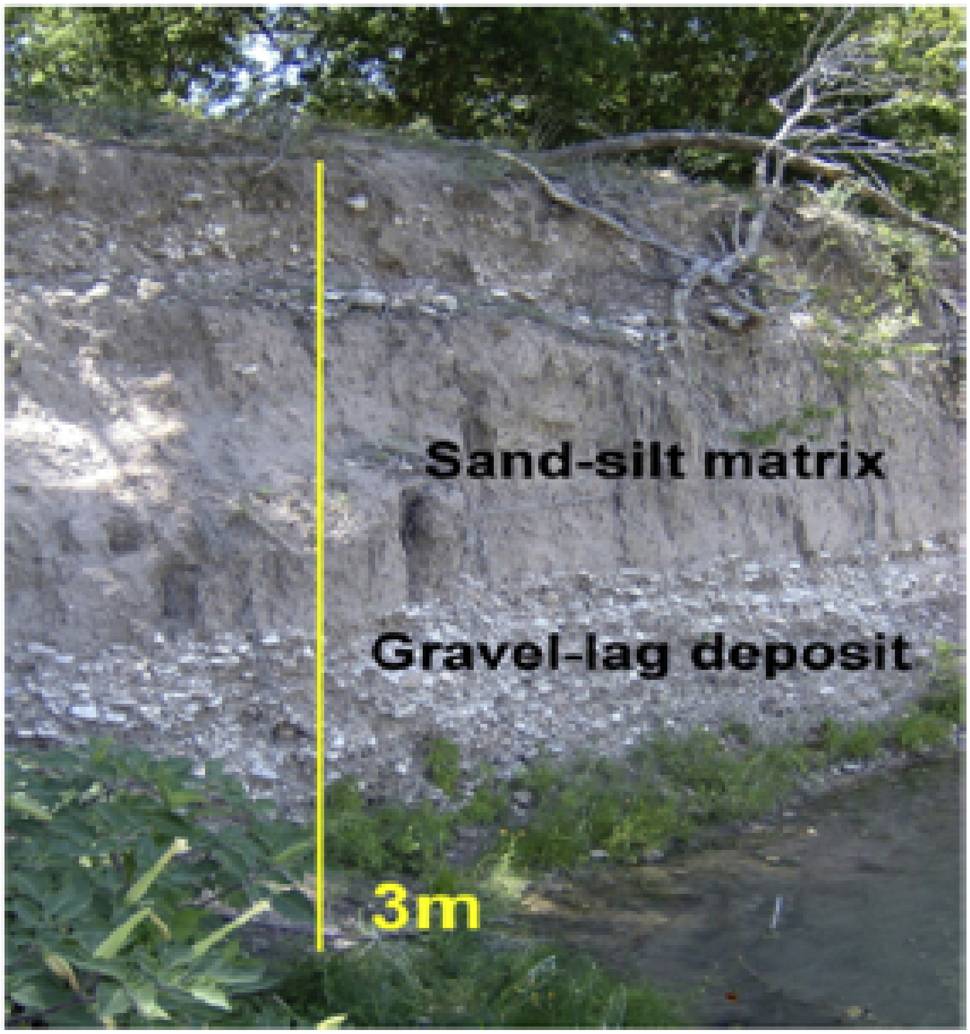


Figure 2.32: Right bank (height 3 m) of South Llano River at Texas Tech University-Junction, Texas. Note: the gravel-lag deposits occurring within a fine-grained matrix at the base (Heitmuller et al, 2009)

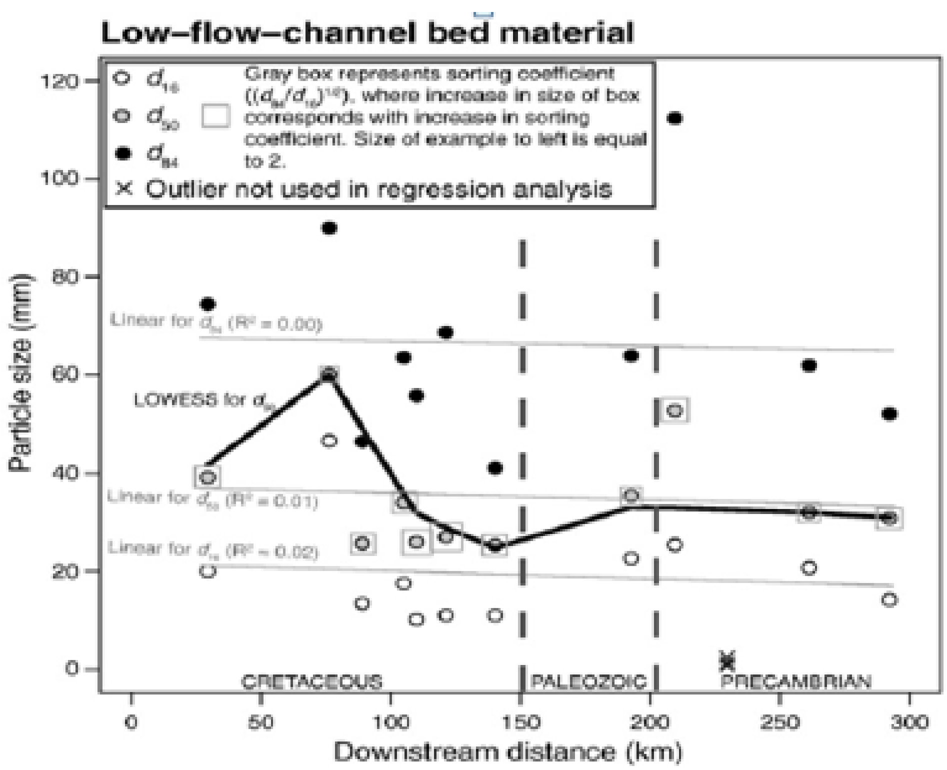


Figure 2.33: Linear regression and LOWESS trend line (smoothing factor of 0.6) of particle size (d16 , d50 , and d84) with downstream distance for low-flow-channel-bed material of the North Llano, South Llano, and Llano Rivers in central Texas. One outlier at Llano River at Castell is not included in the statistical analysis (Heitmuller et al, 2009)

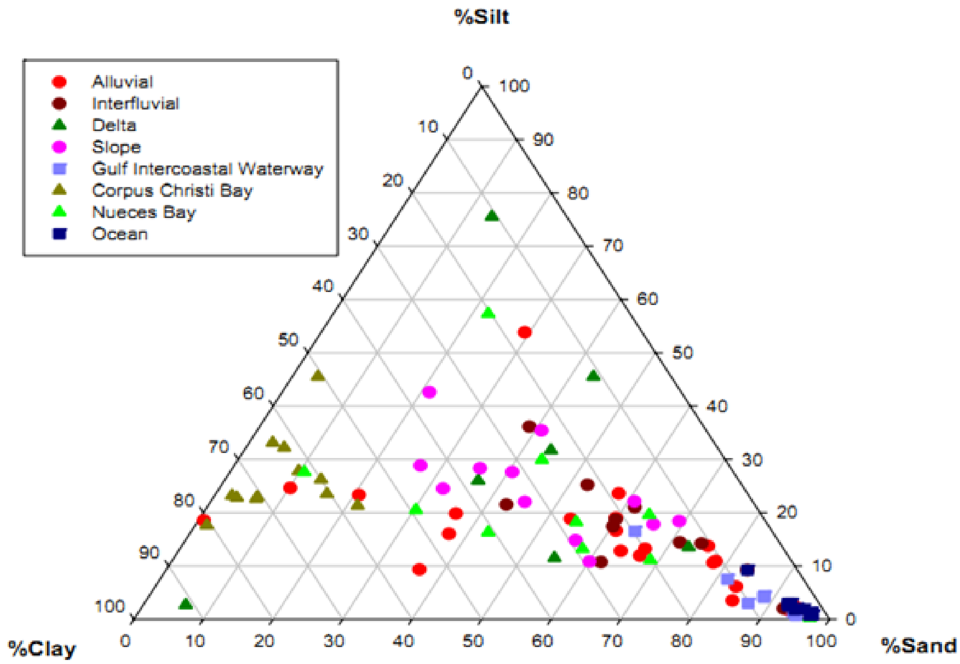


Figure 2.34: Ternary plot of grain size fractions for all surface sediment samples (Santschi and Yeager , 2004)

Suspended sediment size					
USGS St No	Site Name	D16 (mm)	D50 (mm)	D84 (mm)	Source
08176500	Victoria	NA	4.2	25	Holley (1992)
Suspended Load					TWDB
USGS St No	Site Name	NDA,mi²	SSL, T/yr	SSL, T/yr/mi²	
08176500	Victoria	3766	629051	167	TWDB
08167500	Spring Branch	1315	178785	136	Holley (1992)

Figure 2.35: Sediment data at USGS stations in the Guadalupe River basin

Suspended sediment size					
USGS St No	Site Name	D16 (mm)	D50 (mm)	D84 (mm)	Source
08147000	San Saba	NA	NA	0.01	TxDot report (1967)
08160500	La Grange	NA	0.5	NA	Bio-West, Inc (2008)
08161000	Colombus	NA	0.35	NA	Bio-West, Inc (2008)
Suspended Load					
USGS St No	Site Name	NDA,mi²	SSL, T/yr	SSL, T/yr/mi²	
08146000	San Saba	3039	99939	33	TWDB
08147000	San Saba	19819	2657807	134	TWDB
08148000	Burnet	20512	17186	1	TWDB
08151500	Llano	4192	440300	105	TWDB
08158000	Austin	27606	97849	4	TWDB

Figure 2.36: Sediment Data at USGS Stations in Colorado River Basin

Suspended Sediment				
USGS St No	Station Name	NDA, mi²	SSL, Tons/yr	SSY, Tons/yr/mi²
8186000	Falls City	827	118652	143
8188500	Golliad	3921	498410	127
Bed Material				
USGS St No	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Source
08188500	NA	NA	0.005	TxDot report (1967)
08188500	NA	4	25	Holley (1992)

Figure 2.37: Sediment Data at USGS Stations in San Antonio River Basin

Sample Location	At or Near Station	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)
Below Olmos Subreach	At	2.36	23.66	48.7
Park 1 Subreach	At	2	21.79	57.64
Park 2 Subreach	At	1.6	20.35	55.02
Catalpa Ditch	At	0.0003	17.47	54
Urban Subreach	At	0.99	7.9	26.42
Eagleland Subreach	At	2.15	12.5	36.56
Below Outlet Subreach	At	1	10.01	38.6
Conception Subreach	At	2.7	10.01	32.61
Mission Subreach	At	5.72	14.84	31.7
San Juan Subreach	At	4.39	14.85	34.15
Davis Subreach	At	3.07	15.77	57.38
Below Espada Subreach	At	3.87	13.92	43.53
Six Mile Subreach	At	3.99	15.66	45
410 Subreach	At	2.63	17.84	38.89
Below Project Subreach	At	3.35	20.99	39.66

Figure 2.38: Sediment Data for the San Antonio River near San Antonio, Texas (Source: Geomorphic and Sediment Transport Technical Memorandum Mission Reach, S.A.R.I.P)

Sample location	USGS St No	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Source
Bed	08066250	0.0045	0.12	0.6	Musselman (2006)
Bed	08066500	0.063	0.35	NA	Phillips (2003)
Bed	08067000	0.154	0.203	0.354	Phillips (2003)
Bed	08066500	0.21	0.28	0.38	NCHRP

Figure 2.39: Bed Sediment Data at USGS Stations in Trinity River Basin

Suspended Sediment					
USGS St No	Station Name	NDA, sq-mi	SSL, Tons/yr	SSY, Tons/yr/mi^2	Source
8062500	ROSSER	8147	951046	117	TWDB
8064500	CORSICANA	963	438541	455	TWDB
8065350	CROCKET	13911	5112515	368	TWDB
8066200	LIVINGSTON	141	170637	1210	TWDB
8066500	ROMAYOR	17186	3378461	197	TWDB
8067000	LIBERTY	17476	69673	4	TWDB

Figure 2.40: Suspended Sediment Data at USGS Stations in Trinity River Basin

Suspended Sediment					
USGS St No	Station Name	NDA, mi^2	SSL, Tons/yr	SSY, Tons/yr/mi^2	Source
7298500	BRICE	5972	14581838	2442	USGS REPORT 83-693
7299500	ESTELLINE	7293	18844677	2584	USGS REPORT 83-694
7308500	BURKBURNETT	20570	6559516.2	319	USGS REPORT 83-695
7316000	GAINESVILLE	30782	82364871	2676	USGS REPORT 83-696
7331600	DENISON	39720	4333505.9	109	USGS REPORT 83-697
7336820	DE KALB	47348	2089027.7	44	USGS REPORT 83-698
7335500	ARTHUR CITY	44531	14320000	322	Copeland (2002)
Bed Material					
USGS St No	Station Name	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Source
7335500	ARTHUR CITY	0.18	0.3	0.5	Derrick et al. (2000).

Figure 2.41: Sediment Data at USGS Stations in Red River Basin

Suspended sediment size					
USGS St No	Site Name	D16 (mm)	D50 (mm)	D84 (mm)	Source
8028500	Bon Weir	NA	0.06	0.2	Soar and Thorne (2001)
Suspended Load					
USGS St No	Site Name	NDA, mi²	SSL, T/yr	SSL, T/yr/mi²	
8022000	Tatum	3493	132583	38	TWDB
Bed Material					
USGS St No	Site Name	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Source
08028500	Bon Weir	0.06	0.14	0.5	Soar and Thorne (2001)

Figure 2.42: Sediment Data at USGS Stations in Sabine River Basin

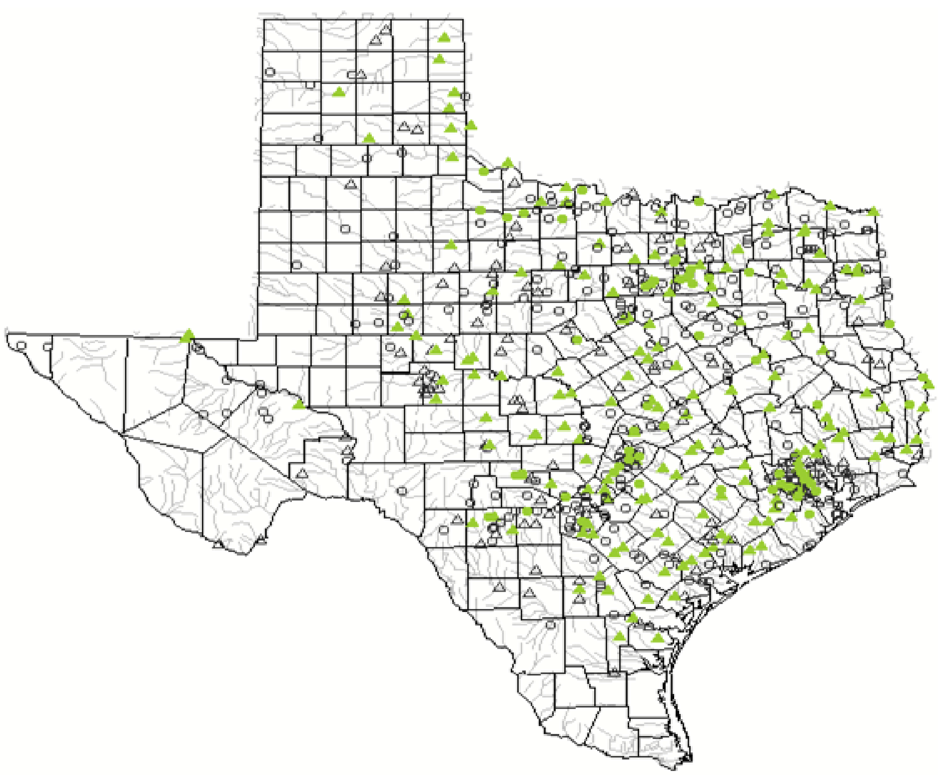


Figure 2.43: Distribution of USGS gauging stations in Texas

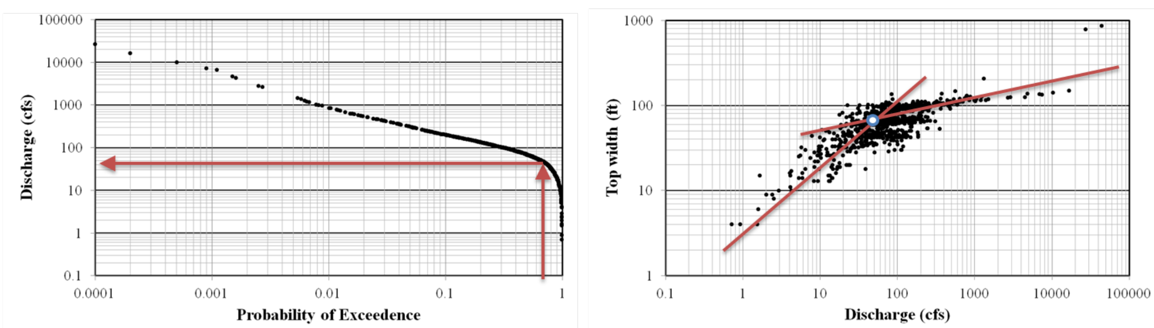


Figure 2.44: Example calculation of bankfull discharge for USGA gaging station 8195000 (Frio River at Concan, TX): (a) Flow duration curve, (b) Discharge as a function of top width. For this station, the bankfull discharge was determined to be about 50 cfs.

Chapter 3

Development of GIS Inventory for Texas Rivers

3.1 Introduction

The primary focus of this technical memorandum is to document an inventory for major Texas Rivers and provide physiographic and related data that may assist in predicting channel migration. In this case, physiography can help account for channel geometry, which in turn greatly impacts the value of the erosion coefficient because the coefficient varies with channel characteristics, bank height, and local channel slope, local channel width, and the availability of the sediment for deposition on point bars.

FHWA guideline, HEC-20 "Stream stability at highway structures", suggests a three-step analysis procedure and specifies what data should be collected. The progression into more advanced levels of analysis is accompanied with an increased need for data, the forms of which can be very different. A good presentation of the data can greatly improve the efficiency of the analysis and reduce the likelihood of mistakes. Therefore, the activity of developing a GIS inventory is of great value.

Texas contains seven primary physiographic provinces and several subdivisions. These were based on distinct types of geologic structure, soil, land cover, and climatology. Each province is characterized by a unique geological history of deposition and erosion processes. Factors that control channel stability differ within and among these subdivisions. These factors include, but not limited to, soil type, land use (e.g. urbanization), sand/gravel removal, slope, sinuosity, and installation of hydraulic structures. This task will compile a GIS database of channel properties and factors that affect channel stability for all subdivisions.

A particular factor that may define the stream stability is the topography, which determines the hydraulic gradient of the channels. ArcGIS is used to compile digital surface topography from USGS. Elevations are assigned according to USGS digital line graph standards. Maps resulting from the combining surface topographic and physiographic analysis will be instrumental in channel stability analysis.

In this GIS database, we have stored the following data: (1) Physiographical map of Texas, (2) DEM of Texas, (3) Major rivers and their watersheds, (4) Soil types and land uses, (5) Texas roadways and bridges, (6) Slopes of rivers at most USGS gauge stations. Some of the data are the results of the Task 2 "Data collection".

The database itself is just a central place for geo-referenced maps and data layers. This technical memorandum will explain some of the data and their implications for channel stabilities. It will help TxDOT engineers have an overview of the major rivers and their watershed. We will focus on the the introduction of physiographic regions, lithology, major river basins, and river slope calculations. Other information is self-evident.

This task is also conducted in close cooperation with another TxDOT research project 0-6654 ("Empirical Flow Parameters - A Tool for Hydraulic Model Validity Assessment"), where researchers from UTSA are participating in a similar task but with different emphasis.

3.2 Details on the data in the GIS inventory

The details on the data in the GIS inventory are shown below with the source of these information. Other information which can not be integrated into GIS database has been summarized in Technical Memorandum 2.

- Texas Department of Water Resources
  - Sediment Load
  - Land Use
  - Erosion Rate
- Texas Natural Resources Information Center (GIS)
  - Texas Bathymetry
  - Hydrologic Unit Codes
  - Texas Precipitation
  - Rivers and streams
  - Texas Ecological Systems
  - TxDOT Roadways
- Texas Water Development Board
  - Suspended sediment load

  - National Resources Conservation Service
  - Soil geochemistry spatial database

- National Weather Services (Nationwide)
  - Observed river gages
  - Forecast river gages
  - Flash flood guidance
  - Significant River Flood Outlook
  - Precipitation Forecasts
  - Precipitation Frequency Analysis
  - Soil Moisture
  - Evaporation
  - Runoff

3.3 Physiographic Regions

Physiography is closely connected to the geology of the watershed and this section is partially from the technical report for TxDOT project 0-6654.

Texas contains seven primary physiographic provinces and several subdivisions. These were based on distinct types of geologic structure, soil, land cover, and climatology. Each province is characterized by a unique geological history of deposition and erosion processes. Factors that control channel stability differ within and among these subdivisions. These factors include, but not limited to, soil type, land use (e.g. urbanization), and gravel removal, slope, sinuosity, and installation of hydraulic structures. These seven physiographic provinces are plotted in Figure 1. Seven physiographic provinces, three of which are further divided into subdivisions, have been identified by the Texas Bureau of Economic Geology (TBEG), as shown by the colored regions of Figure 1, and as listed in Table 3.1. The United States Geological Survey (USGS) has also developed a physiographic map of the United States including Texas (”tapestry of time and terrain”, http://tapestry.usgs.gov) based on the work of Fenneman and Johnson (1946), as indicated by the gray boundary lines in Figure 3.1.

3.4 Lithology

As for the physiography part, this section is also partially from the technical report for TxDOT project 0-6654.

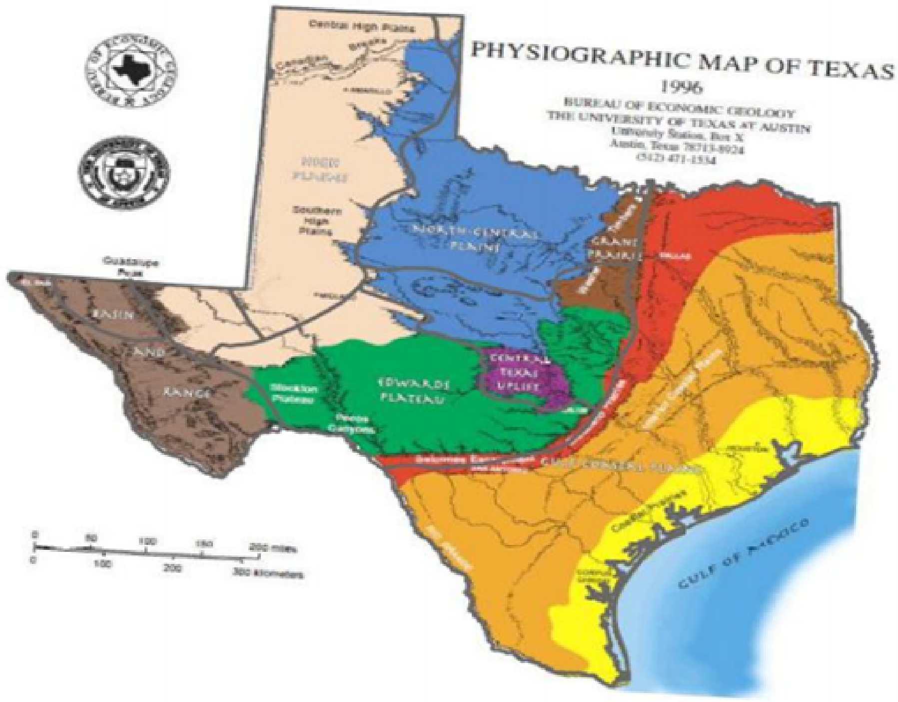


Figure 3.1: Colored physiographic provinces as defined by the Texas Bureau of Economic Geology and gray boundaries of physiographic regions as defined by USGS (`http://tapestry.usgs.gov`).

PROVINCE	MAX. ELEV. (ft)	MIN. ELEV. (ft)	TOPOGRAPHY	GEOLOGIC STRUCTURE	BEDROCK TYPES
Gulf Coastal Plains					
Coastal Prairies	300	0	Nearly flat prairie, <1 ft/mi to Gulf	Nearly flat strata	Deltaic sands and muds
Interior Coastal Plains	800	300	Parallel ridges (questas) and valleys	Beds tilted toward Gulf	Unconsolidated sands and muds
Blackland Prairies	1000	450	Low rolling terrain	Beds tilted south and east	Chalks and marls
Grand Prairie	1250	450	Low stairstep hills west; plains east	Strata dip east	Calcareous east; sandy west
Edwards Plateau					
Principal	3000	450	Flat upper surface with box canyons	Beds dip south; normal faulted	Limestones and dolomites
Pecos Canyons	2000	1200	Steep-walled canyons		Limestones and dolomites
Stockton Plateau	4200	1700	Mesa-formed terrain; highs to west	Unfaulted, near-horizontal beds	Carbonates and alluvial sediments
Central Texas Uplift	2000	800	Knobby plain; surrounded by questas	Centripetal dips, strongly faulted	Granites; metamorphics; sediments
North-Central Plains	3000	900	Low north-south ridges (questas)	West dip; minor faults	Limestones; sandstones; shales
High Plains					
Central	4750	2900	Flat prairies slope east and south	Slight dips east and south	Eolian silts and fine sands
Canadian Breaks	3800	2350	Highly dissected; local solution valleys		
Southern	3800	2200	Flat; many playas; local dune fields		
Basin and Range	8750	1700	North-south mountains and basins	Some complex folding and faulting	Igneous; metamorphics; sediments

Table 3.1: Descriptions of physiographic provinces and subdivisions in Texas by the Texas Bureau of Economic Geology

Figure 2 displays the lithology identified by the USGS within each physiographic region (`http://mrdata.usgs.gov/geology/state/state.php?state=TX`). The corresponding lithologic legend of colors can be found that website. Lithology is worthy of special attention here because the other factors that help define physiography - primarily vegetation, climate, and topography - may be covered to a substantial extent by the database developed.

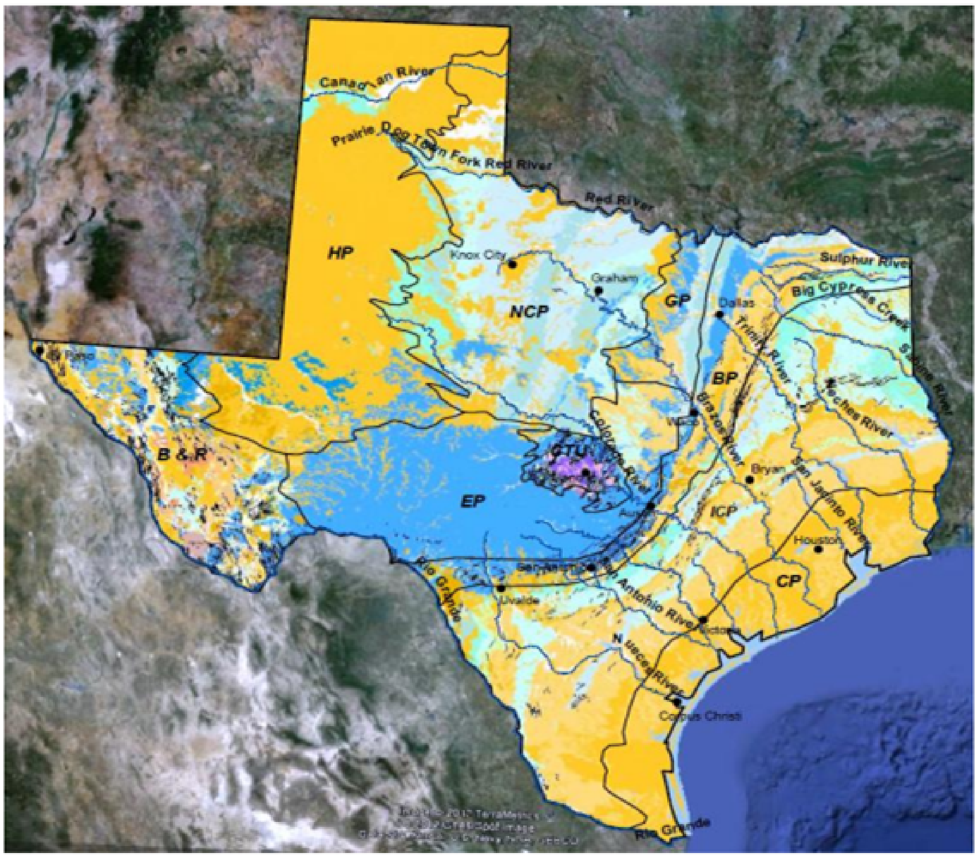


Figure 3.2: Physiographic provinces (outlined in black) and lithology (colored according to code in Appendix) for Texas by the Texas Bureau of Economic Development and its utilization in Google Earth. Physiographic names are abbreviated due to space limitation: Basin and Range (B & R), Blackland Prairies (BP), Central Texas Uplift (CTU), Coastal Prairies (CP), Edwards Plateau (EP), Grand Prairie (GP), High Plains (HP), Interior Coastal Plains (ICP), and North-Central Plains.

3.5 Major River Basins in Texas

This section briefly introduce the major river basins in Texas. The GIS database has layers of geospatial information related to these rivers. The information presented are collected through various sources including the websites of local and state agencies, reports, journal papers, and others.

There are 3,700 named streams and 14 major rivers that meander through 191,000 miles of Texas landscape. These important aquatic ecosystems play a major role in protecting water quality, preventing erosion, transport tremendous amount of sediments and providing nutrients and habitat for fish and wildlife. Along the way, water that eventually flows into seven major estuaries supports over 212 reservoirs, countless riparian habitats, wetlands, and terrestrial areas. The 14 major Texas rivers are the: Canadian, Red, Brazos, Sulphur, Trinity, Sabine, Neches, San Jacinto, Guadalupe, Lavaca, San Antonio, Colorado, Nueces, and the Rio Grande. These major rivers form a series of 13 major river basins, which consist of the Brazos, Canadian, Colorado, Guadalupe, Lavaca, Neches, Nueces, Red, Rio Grande, Sabine, and Trinity River basins.

In this section, several of the major rivers and their watersheds will be discussed. In Task 2, we also collected substantial amount of sediment data for these rivers. Most of the sediment data are at or near USGS gauge stations. The locations of these gauge stations in the corresponding watershed, if available, are also plotted.

3.5.1 Brazos River Basin

The Brazos River basin originates in eastern New Mexico has a watershed of 42,000 square miles and a total length of approximately 640 miles southeasterly across Texas to the Gulf of Mexico south of Houston. Its watershed width varies from about 70 miles on the High Plains in the upper basin to a maximum of 120 miles in the vicinity of Waco to about 10 miles near the city of Richmond in the lower basin. The Brazos River basin divides into 14 sub-watersheds with a variety of environmental conditions unique to each one (source: Water - Resources Investigations Report 01-4057, USGS).

3.5.2 Llano River Basin

The Llano River watershed (11,568 km^2) is a geologically variable, unregulated, flood prone, rural fluvial system in the Edwards Plateau of central Texas. The following is a geological description of the watershed from Heitmuller et al, (2009). The surface extent of an uplift in central Texas is located in the eastern part of the watershed. The lower, eastern side of the watershed is dominated by Precambrian intrusive igneous and metamorphic rocks, which comprise 19% (2180 km^2) of the total watershed area. Transitioning out of the Llano Uplift, Paleozoic sedimentary rocks comprise almost 12% (1369 km^2) of the total watershed area. Paleozoic sedimentary units consist of various lithologic types, mostly Ordovician limestone and dolomite and Cambrian sandstone. The western, upper side of the Llano River watershed occurs in the central Edwards Plateau, an elevated, dissected lower-Cretaceous carbonate and with high elevations above 700 m. Formations of the plateau are mostly comprised of horizontally bedded, fossiliferous limestone and dolomite sequences, with varying amounts of chert. Sand and conglomerate formations, notably the Hensell Sand, are exposed in the valley in the west-central part of the watershed. In total, lower-Cretaceous

Figure 3.3: Major River Systems of Texas (geology.com)

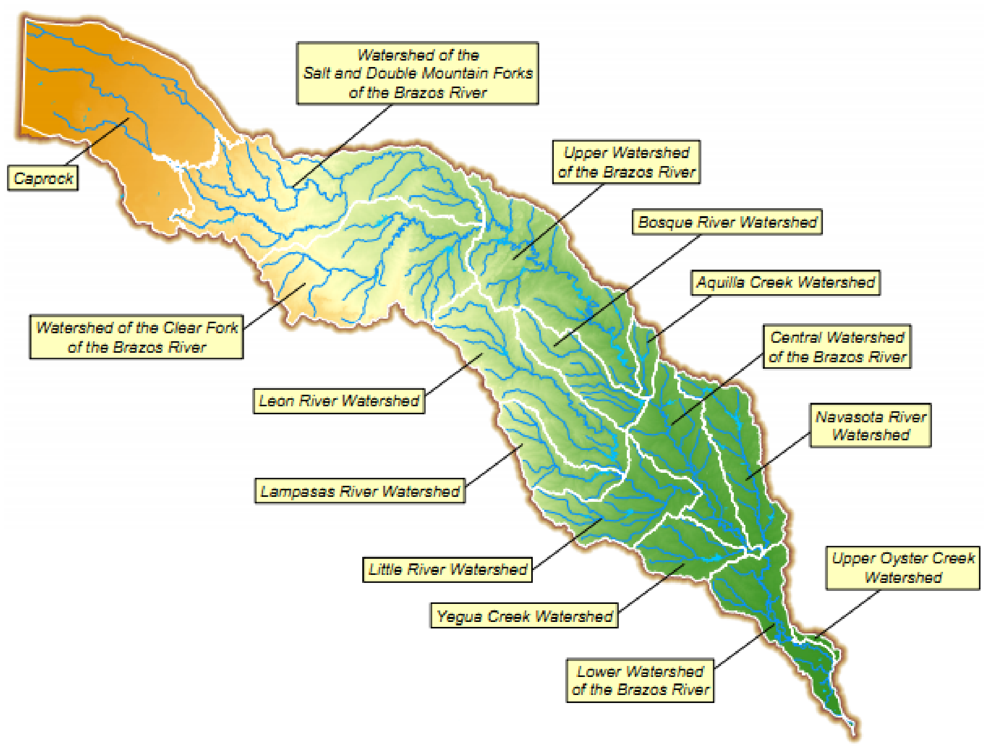


Figure 3.4: Brazos River Basin

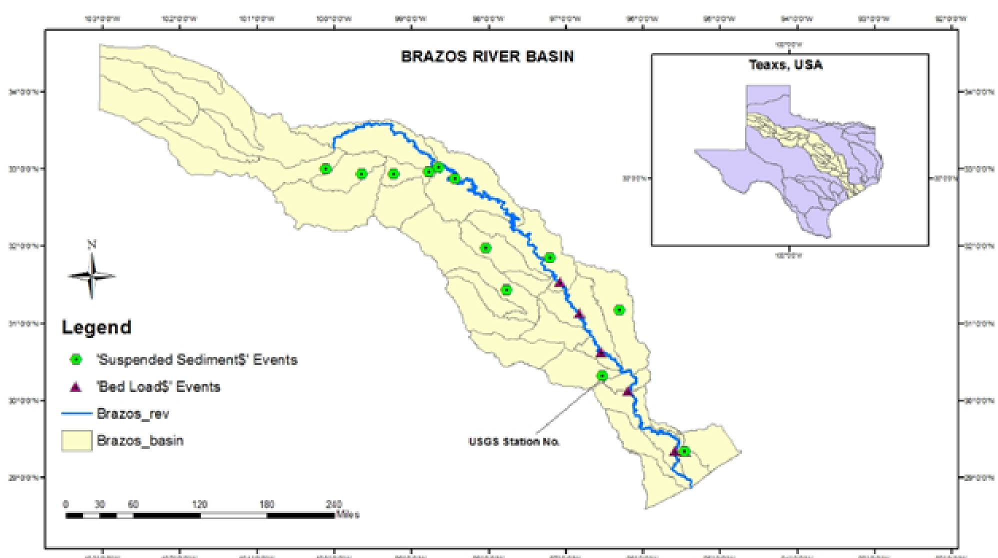


Figure 3.5: USGS stations along the Brazos River basin

formations comprise 66% (7629 km^2) of the total watershed area. The remaining 3% (390 km^2) of the watershed area is mostly comprised of Quaternary alluvial deposits. Differential rates and patterns of weathering in the Llano River watershed strongly influence valley confinement, alluvial development, and sedimentary composition(Heitmuller et al., 2009).

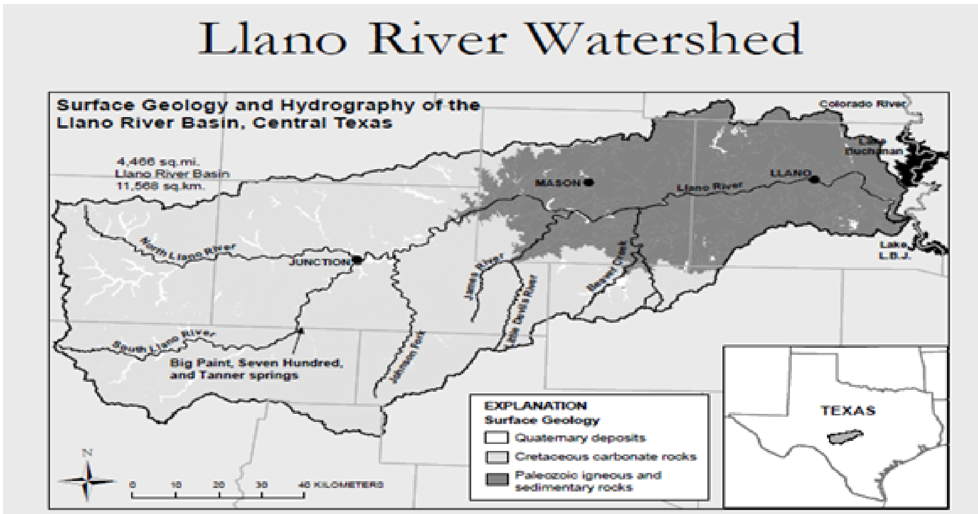


Figure 3.6: Llano river watershed (Heitmuller et al., 2009)

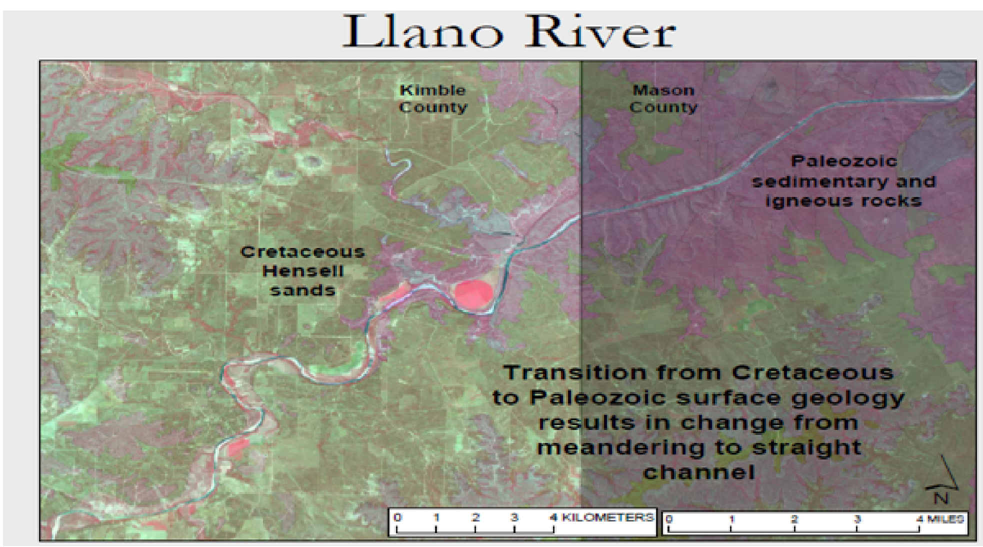


Figure 3.7: Transition from meandering to straight channel of Llano River (Heitmuller et al., 2009)

3.5.3 Neches River Basin

The Neches River basin spans 9,688 square miles (25,092 km^2) with its principal tributary the Angelina River. In the upper part, most of the cultivated floodplain land is confined to the smaller tributaries. Sheet and rill erosion accounts for 75 percent, and 25 percent bank erosion accounts by gully and stream, of the gross annual erosion occurring within the basin.

3.5.4 Nueces River Basin

The Nueces River watershed is one of the largest in the state of Texas. Its watershed drains all or parts of 23 counties over approximately 45,000 km^2. The watershed covers three regions with distinct geographic and economic features, the Hill Country, Brush Country and Coastal Prairie (Santschi and Yeager 2004).

3.5.5 Rio Grande Basin

The Rio Grande basin has a total land area of 128,332 km^2 in Texas, of which 2,130 square miles (5,517 km^2) is considered noncontributing. The basin lies in portions of eight land resource areas. Sheet and rill erosion accounts for 78 percent, and gully and stream bank erosion accounts for 22 percent of the gross annual erosion occurring within the basin (Christopher and Johnson, 2004).

3.5.6 Bosque River Watershed

Before discharging into the Brazos River downstream, the Bosque River watershed drains approximately 1,652 square miles into Waco lake, in McLennan County, which provides flood control for the area and is the primary drinking water source for 300,000 residents.

3.5.7 Guadalupe River Basin

Figure 3.14 outlines the Guadalupe River Basin and the major cities and counties within GBRA's ten-county statutory district, which begins near the headwaters of the Guadalupe and Blanco Rivers, ends at San Antonio Bay, and includes Kendall, Comal, Hays, Caldwell, Guadalupe, Gonzales, DeWitt, Victoria, Calhoun and Refugio counties.

From the annual basin highlight report of Guadalupe-Blanco River Authority a series of watershed maps were extracted, which shows the major river and stream segments, as well as the monitoring stations within the watershed.

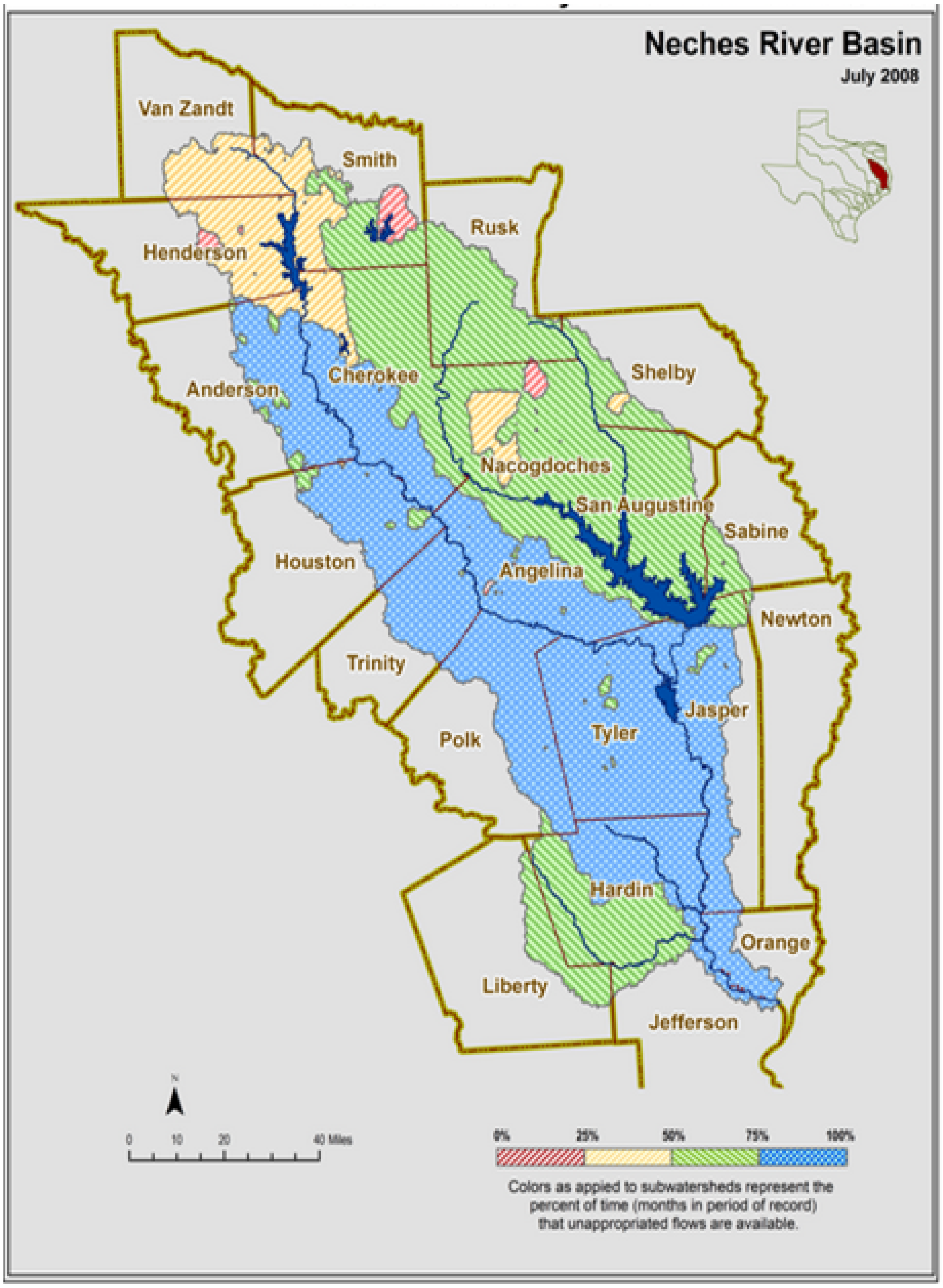


Figure 3.8: Neches River Basin (Texas Commission on Environmental Quality, 2009)

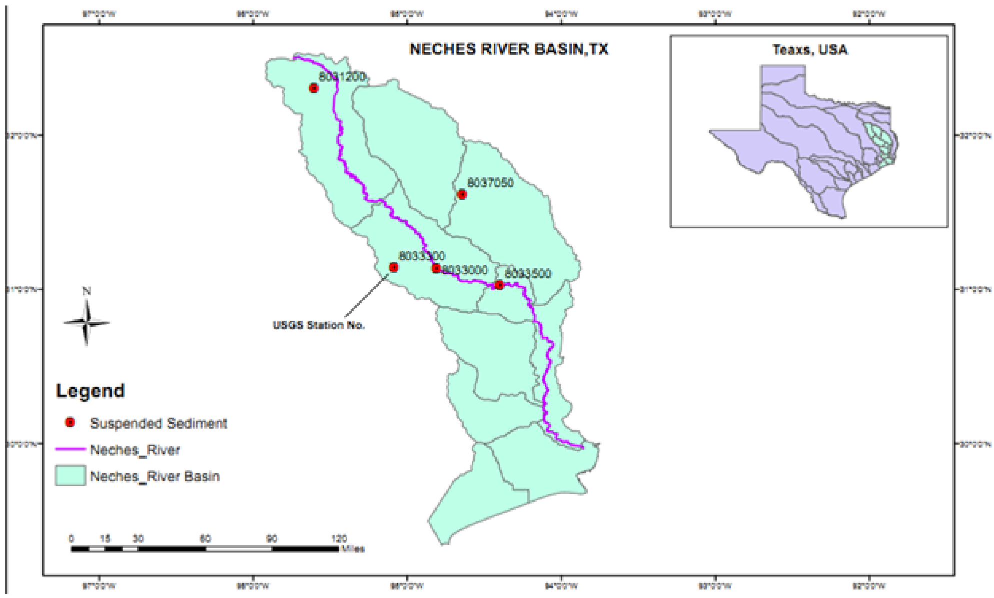


Figure 3.9: USGS stations along the Neches River basin

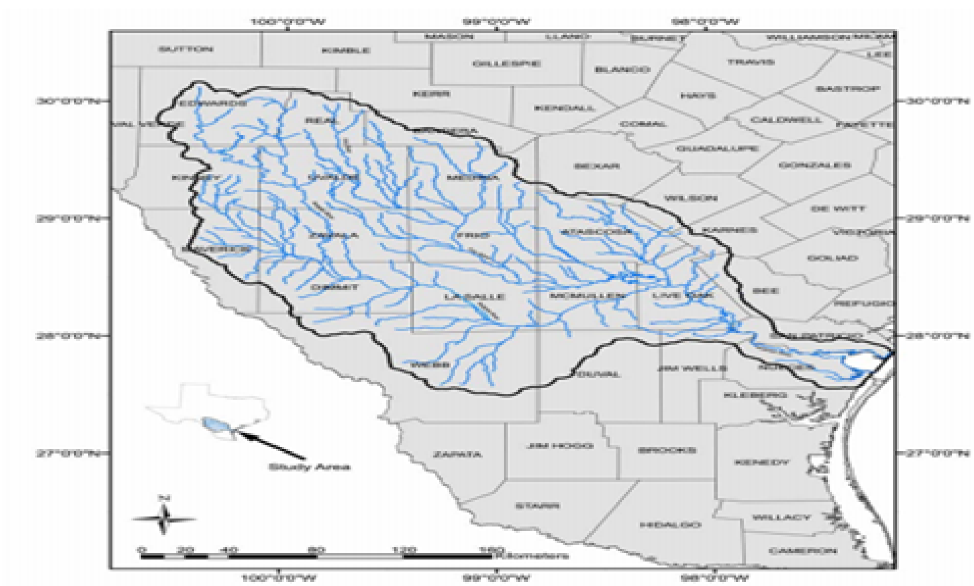


Figure 3.10: Map of southwestern Texas, showing the Nueces River watershed, major rivers and tributaries and Texas county delineations (Santschi and Yeager, 2004)

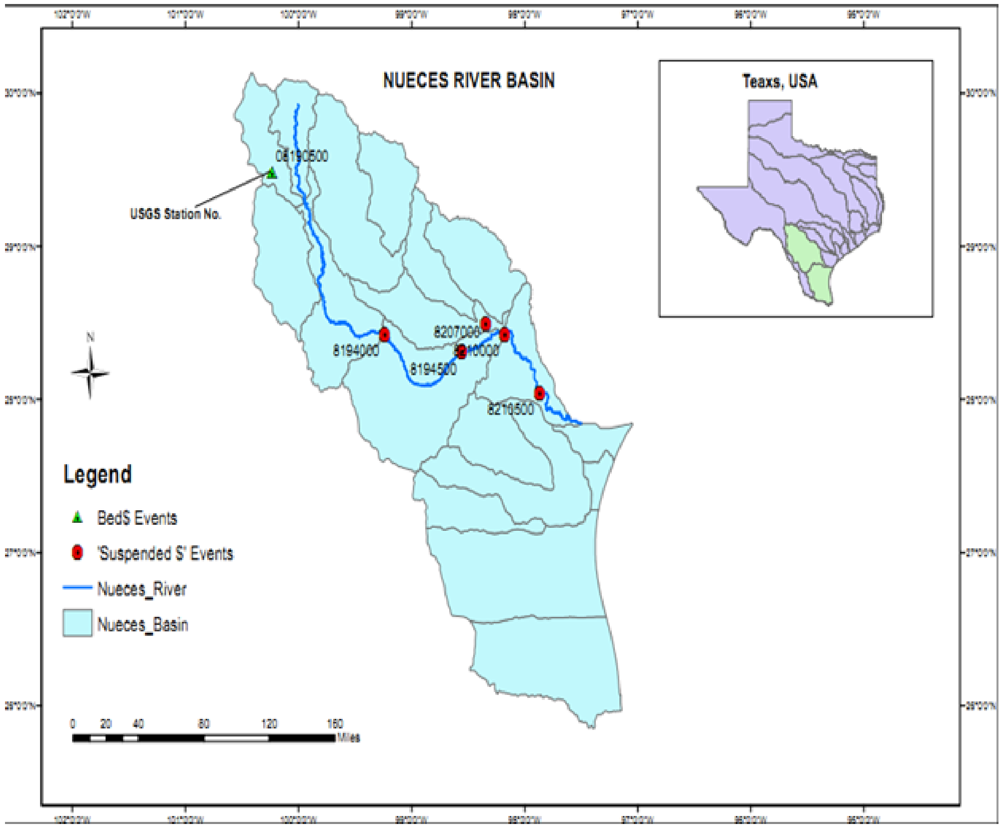


Figure 3.11: Map of southwestern Texas, showing the Nueces River watershed, major rivers and tributaries and Texas county delineations (Santschi and Yeager, 2004)

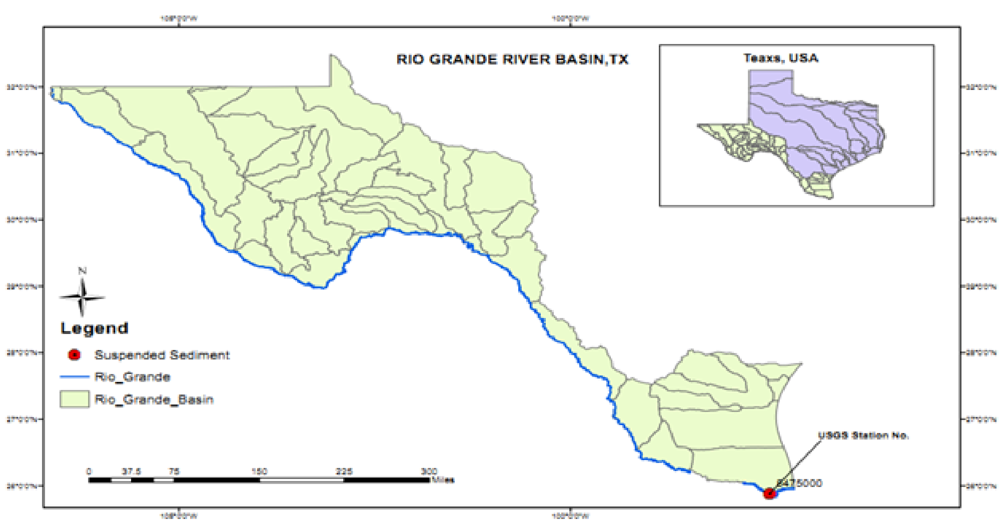


Figure 3.12: Rio Grande River Basin in Texas

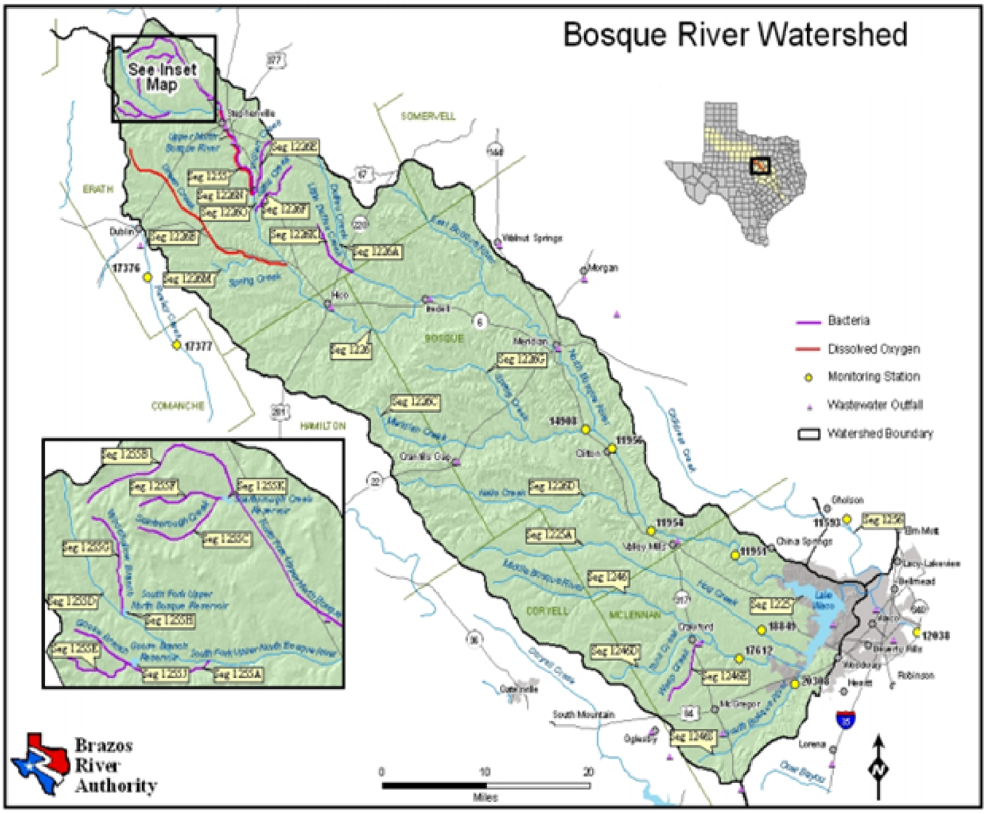


Figure 3.13: Bosque River watershed (Brazos River Basin Highlights Report, 2009)

Figure 3.14: Guadalupe River basin (Guadalupe-Blanco River Authority)

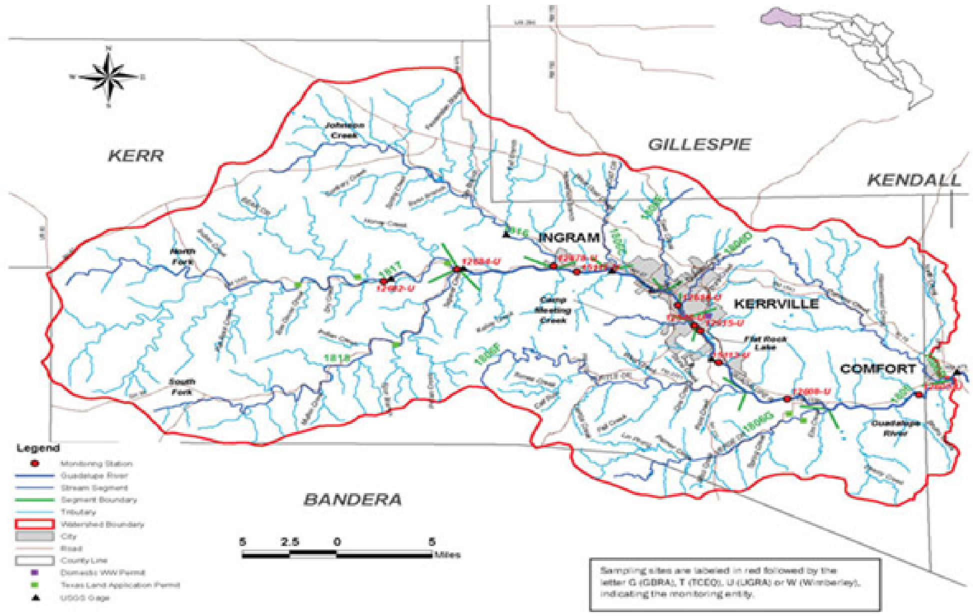


Figure 3.15: Upper Guadalupe River above Comfort (Guadalupe-Blanco River Authority)

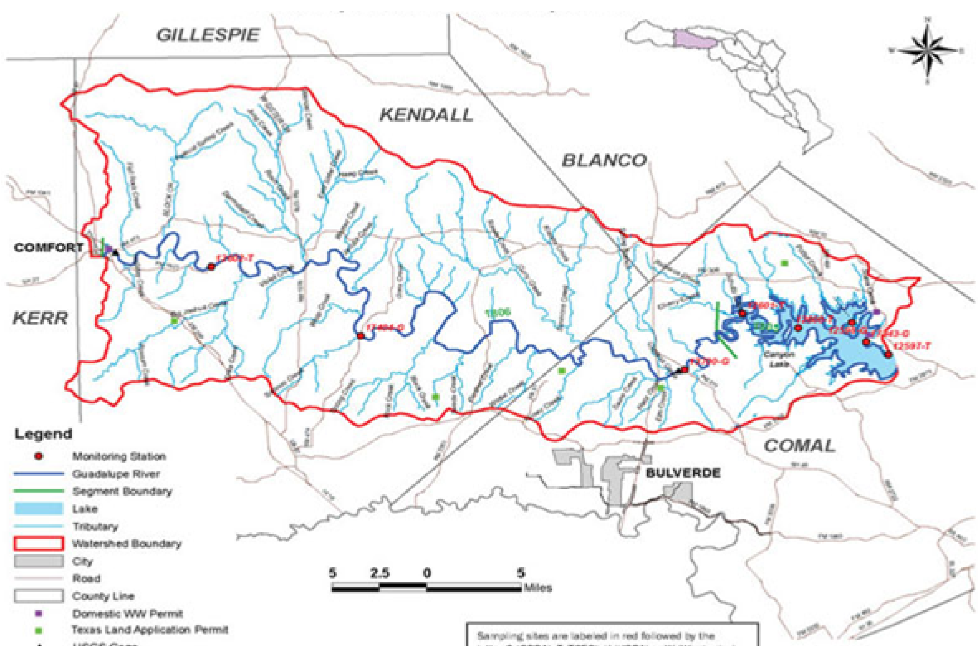


Figure 3.16: Guadalupe River above Canyon Lake (Guadalupe-Blanco River Authority)

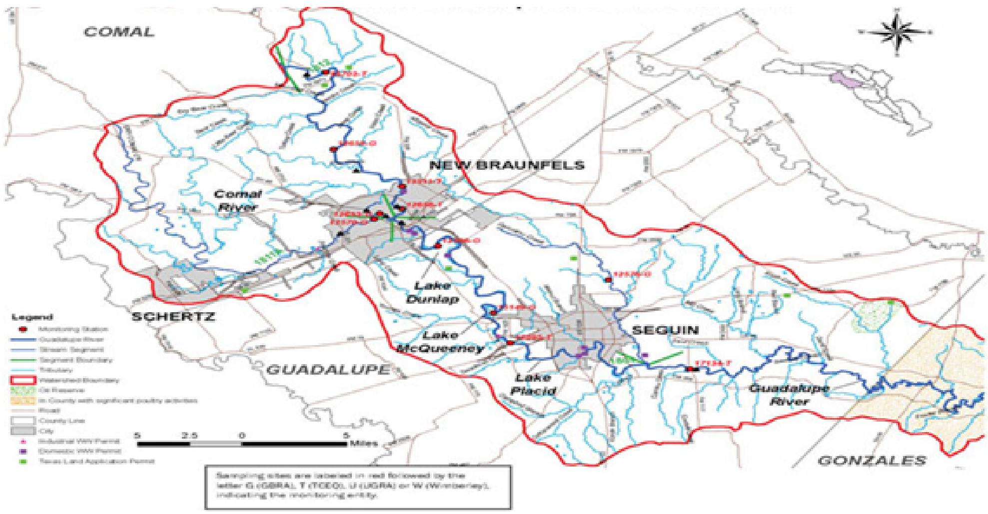


Figure 3.17: Middle Guadalupe River Watershed- Part A (Guadalupe-Blanco River Authority)

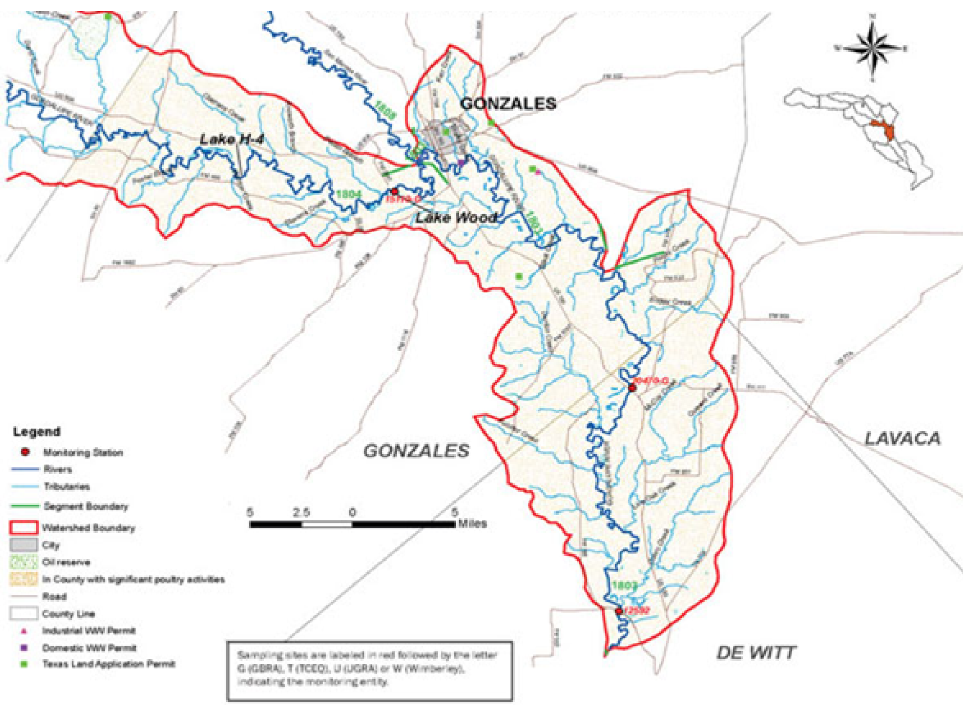


Figure 3.18: Middle Guadalupe River Watershed- Part B (Guadalupe-Blanco River Authority)

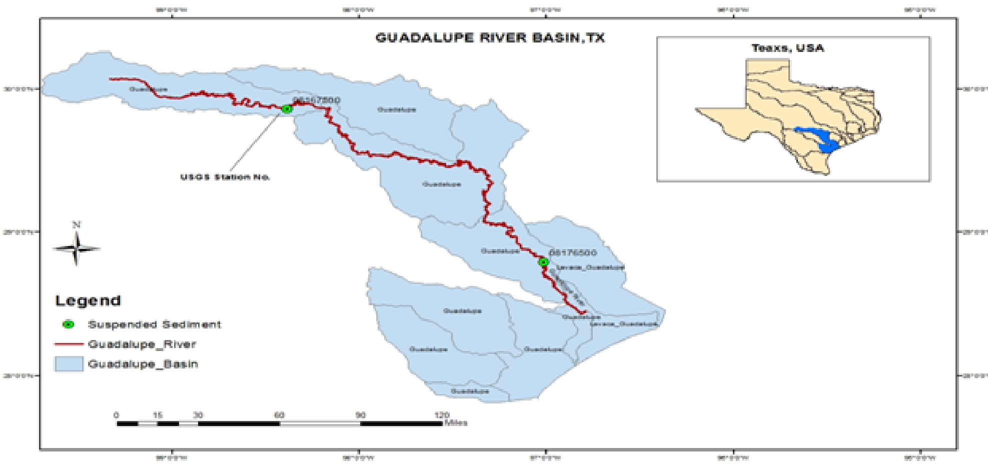


Figure 3.19: USGS stations along the Guadalupe River basin

3.5.8 Colorado River basin

The drainage basin of the Colorado River encompasses 246,000 square miles (640,000 km^2) of southwestern North America, making it the seventh largest on the continent. About 238,600 square miles (618,000 km^2), or 97.0% of the watershed, is in the United States. Most of the basin is arid although significant expanses of forest are found in the Rocky Mountains, the Kaibab, Aquarius, and Markagunt Plateaus in southern Utah and northern Arizona, the Mogollon Rimthrough central Arizona, and other smaller mountain ranges and sky islands. Elevations range from sea level at the Gulf of California to over 13,000 feet (4,000 m) in the mountains of Colorado and western Wyoming, with an average of 5,500 feet (1,700 m) across the entire basin (source: http://en.wikipedia.org).

3.5.9 San Antonio River basin

The San Antonio River is a major waterway in central Texas. It originates in a cluster of springs in Midtown San Antonio, approximately four miles north of Downtown, and follows a roughly southeastern path through the state. It eventually feeds into the Guadalupe River about ten miles from San Antonio Bay on the Gulf of Mexico. The river is 240 miles long. (Source: http://en.wikipedia.org).

Surface geology directly impacts soil mineralogy as well as influences valley and channel morphology. The San Antonio watershed can be coarsely divided into four physiographic regions. In the upper basin, the Edwards Plateau region dominates with thin, poorly developed soils and exposed upper and lower Cretaceous period limestone. Due to the combination of thin soils and steep topography, this physiographic region may produce extreme peak discharges from flood events (Baker 1977).

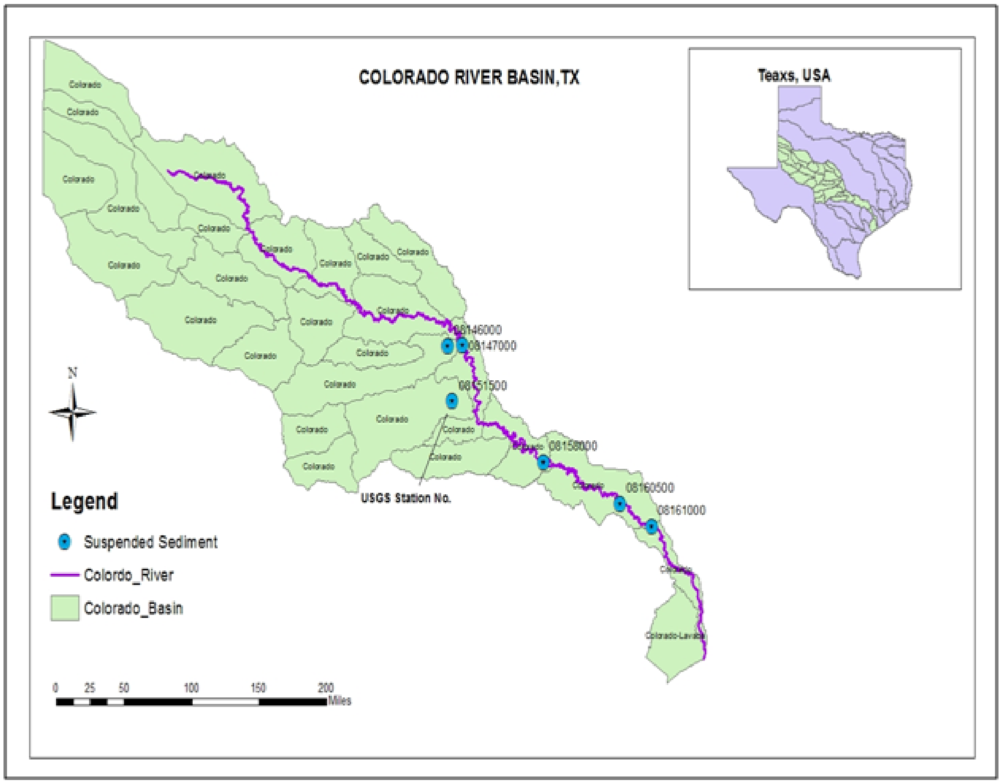


Figure 3.20: Colorado River basin in Texas

Figure 3.21: Associated watershed of San Antonio River in South Texas (Wikipedia)

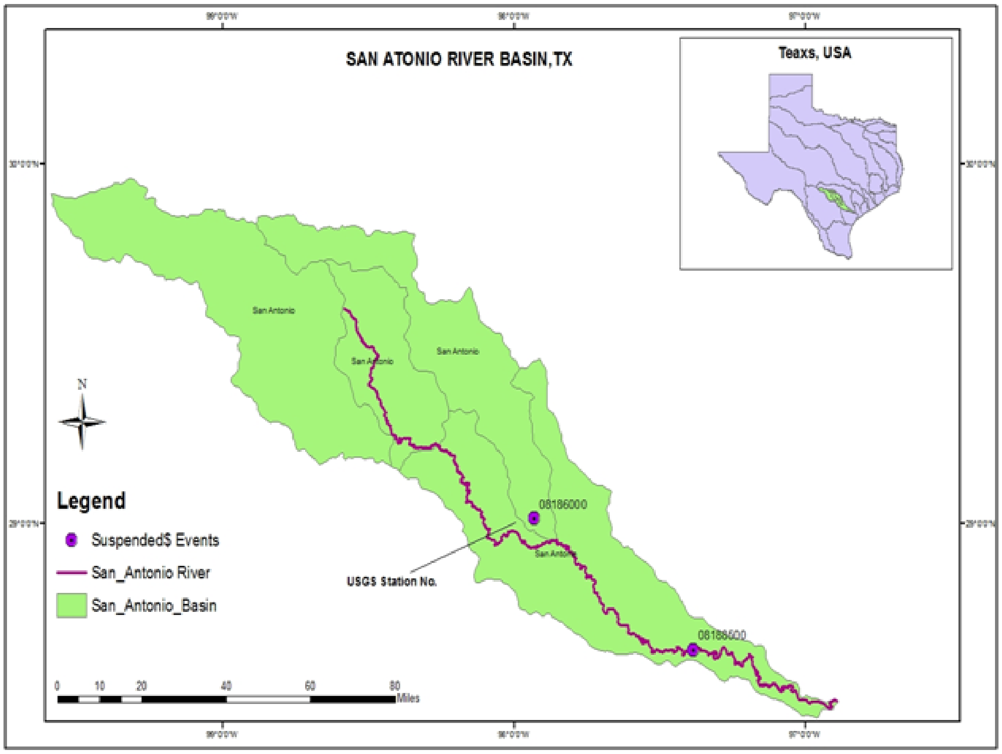


Figure 3.22: USGS Station at San Antonio River Basin

3.5.10 Trinity River basin

The Trinity River flows 512 miles before discharging into Galveston Bay near Houston. There are also 1,983 miles of major tributaries that drain into the Trinity. The Trinity River watershed encompasses 18,000 square miles (7% of state's land area), and includes all or parts of 38 Texas counties. Many human activities affect the Trinity River, including 22 reservoirs on the river to provide drinking water and flood control. Different land uses also affect the Trinity River, such as urbanization, commercial/industrial development, row-crop farming, livestock production, outdoor recreation and timber production. Annual precipitation ranges from 36 inches at the headwaters up to 52 inches near the Gulf of Mexico. There are various habitats within the Trinity River watershed, including native grasslands, bottomland hardwood forests, and wetlands, though the extent of these has been reduced due to human activities. The Trinity River Basin is the most populated river basin in Texas with nearly 8 million people (source:http://trinitywaters.org).

3.5.11 Red River basin

The Red River Valley is a region in central North America that is drained by the Red River of the North. It is significant in the geography of North Dakota, Minnesota, and Manitoba for its relatively fertile lands and the population centers of Fargo, Moorhead, Grand Forks, and Winnipeg

Figure 3.23: Trinity River and associated watershed (Source: Texas Agri-Life Extension Service Graphic)

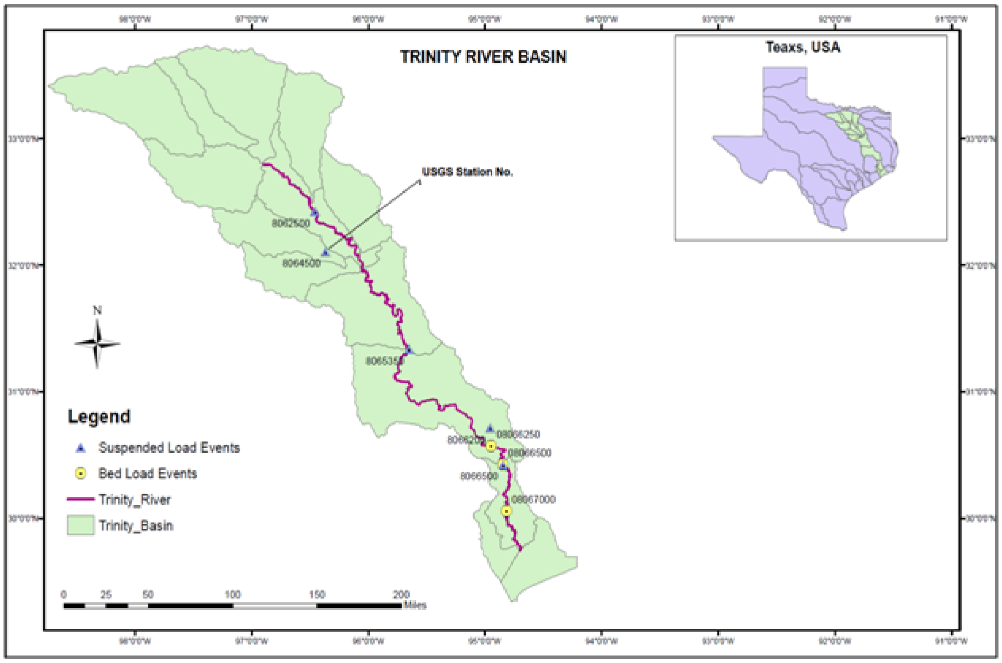


Figure 3.24: USGS Station at Trinity River Basin

(source:http://en.wikipedia.org).

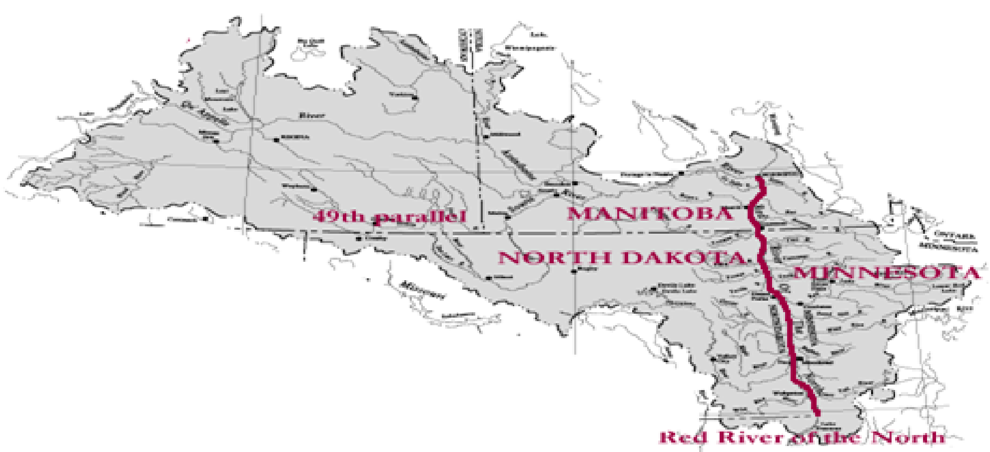


Figure 3.25: Red River basin (Wikipedia)

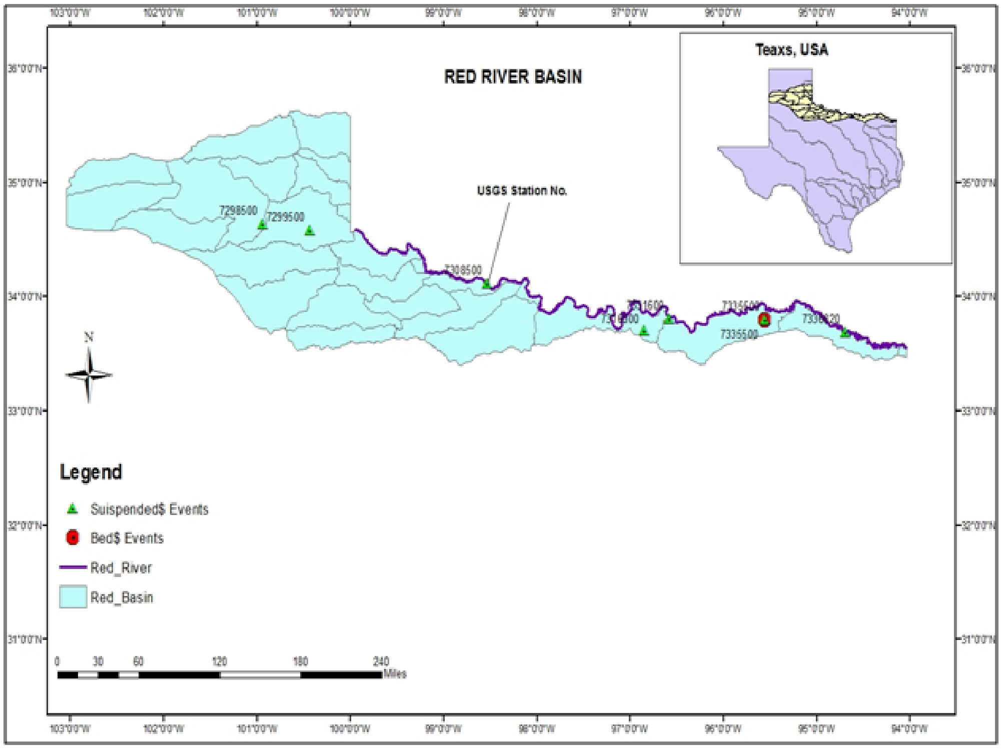


Figure 3.26: USGS Station at Red River Basin

3.5.12 Sabine River basin

The Sabine River basin has a length of approximately 300 miles and a maximum width of approximately 48 miles. It is roughly crescent-shaped, extending in a general southeasterly direction for a distance of some 165 miles from its source in Hunt County, Texas, to the Texas-Louisiana border in the vicinity of Logansport, Louisiana, thence in a southerly direction to Sabine Lake and the Gulf of Mexico. The Sabine River Basin is bounded on the north and northeast by the Red River Basin, on the east by the Calcasieu River Basin, on the west by the Neches River Basin, and on the northwest by the Trinity River Basin (source: http://www.sratx.org/basin/overview.asp).

3.6 River Slopes Database

River bottom slope is one of the most important parameters controlling the energy of the flow water, which in turn shapes the river and its floodplain. It is however not an easy task to accurately calculate the slopes given the irregularity of rivers in both plane and vertical directions. River slopes are input parameters for many channel migration models.

In conjunction with TxDOT project 0-6654, the slopes of Texas rivers at 437 USGS gauge stations are calculated. The following is an excerption from the corresponding part of TxDOT 0-6654 project

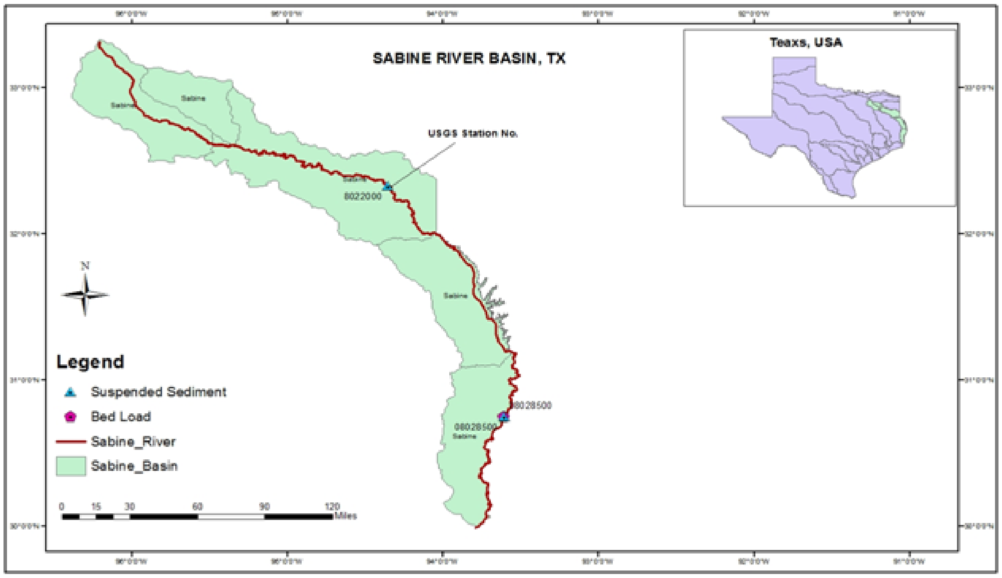


Figure 3.27: USGS Station at Sabine River Basin

report. It is noted that these slopes are rough estimations using the following methods:

- A shapefile of the 21 major Texas river basins was superimposed on 30 m resolution digital elevation model (DEM) raster files. For each basin, raster files visually identified as falling within the basin were combined into a mosaic. However, as it was later learned that DEMs of 30 m resolution caused the computer to crash in basin autodelineation, the cells were aggregated to a 90 m resolution.

- For each major river basin, ArcSWAT (which was used as a plug-in to ArcGIS) was used for autodelineation. One of the user-defined parameters in the ArcSWAT autodelineation process is the threshold sub-basin area. By trial-and-error, it was discovered that a value of 1,000 hectares for this parameter would lead to a stream channel appearing at all but 6 of the 437 gaging stations, and that substantially lower values would still not capture these few sites. The threshold of 1,000 hectares was set for all autodelineations to capture 431 stations.

- For each of the 431 station sites, a distance of 500 m was traced upstream along the SWAT-generated stream and the elevation of the DEM raster cell at that distance was copied into an Excel spreadsheet. The same was repeated for 500 m downstream. The upstream elevation minus the downstream elevation, divided by 1,000 m, was taken as the slope.

The following analysis and discussion on the slope results are also from the corresponding technical report for TxDOT project 0-6654: The above process generated some estimates of channel bed slopes that are negative, suggesting that the water would be flowing uphill. A negative channel bed slope, though unlikely, is possible. Relatively dead water would rest in the depressed zone, but the water surface itself would no doubt decline in the direction of stream flow. Phillips et al. (2005) identified the channel bed of the Trinity River to be below sea level in a large portion of its length in the Coastal Prairies. Yet, many of the negative slopes estimates cannot be thought of as representing actual channel bed slopes. Too many of them, approximately 14%, were found to be negative, and most of these are not near the coast line. We believe that errors in estimation are due to the fact that some DEM cells lying along the SWAT-delineated streams are average elevations over a 90m by 90m area. In some cases that average may be closer to the stream bed channel elevation, while in other cases that average may be closer to that of the river bank or other topography. A negative slope estimate could easily arise when the upstream elevation estimate is more representative of the channel bed, but the downstream elevation estimate is more representative of higher topography in the area. With some care, the distribution of negative slope estimates may be helpful in modeling the distribution of errors for the entire set of slope estimates. This error distribution might prove helpful in accounting for a portion of error variances in the regional curves. In an effort to reduce the errors in slope estimation, R script was written to extract the SWAT-estimated sub-basin channel slope for each ArcSWAT-delineated sub-basin containing a gaging site. All such estimates are positive. The disadvantage of this methodology is that the slopes are measured over varying lengths. Nearly all are less than 10 km, but 20 are in the 10 km to 30 km range. Varying the sub-basin threshold size such that all sub-basin main channels are of the same length is not possible.

3.7 Summary

In this technical memo, we documented GIS database created for this project. The documentation focused on the physiographic regions, lithology, and major rivers in Texas. The river bottom slope information was also estimated using ArcGIS and other tools. This database is an expandable central place for storing channel instability information for Texas. It provides a convenient way for TxDOT engineers to sort out available data.

Chapter 4

Field Survey and Observation

4.1 Introduction

In Task 2 and 3, we collected a wide range of data and identified what was missing for the purpose of this project. The missing data is in part acquired within this task of field survey and observation. In addition, to demonstrate the analysis procedure and design guidelines resulting from this research, examples will be given to analyze the regional channel stability at the proposed field survey sites.

The team examined geomorphological features and made hydraulic measurements during the field visits in the summer of 2012. The data collected include sediment size distribution, channel geometry, vegetation, bank erosion patterns, bedforms, floodplain characteristics, debris clogging and local scour around roadway hydraulic structures. These sites are studied in detail in order to develop a simple methodology for TxDOT use.

For most of the sites, we also filled out two forms recommended by NCHRP, namely "Stream Reconnaissance Record Sheets" and "Rapid Assessment of Channel Stability" forms. The major part of the forms was filled right at the sites.

This technical memorandum documents the details of these field surveys. It also provides demonstrations on how to prepare and conduct a field survey for channel stability assessment. TxDOT engineers can use these as templates for future assessment. The data collected during the field surveys have been reported in TM-2 "Data collection". They will not be repeated here.

4.2 Procedure for the field survey and observation

To conduct a successful field survey, thorough preparation and office investigation are needed prior to the trip. Upon arrival, the following general procedure is followed:

- Initial survey and observation of the field site. We tried to get an idea of the surrounding environment, current condition of the river, identify major issues and existing counter measures. We also decide representative locations to take samples and make measurement.
- Sampling and measurement. Samples of sediment material were taken and the locations were recorded using GPS. For most of the rivers we visited, the flow was low and the river was wadable. As a result, we collected river bed materials which might need to use other equipment to take during high flows. For the bank materials, we took samples at various locations in the meandering bends near the bridges. Some samples were taken in the flood plain where accessible.
- Filling assessment sheets. For each site, we tried to fill out the two forms recommended by NCHRP, i.e., "Stream Reconnaissance Record Sheets" and "Rapid Assessment of Channel Stability" forms. We recommend to fill out most part of the two forms while in the field.
- Notes taking and image/video recording. Detailed notes were taken for each of the sites. To help the evaluation process, images and videos were recorded for the major features of the river and bridge.

An important part of the sampling effort was to collect bed materials (undertaken by UTSA and UH) and bank materials (undertaken by TAMU). Figure 4.1 shows two pictures taken during the field visit in the summer of 2012. Sediment samples were tested in the lab for sizes and erodibility. The results from the lab test have been documented in Chapter 2.

The team from TAMU was in charge of the materials on the bank. Shelby tubes were driven into the soil and samples were carefully taken. Two standard tests to determine the size distribution of soils were performed in the laboratory according to the ASTM standard D 422-63 (2007). The first test is a sieve analysis, in which the soil is separated by a stack of sieves. Each of these sieves has a number that represents the amount of openings per linear inch. The second test is the hydrometer analysis, which is a test used for particles smaller than 0.075 mm (particles that pass sieve #200). In this test the soil is mixed with water and a dispersing agent, and the distribution is obtained by a process of sedimentation. The results from both tests are plotted and then used to obtain the classification of the soil, with the Atterberg limits of the soil.

For the sieve analysis, 5 sieves and a pan are put together and the soil is shaken in the sieves for a period of time to separate the coarse soil particles from the fines. The fines are those particles that have a diameter smaller than 0.075mm. The hydrometer was conducted for the soil samples after the sieve analysis test. The soil retained in the pan was analyzed with the hydrometer test. There are other different ways to perform the soil particle size analysis such as performing the hydrometer first and then the sieve or performing a wet sieve analysis. For the soils obtained at the sites, the soil was dried and then separated in the sieves. Only the particles that passed the #200 sieve were tested with the hydrometer test. It is desirable to perform a wet sieve analysis for soils containing large quantities of clay. Soil from the North Sulfur River contains clay and wet analysis have to be conducted to obtain the size distribution.

Figure 4.1: Sampling of the field sites: (a) Bed material sampling in the Brazos River at SH105, (b) Bank material sampling in the bank of the Sabine River at SH63.

4.3 Locations of the field survey and observation

Five roadway crossings were initially chosen for field survey. During the project, the team proposed to add another site near Austin where substantial erosion has occurred. In addition, due to a misunderstanding between the team and TxDOT engineers, an extra site for the Sabine River was added. So there were total of sixe rivers and seven sites surveyed in this project.

The sites we selected are good candidates for collecting data as they exhibit meander migration and degradation. It is impossible to canvas the river crossings in the whole state of Texas. The selected few cover a wide range of river types, sediment characteristics, and erosion patterns. The locations of the sites are listed below and plotted in Figure 4.2.

- SH63 and SH190 at Sabine River
- SH105 at Brazos River
- FM787 at Trinity River
- US90 at Nueces River
- SH34 at N. Sulphur River
- FM973 at Colorado River

For each of the site we visited, we had taken detailed notes while in the field. We also filled out the “Stream Reconnaissance Record Sheets” and “Rapid Assessment of Channel Stability” forms for most of the sites. The notes and the sample forms are listed in Appendix A .

4.3.1 SH63 at the Sabine River

This site was added to the list upon the recommendation for TxDOT engineers. There are great concerns over the stability of the river and the impact on the bridge. Since the Sabine River forms part of the boundary between Texas and Louisiana, the bridge and SH63 connect the two states at the crossing. The river shows very evident migration and instability. During the field trip, we observed the exposure of bridge foundation due to erosion. Several countermeasures constructed in the past were observed.

Upon arrival, a brief examination of the river under the bridge was undertaken right away to assess the condition of the channel. This bridge is right on the middle of a meander bend. This reach of the Sabine River forms the boundary between Texas and Louisiana. The outer bank (Louisiana side) shows a lot of signs for erosion. A big bar formed on the inner side (Texas side). After the initial examination, we started to take samples of bed and bank materials. One group (Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials. Positions of the samples were recorded by GPS. We observed large dunes and ripples on the point bar and also inside the river. It seems the river is regulated a lot by the dam not far from upstream.

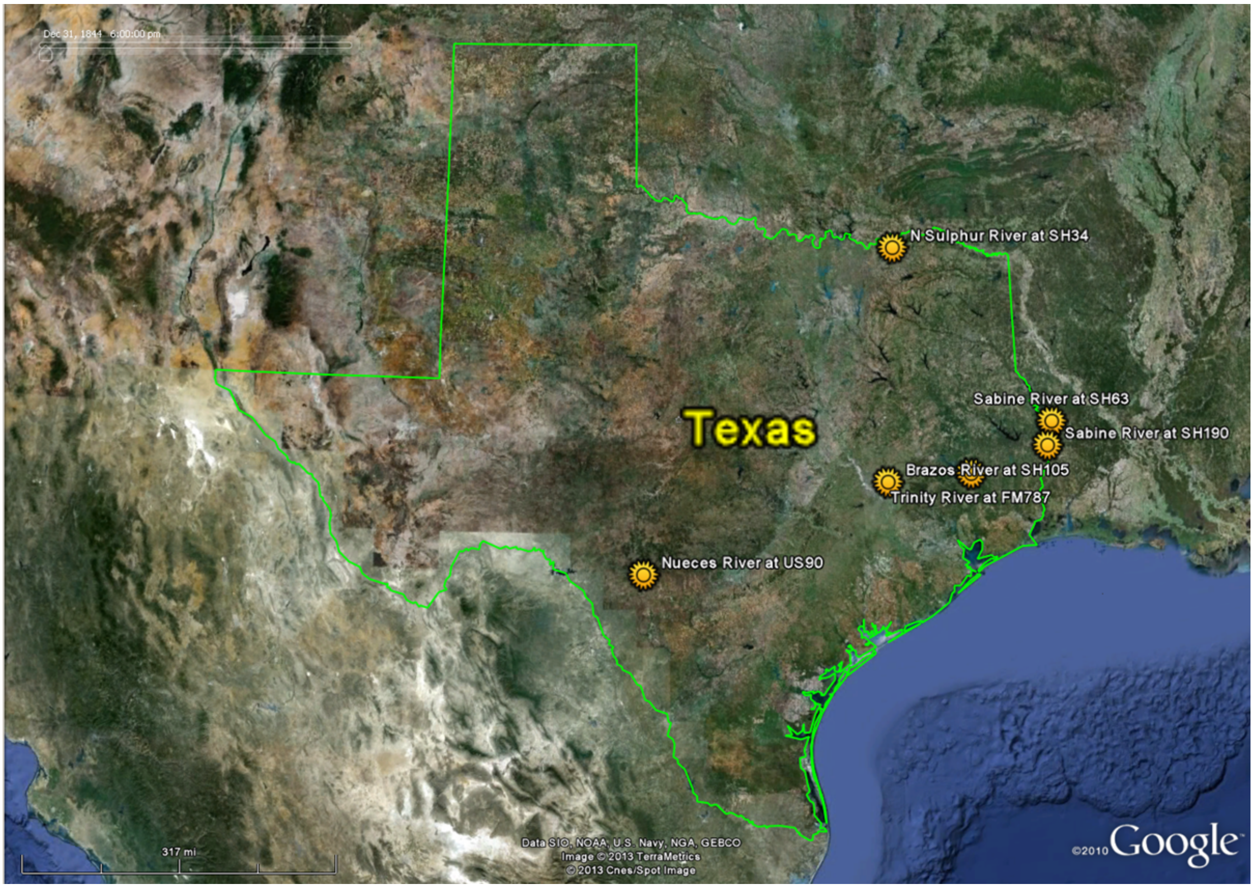


Figure 4.2: Location map for the field survey and observation

Figure 4.3: SH63 over the Sabine River. The pictures show the exposure of the bridge foundation and the existing erosion counter measure on the left bank of the river.

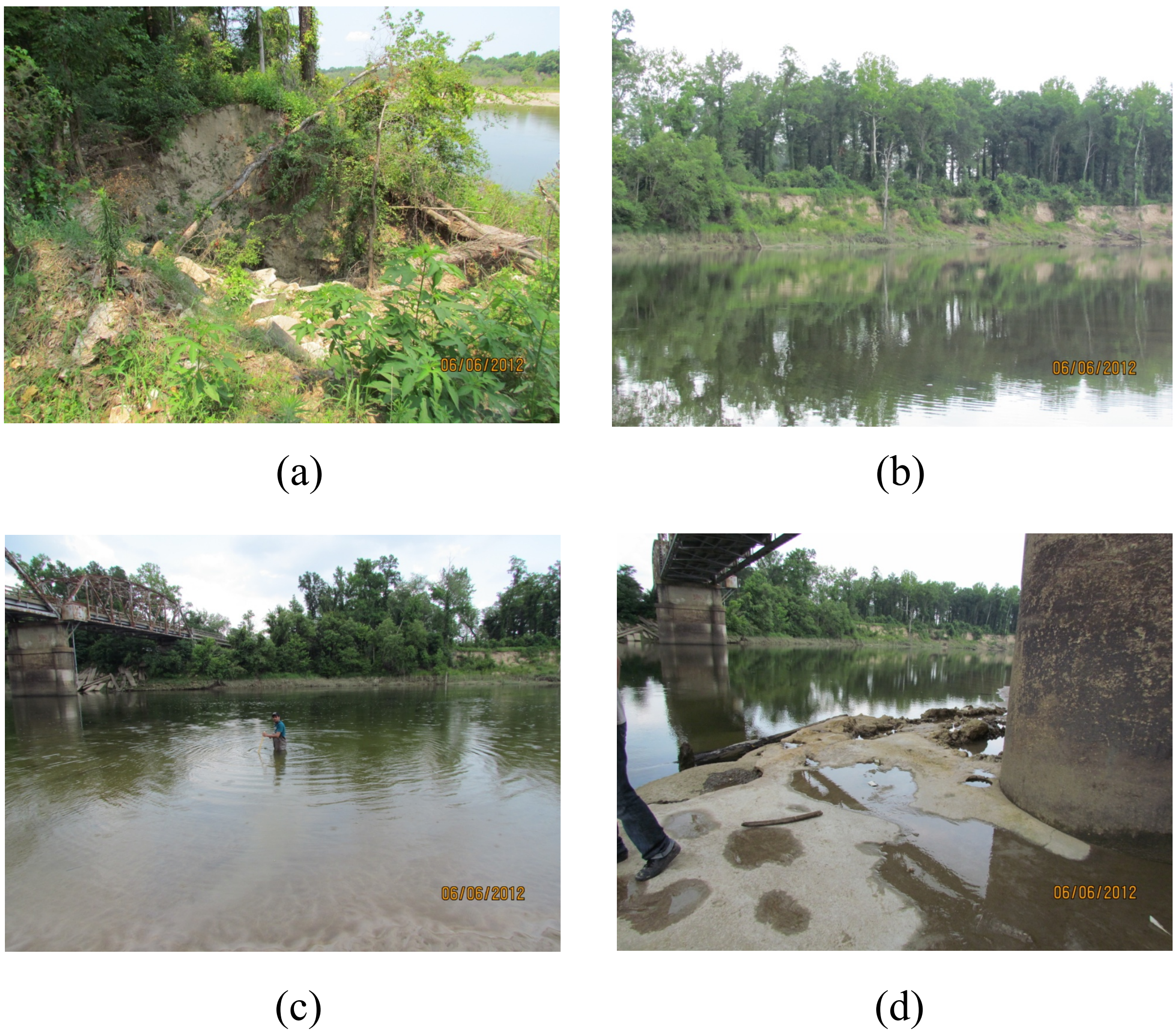


Figure 4.4: More photos taken at SH63 over the Sabine River. (a) Bank failure upstream of the river right next to the bridge, (b) Typical steep outer bank just downstream of the bridge, (c) Taking of river bed samples, and (d) Exposure of bridge pier foundation protection due to lowering of the river bed.

Due to a misunderstanding between the research team and the TxDOT engineers, we initially went to the crossing between SH190 and the Sabine River. This crossing is about 30 miles downstream of the supposed site at SH63. Due to the proximity, the geomorphic and hydraulic conditions are similar. The migration and erosion also pose as a big threat to the bridge. The data we collected there will also be included in the report of this project.

At the end of the field trip, we filled out the "Stream Reconnaissance Record Sheets" suggested by NCHRP. It is a long form with a lot of details. However, it is less useful, time consuming, and sometime hard to make choices. We also tried the "Rapid Assessment of Channel Stability" method and gave scores to each of the 13 indicators. The total score for this side was 60. Accordingly, it is classified as "Fair" in terms of channel stability.

4.3.2 SH105 at the Brazos River

The SH105 crossing of the Brazos is located about 5 miles west of Navasota, Texas, and about 1/4 mile west of the intersection of FM 159 and SH 105. Over the past 30 years, the channel upstream of the bridge has migrated about 400 feet towards the SH105.

We started at the left side of the channel where public access is available. A brief examination of the river under the bridge was undertaken right away to assess the condition of the channel. We also talked to the TxDOT personnel (Anthony L. Garcia, Anthony.L.Garcia@txdot.gov) who assisted us at the site.

Garcia mentioned that this bridge was built in the 1950s and is scheduled to be replaced in 2014. This replacement was due to the aging of the bridge and the meander threat right upstream. The new bridge will be located 500ft downstream from its current site. He recalled that the highest level of river stage during floods reached about 70ft below the bridge deck. We also saw water mark high up on the bridge pier and trash lines on the trees upstream which confirmed his description.

Garcia also mentioned Doug Marino (Doug.Marino@txdot.gove) -Bridge Engineer for more detailed information, such as aerial maps, channel cross sections, and surveys.

After the initial examination, we started to take samples of bed and bank materials. One group (Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials. Locations of the samples were recorded with GPS.

We filled out the "Stream Reconnaissance Record Sheets" suggested by NCHRP. We also tried the "Rapid Assessment of Channel Stability" method and gave scores to each of the 13 indicators. The total score for this side was 67. Accordingly, it is classified as "Fair" in terms of channel stability.

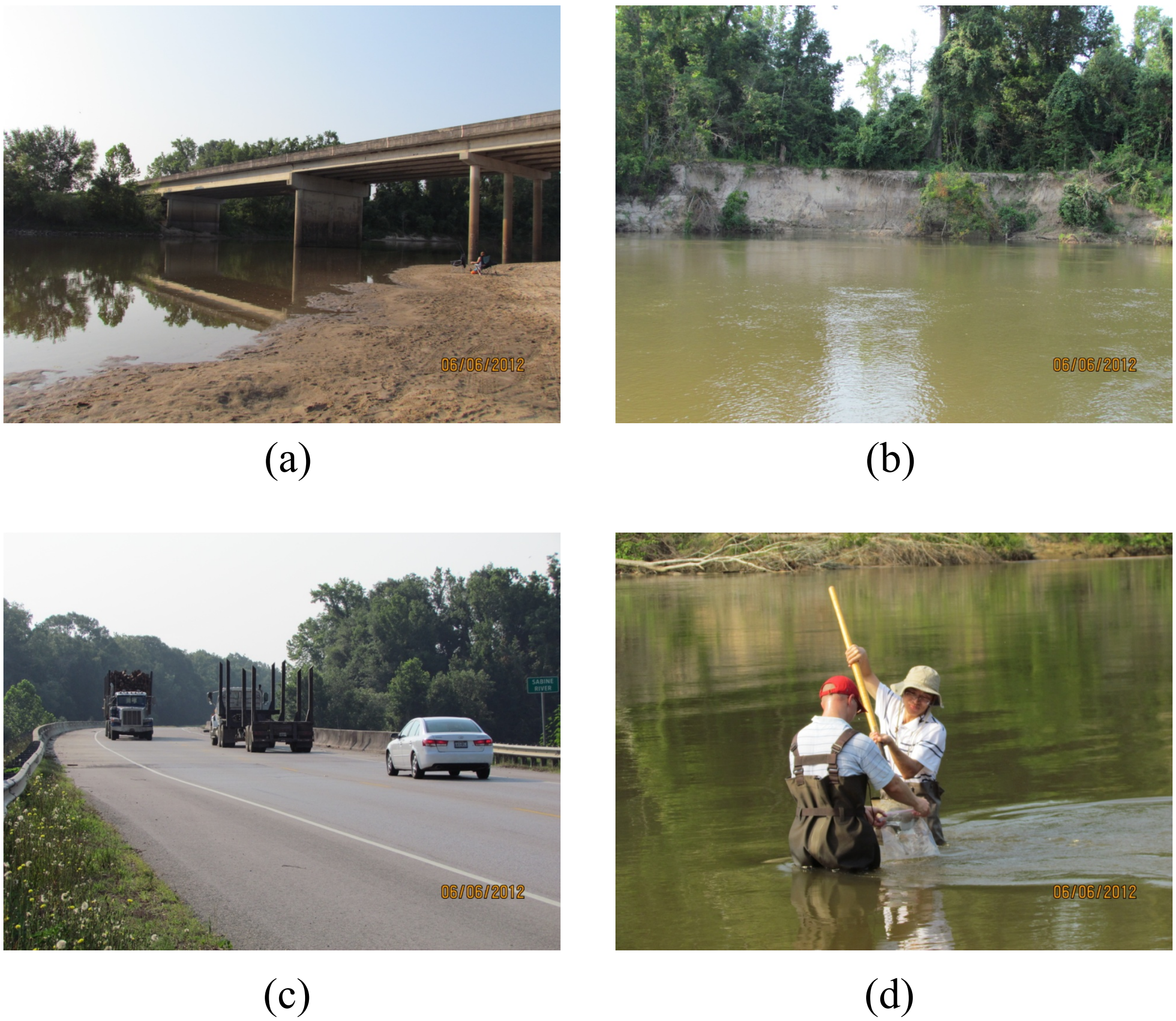


Figure 4.5: Photos taken at SH190 over the Sabine River. (a) The bridge crossing and mix of foundation types, (b) Typical steep outer bank just downstream of the bridge, (c) Traffic over the bridge, and (d) Taking of river bed samples.

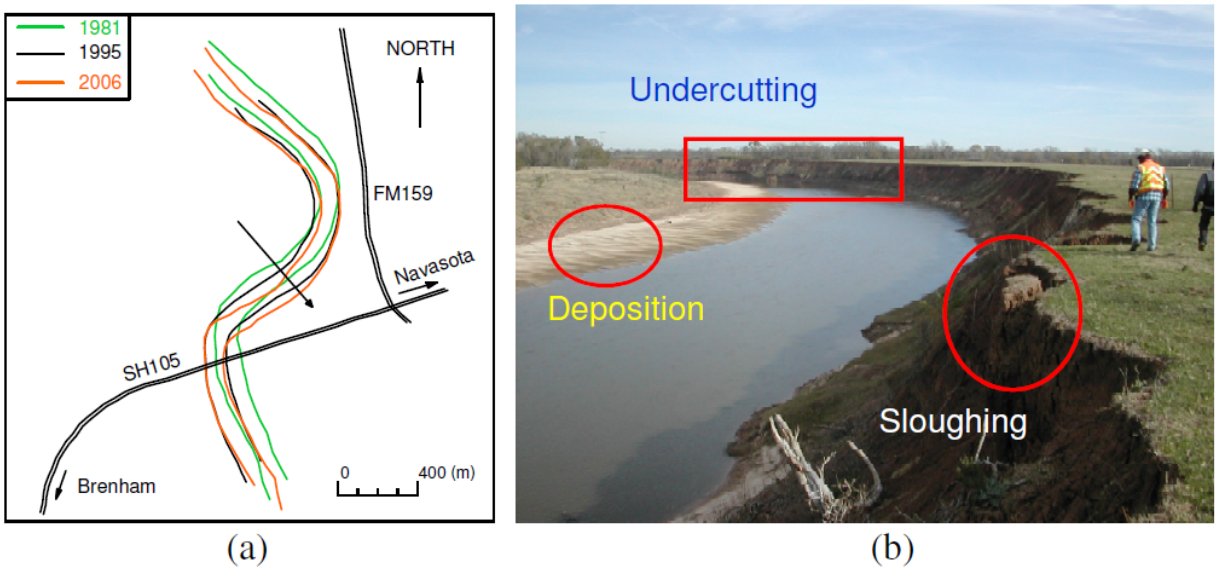


Figure 4.6: SH105 over Brazos: (a) Evolution of the banks over 25 years (b) Erosion of left bank

4.3.3 US90 at the Nueces River

The U.S. 90 crossing of the Nueces River is located about six miles west of Uvalde, Texas, and about 88 miles west of San Antonio (Figure 4.8). It consists of a west bound bridge and a relief structure which were constructed about 1967, and an older east bound bridge and relief structure. Bridge performance at the site appears to have been satisfactory until 1996 when an apparent shift in the river and degradation of the streambed became noticeable. The most damaging event occurred during the 1998 flooding, which resulted in the failure of the concrete riprap of the west abutment of the West Bound Main Lane (WBML) Bridge and threatened the west abutment of the East Bound Main Lane (EBML) Bridge. This damage was contained and repaired by placement of a rock berm along the damaged reach.

4.3.4 FM787 at the Trinity River

Extensive erosion was noted in 1957 on the western side of the river at the bend immediately upstream of the bridge. More importantly, the erosion was observed to be advancing toward the bridge (Figure 4.10). The first remedial action at this site was undertaken at this time. The erosion became a more serious problem because of the encroachment of the river on the right of way of FM 787 coming from Romayor, on the east approach to the bridge. The height of the approach above the water and the steep embankment caused concern as the shoreline rapidly moved toward the roadway. The original construction to prevent the eastern side of the river from encroaching on the roadway was found to be no longer effective in 1985 and a remedial measure was added.

We started at the left side of the channel where public access is available. A brief examination

(a)

(b)

(c)

(d)

Figure 4.7: Photos taken at SH105 over the Brazos River. (a) The bridge foundation on the left bank, (b) The bridge foundation on the right bank, (c) Bank material with clay lens on the outer bank just upstream of the bridge, and (d) Steep outer bank and flat inner bank.

(a) (b)

Figure 4.8: U.S. 90 Bridge at the Nueces River: (a) Aerial photo (b) 1998 flooding

of the river under the bridge, upstream and downstream was undertaken right away to assess the condition of the channel.

At the upstream side, we found there were very evident signs of channel instability. Upstream very close to the bridge, the outer bank is attaching the road. The shoulder of the road starts falling off to the river. There are some sheet piles to prevent the failure. However, the effect is minimal due to the fact the sheet piles are only local protection. The location of shoulder failure and sheet pile failure is recorded by GPS at (N30o25.701', W094o50.831') and Sheet pile (on the river) at (N30o25.686', W094o50.876').

We also found some scour protection and river training works. Upstream adjacent to the bridge, there are some piles standing in the water close to the right bank. They are failed scour protection works. There are some more on the left side of the river more upstream.

Grouted ripraps were put on the outer bank and under the bridge. It seems they stay in place and are working well. Maybe they are newly installed.

The river is at low flow condition. Downstream of the bridge, the river experiences expansion and creates recirculation zones when the stage is high. That might be the reason for the large sand bars there. The bridge has significant contraction effect to the river.

Even though the river stage is low, the scour condition of the piers, especially those in the river, is not known. However, for the bridge piers on the left bank, though they were protected by grouted ripraps, one pier shows very evident erosion since it deck has been exposed (picture was taken).

There is evidence of debris accumulation on the bridge pier deck left during floods (pictures were taken). Part of the traffic over the bridge is track-trailer for lumbers.

After the initial examination, we started to take samples of bed and bank materials. One group

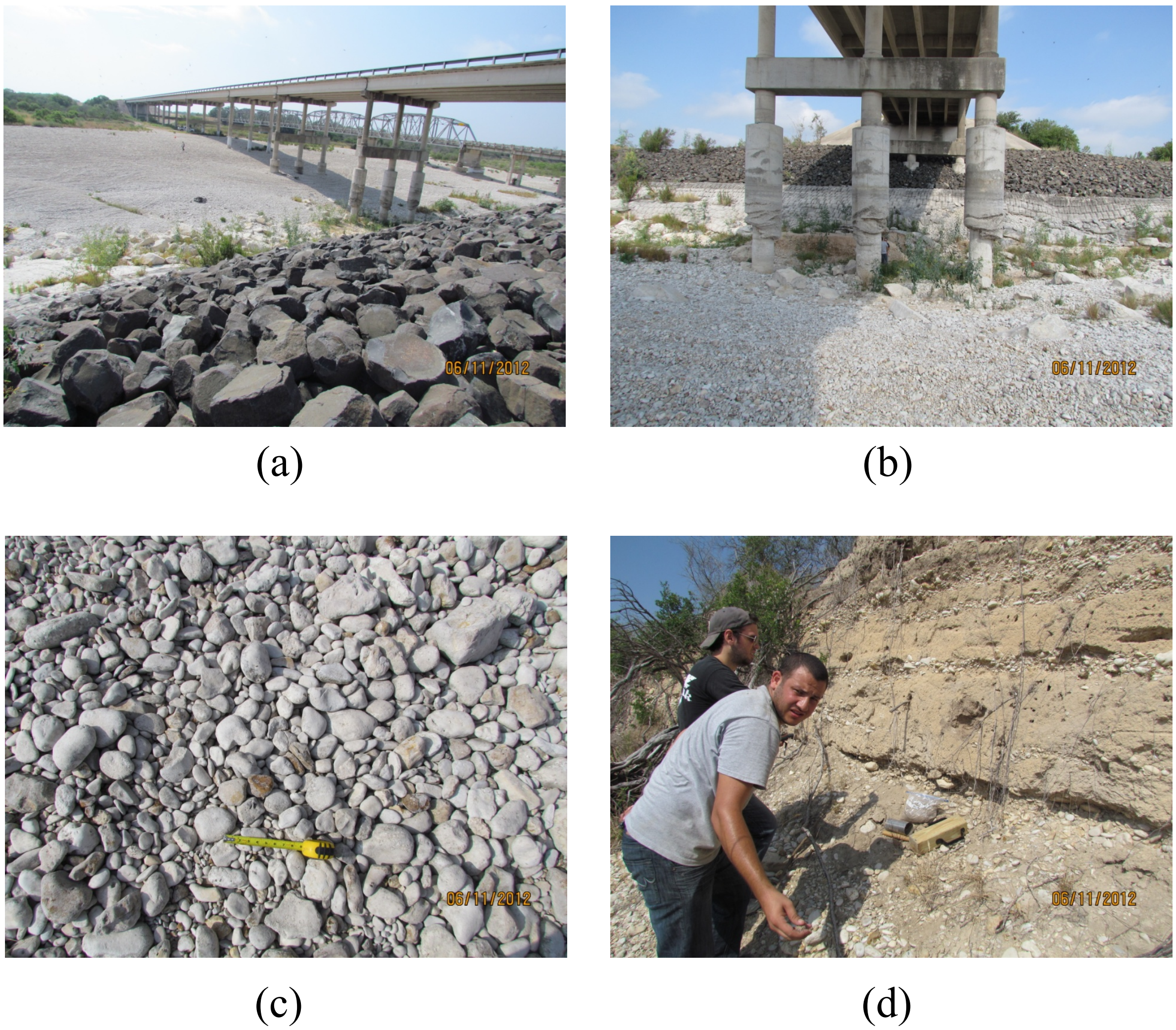


Figure 4.9: Photos taken at US90 over the Nueces River. (a) The bridge over the river, (b) Extensive roadway foundation failure due to the erosion just upstream of the bridge, (c) Survey of the downstream bank, and (d) Taking of river bed samples.

Figure 4.10: Location of the meandering Trinity River and various counter measures

(Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials. We only took sediment samples at the downstream side of the bridge since it is more accessible.

For the first sample we took (Sample 1), it was in the rive where we found gravels on bottom bedrock (limestones or marle). These bedrocks are not so hard to be broken apart. At this location and to some extend both upstream and downstream, the river bottom is on bedrock. However, all the banks are fluvial

At the end of the survey, we filled out the “Stream Reconnaissance Record Sheets” suggested by NCHRP and the “Rapid Assessment of Channel Stability” form which gave scores to each of the 13 indicators. The total score for this side was 78. Accordingly, it is classified as ”Poor” in terms of channel stability.

(a)

(b)

(c)

(d)

Figure 4.11: Photos taken at FM787 over the Trinity River. (a) The bridge over the river, (b) Extensive roadway foundation failure due to the erosion just upstream of the bridge, (c) Survey of the downstream bank, and (d) Taking of river bed samples.

4.3.5 SH34 at the N. Sulphur River

The North Sulfur River originates near Bailey, Texas, north of Dallas. After about 50 miles it merges with the South Sulfur River to become the Sulfur River. The North Sulfur River has a 25 year mean discharge of approximately 20,000 cfs and a mean drainage area of approximately 100 square miles. Before 1920 the river had a relatively shallow slope, numerous meanders, and a large flood plain. This created repeated floods in farm lands and inconvenienced the farmers. In order to avoid the flooding events, it was decided in the mid 1920s to straighten and deepen the river. This straightening led to increased slope, and therefore increased velocity and severe degradation and widening of the initial channel. This degradation and widening process has been taking place over the last 70 years and seems to be slowing down. The combination of streambed degradation and channel widening has led to vertical soil erosion of up to 25 ft for some of the bridge piers (Figure 4.12).

Figure 4.12: Severe degradation on the North Sulfur River and the impact on bridge piers.

Upon arrival, we found the bridge crossing is experiencing severe erosion problem due to channelization. It was very evident from the pictures taken. The sediment in the river bed and its banks are very fine, except several places we saw scattered gravels. Gravel count was done at one location where the gravels accumulate. 5. At the center of the channel, large amount of debris accumulated in front of the bridge pier, which is a sign of bank failure upstream. The banks at the site on both sides are very steep (almost vertical). Very severe bank erosion is going on.

4.3.6 FM973 at Colorado River

The Colorado River in Austin flows through the city of Austin and is one of the longest rivers in all Texas. The Texas Department of Transportation has detected problems of vertical degradation at

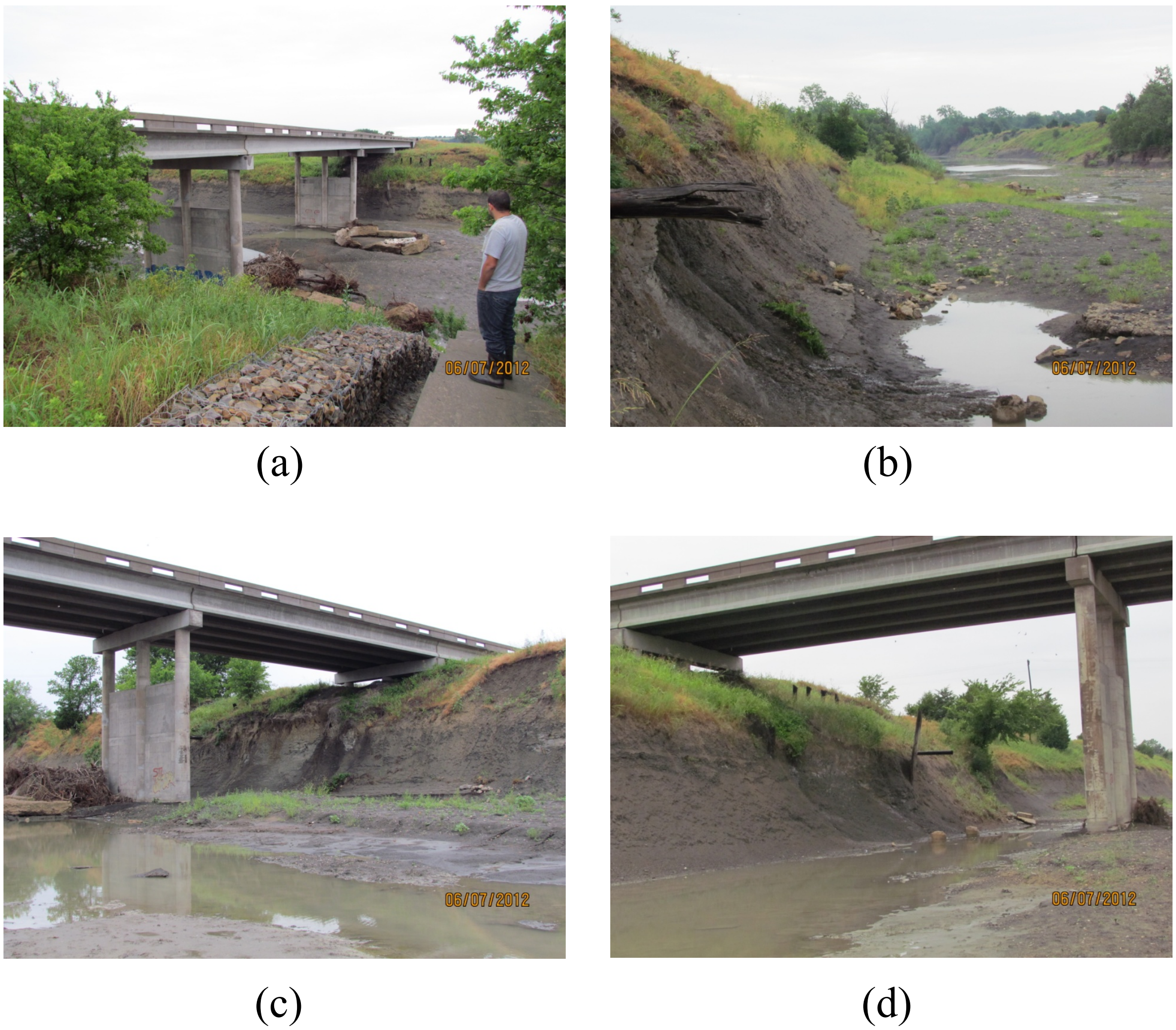


Figure 4.13: Photos taken at SH34 over the N. Sulphur River. (a) The bridge over the river, (b) Active erosion and bank failure downstream of the bridge, (c) Foundation and the bank on the right side of the river, and (d) Foundation and the bank on the left side of the river.

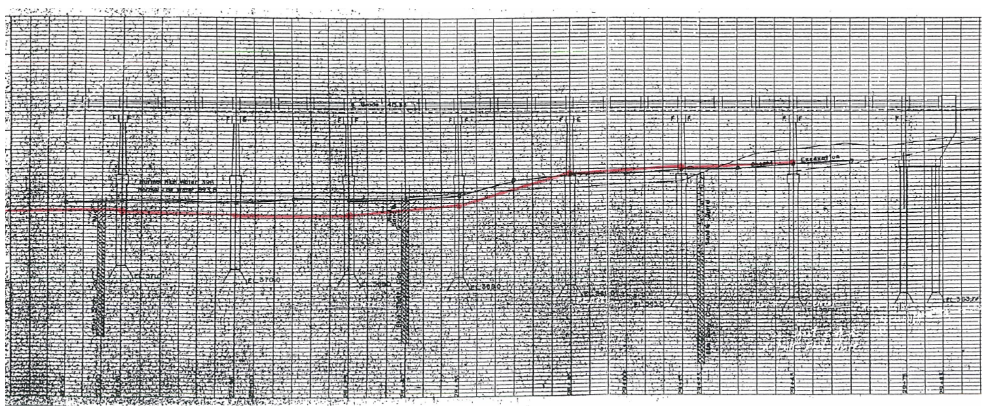
one of the bridges that crosses this river. This bridge is located 5 minutes away from the Austin-Bergstrom International Airport and it is about 450 feet long. Inspections of this bridge have shown that the drilled shafts of the piers have been exposed due to the erosion of the river bed. The location of this river can be seen in Figure 4.14. Reparations of this bridge or the construction of a new one have been considered.

Figure 4.14: Site FM973 at Colorado River

The site has been visited twice. The first one was in April 5, 2013. This first visit had the purpose of a general visual examination of the site. The bridge can be seen and accessed from the north side. The drilled shafts below the bottom of the pier base cap have been exposed, as can be seen in Figure 4.15. The condition of these drilled shafts varies and it looks like the concrete has also failed in some of them. The velocity of the river on this day was very low.

The drilled shafts of the first three or four piers from the north side of the bridge are still under the soil. Only during big floods the water can get to this side of the bridge (Figure 4.16). There is a lot of vegetation under this side of the bridge, which makes it difficult to access the other side by walking. The south side of the bridge has a very steep slope and there is no access to get under the bridge. This bridge has 14 piers in total.

The second site visit, on April 23, 2013, was specifically to obtain soil samples. The samples were



(a)

Exposure of Drilled Shafts below Bottom of Pier Base Cap

	Pier No. (from South)	Bent #	West Shaft (ft)	Center Shaft (ft)	East Shaft (ft)
	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

(b)

Figure 4.15: Cross section profile for the Colorado River at FM973.

(a)

(b) (c)

Figure 4.16: Photos taken at FM973 at the Colorado River.

collected using modified Shelby tubes of 6 inches for erosion testing. The erosion tests are performed using the Erosion Function Apparatus. Because the samples could not be obtained from the bottom of the river, they were taken from as close as possible from the water. The exact location of the samples can be seen in the Figure. All the samples were obtained from point A (Figure 4.17). The soil samples were obtained from this point because the soil was wetter and the tubes were easier to drive into the soil. The soil was sandy with some plasticity.

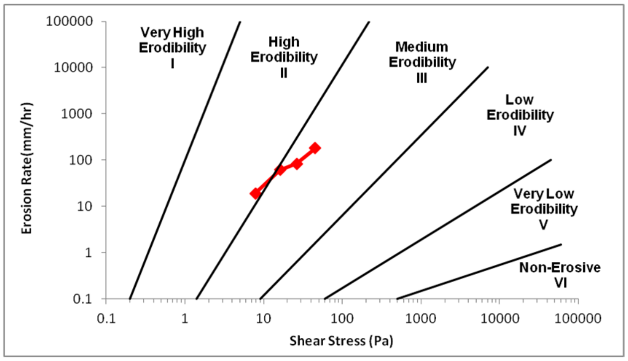
(a)

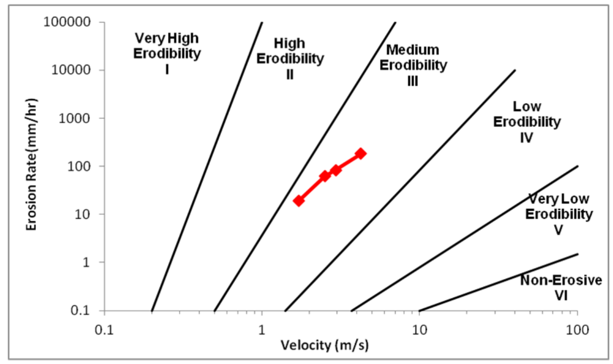
(b)

(c)

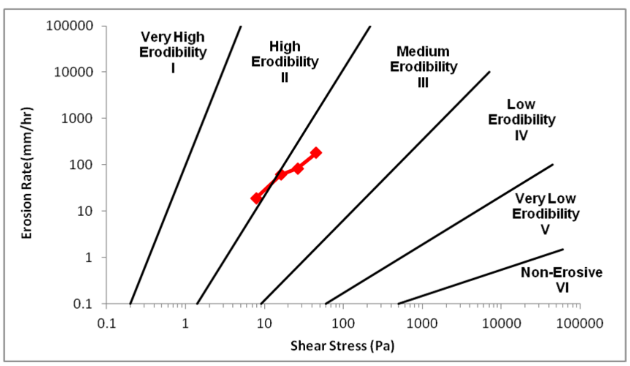
Figure 4.17: Location and Soil Samples taken at FM973 at the Colorado River.

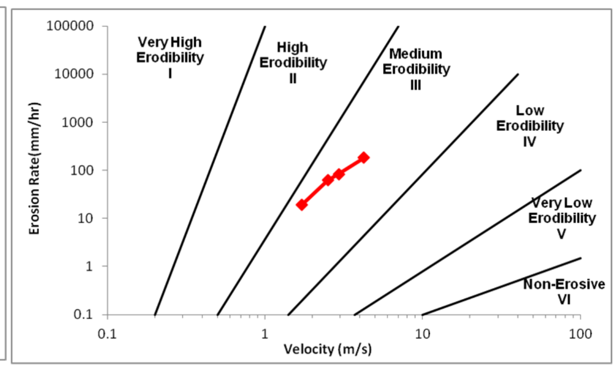
After performing erosion testing to these soils, the results are shown in Figure 4.18. The first two figures correspond to Sample #1 (S6B1) and the next two correspond to Sample #2 (S6B2). The results show that the soil at this site is in the Category III of Medium Erodibility.





(a) (b)





(c) (d)

Figure 4.18: EFA test results for Soil Samples taken at FM973 at the Colorado River: (a) Test 1 for Sample 1 (S6B1), (b) Test 2 for Sample 1 (S6B1), (c) Test 1 for Sample 2 (S6B2), and (d) Test 2 for Sample 2 (S6B2).

4.4 Summary

In this technical memo, the field survey and observation task for TxDOT research project 0-6724 was documented. In the previous tasks (Task 2 and 3), we collected a wide range of data and identify what is missing for the purpose of this project. The missing data will be complemented with the task of field survey and observation. Detailed surveying has been conducted. The team examined geomorphological features, took samples, and made hydraulic measurements during site visit. The data collected includes sediment size distribution, channel geometry, vegetation, bank erosion patterns, bedforms, floodplain characteristics, debris clogging and local scour around roadway hydraulic structures. Six sites were surveyed which covered a wide range of hydraulic and geomorphic conditions in the state of Texas. The field survey notes and example NCHRP assessment forms provided in this report serve as good demonstrations for similar TxDOT projects in the future.

Chapter 5

Survey of Numerical and Physical Modeling Efforts

5.1 Purpose of the survey

The overall goal of this project is to update the design guidelines for TxDOT on the evaluation of channel stability and its effect on transportation infrastructures. Most of the procedures involve both qualitative and quantitative evaluations. In the three-level analysis procedure suggested by FHWA in HEC-20, the most advanced Level-3 applies numerical and physical models. A survey of past numerical and physical modeling efforts on channel stability will help understand the current status in the field. The strength and weakness of each modeling approaches will be discussed. It will help writing a practical guideline for TxDOT on this issue.

For numerical models, this project will survey 1D, 2D, and 3D numerical models of hydraulics, sediment transport, and channel morphology related to roadway structures. FHWA HDS-6 has a survey of 1D and 2D numerical models for alluvial river systems up to the year 2001. There has been some progress made in this field during the past 10 years. This report will synthesize the models in HDS-6 and provide updates on the most recent models available. Based on the survey results of the numerical models and available data, this project will try to conduct test runs of the selected field survey sites. Some models will be used to evaluate the hydraulics and sediment transport during the channel degradation and bank erosion process. The input and output of these cases will be fully documented, and the channel stabilities projections from the models will be compared. How to select numerical models in the advanced level analysis will be incorporated in the analysis procedures.

There are other types of channel stability prediction tools that can be loosely classified as numerical models, such as those using empirical equation to predict migration rates. They are very simple comparing to other models. However, they also have limitations due to the overly simplified assumptions. Care needs to be taken when they are used.

For physical models in laboratories, due to the variety of structures and river geometries encountered in the field, it is impossible to do a general physical model for channel stability that would be applicable to all. Instead, this project surveyed the literature, particularly past TxDOT reports, on experiments of scour, channel meandering and their interactions with roadway structures. A synthesis of the findings from past physical modeling efforts will be useful for TxDOT engineers when they plan new bridges and culverts in similar hydraulic and geomorphic settings. The synthesis will be incorporated into the procedures and guidelines.

This technical memorandum overlaps with the literature review report since most of the survey we did was based on the documents we collected. Much part of this report has already been shown in the literature review.

5.2 Numerical models

In a previous TxDOT project, Briaud et al. (2001) did a comprehensive review on the meander prediction models. They listed more than ten representative references on this topic, which ranges from simple empirical predictors to more sophisticated three-dimensional models. We will not repeat these. Interested readers can find the review in Briaud et al. (2001). In Table 5.1, a sample of meander migration predictors and related sediment transport models is listed. Those are by no means complete.

As empirical formulas are loosely classified as numerical models, they will also be introduced here. In fact, some of the computational models use a hybrid approach which numerically solve the governing equations with the help of empirical parameters.

5.2.1 Empirical and observational methods to predict meander migration

These methods are classified into three categories: empirical methods, time rate observations and extrapolation, and predictions through simplified modeling.

Empirical methods have been proposed by several authors. The following is the four methods used in a previous TxDOT project 0-2105: (1) Keady and Priest (1977) consider the rate of downstream migration to be a function of the free-surface slope of the river, the meander amplitude, and the specific weight of water; (2) Hooke (1980) proposed that the erosion rate is most closely related to the catchment area (as a surrogate of discharge and width); (3) Brice (1982) proposed that the rate of bank migration increases with increasing channel width; (4) Nanson and Hickin (1983) showed that the ratio of radius of curvature of a bend (R_c) to channel width (W) influences the lateral migration rate of a meandering river. They proposed the relationship between channel migration rate (MR) and the ratio of radius of curvature to channel width. These methods have been used in project TxDOT 0-2105 for the following four sites:

- Brazos River at SH 105,

Number	Reference	Notes
1	Keady and Priest (1977)	Predict rate of migration as a function of slope
2	Hooke (1980)	Predict rate of migration as a function of catchment area
3	Brice (1982)	Predict rate of migration as a function of channel width
4	Nanson and Hickin (1983)	Predict rate of migration as a function of the ratio between radius of curvature to cahnnel width
5	Odgaard (1987)	Predict erosion rate to be proportional to the difference between near-bank velocity and reach-averaged mean velocity at bankful condition
6	Ikeda et al. (1981)	A theory was proposed for the formation of meanders
7	Blondeaux and Seminara (1985)	Used a 2D numerical model for the instability of the system. Resonance condition was solved for and used for prediction.
8	Pizzuto (1990)	Used a 2D numerical model to calculate shear stress distribution and then sediment transport.
9	Darby and Thorne (1994,1996)	Used a 2D numerical model to simulate channel widening. The 2D model was depth-averaged.
10	Mosselman (1998)	Used a 2D depth-averaged numerical model for a gravel-bed river.
11	Sun et al. (2001)	Used linear stability theory to develop a 2D numerical model.
12	Duan et al. (2001)	Used CCHE2D to simulate channel migration.
13	Chen (2002)	Used 3D RANS model to predict maxium shear around bridge pier.
14	Olsen (2003)	Used 3D RANS model to predict the migration of channels.
15	Abad and Garcia (2004)	Used quasi-2D model (essentially 1D but considering 2D effect) to predict the migration of bends.
16	Rodriguez et al. (2004)	Used both 2D and 3D models to simualtion flow field. They compared with field data.
17	Jang and Shimizu (2005)	Used 2D model to predict bar growth and channel widening.
18	Liu and Garcia (2008a)	Used 3D RANS model to predict local scour process.
19	Liu and Garcia (2008b)	Used 2D depth-averged model to predict scour
20	Liu et al. (2012)	Used 2D and 3D models to predict the sediment transport in a large river.
21	Motta et al. (2012)	Used a physically-based 1D/2D model and implemented in RVR Meander

Table 5.1: A sample of meander migration predictors and related sediment transport models

- Nueces River at US 90,
- Trinity River at FM 781,
- Guadalupe River at US 59.

The values predicted by the empirical equations were compared with the measured values for the migration rate. The conclusion on the accuracy of these methods were given in Briaud et al. (2001).

The time rate observations and extrapolation method is based on aerial photos taken at different times. This method has been documented in detail in Lagasse et al. (2004). First, circles at two different times are fitted for a given bend. Then, the location of the center and the magnitude of the radius are linearly extrapolated with respect to time. The direction of new migration increment can be extrapolated based on the direction of the two previous increments. The process is shown in Figure 5.1. The drawback of this method is that it cannot incorporate a change in soil condition and a future hydrograph different from the past.

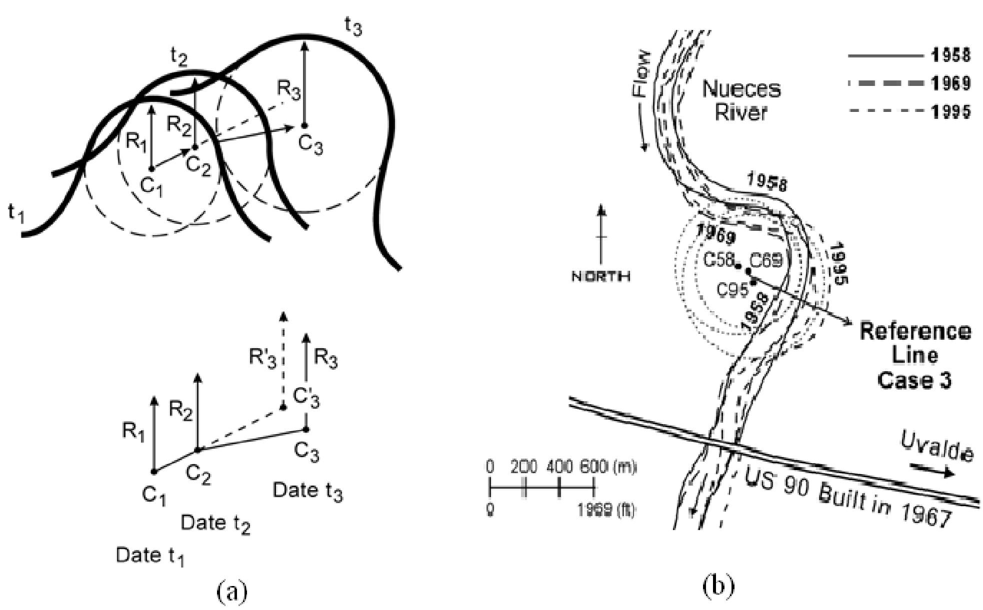


Figure 5.1: Time rate observation and extrapolation method (Briaud et al., 2001): (a) fitting of circles, (b) application example Meander for the meander migration of the Nueces River at US 90

To take into account the soil properties, a prediction method through simplified modeling was developed in Briaud et al. (2007). It uses the *MEANDER* program funded by TxDOT (Figure 5.2). This method has the advantage of taking into account many of the factors influencing the meander migration process but it is more complicated to use than the empirical methods and historical extrapolation methods described above.

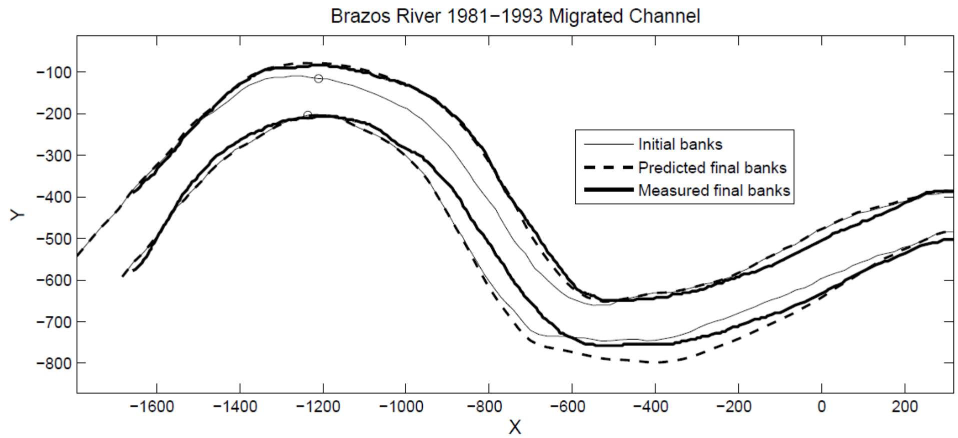


Figure 5.2: Example of results obtained with the MEANDER program (Briaud et al., 2007)

5.2.2 Methods to predict aggradation and degradation

Channel vertical stability, namely aggradation and degradation, is a very special case of channel stability. The prediction of aggradation and degradation is different from the prediction of channel meanders, though they are related. That is the reason it is discussed in a separate section here. Vertical instability is the result of imbalance between sediment transported into and out of a river reach. One can qualitatively and quantitatively analyze the channel vertical stability using the sediment continuity concept. Another useful tool for qualitative analysis is the Lane relationship. The essence of this relationship is that river channels respond to a change in flow discharge or sediment load and move from one equilibrium to another by changing its slope or sediment grading. However, it is not capable to predict the amount of aggradation and degradation and the time it needs to adjust.

In Section 6.3 of FHWA HEC-20 (Lagasse et al., 2001), a detailed discussion on predicting aggradation and degradation is given. In addition to the sediment continuity equation (termed as Exner equation in the sediment transport literature), analysis on incipient motion of sediment particles and armoring is needed. The resulting tool for degradation analysis is formulas to predict new equilibrium slope. Several typical scenarios which could cause channel slope adjustment are given, namely sediment supply cutoff (no sediment supply), reduced sediment supply, and base level control.

More advanced models can be used to predict the sediment transport in a river channel. These models route sediment down a channel and adjust the channel geometry to reflect the imbalance between sediment supply and river capacity. There is a variety of choices for such purpose, most notably the BRI-STARS and HEC-RAS models, which will be introduced in Section 5.2.3.

5.2.3 1D, 2D, and 3D Numerical models

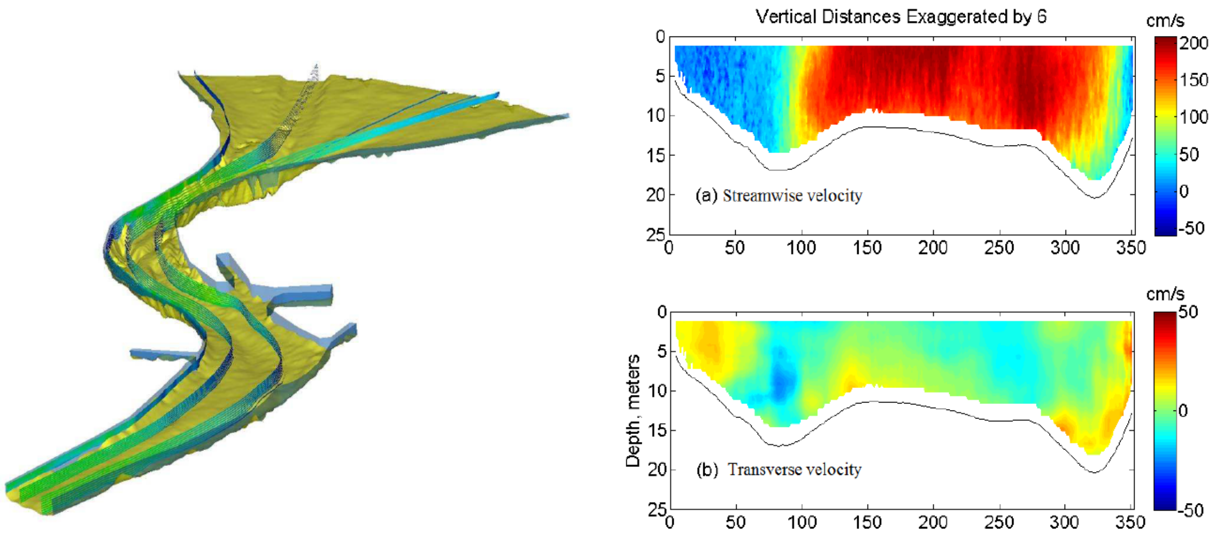
Numerical models, also termed mathematical models in HEC-23 and computer models in HDS-6, solve the set of quantitative equations for the relevant physical processes involved in stream channel stability. There is a big pool of numerical models available for the evaluation of sediment transport, channel migration, and profile change. A good survey and discussion on the usage of numerical models on this topic is provided in Chapter 15 of García (2008). The use of these models can provide very detailed information on flow field and sediment motion.

A survey of 1D and 2D numerical models is provided in HDS-6. Examples of 1D models include the BRI-STARS (BRIdge Stream Tube model for Alluvial River Simulation) model (Molinas, 2000), HEC-6 model (outdated, replaced by HEC-RAS software), and FLUVIAL-12 model (Chang, Chang). BRI-STARS model is a generalized semi-two-dimensional water and sediment-routing computer model that includes an integrated graphical interface. It is capable of simulating the channel widening/narrowing phenomenon as well as local scour due to highway encroachments. It contains a subset of Federal Highway Administration's WSPRO subroutines for computing bridge hydraulics. HEC-6 and its replacement HEC-RAS are only suitable for aggradation/degradation simulations. The stream banks are fixed in space which makes it not suitable for simulating meanders. At bridge crossings, they calculate local scours which include contraction scour, pier scour, and abutment scour. The FLUVIAL-12 model has the capacity to simulate bank erosion and is described as an erodible-boundary model. HDS-6 also discussed two 2D models, i.e., SED2D (Letter et al., 1998) and Flo2DH (Froehlich, 1996). With the increasing of model dimensionality, the data requirement also increases.

In general, a basic numerical model of water flow and sediment transport in an alluvial river consists of three conservation principles: conservation of mass for water; conservation of mass for sediment, conservation of water momentum. The flow resistive force drives the motion of sediment which is usually described by a sediment transport rate formula. These equations form a nonlinear partial-differential equation system which in general cannot be solved analytically.

For channel stability problems, especially those involve large river reach and long term prediction, 1D model is probably the most reliable and affordable choice. However, the simplicity of 1D models come with the price of loosing too much physical information. To improve this situation, 2D models (usually depth-averaged in the water column) can provided more details about the flow field, particularly the cross-channel flow which is important for the channel cross section profile evolution. Examples in the literature of 2D morphodynamic modeling include Darby and Thorne (1996), Mosselman (1998), Duan et al. (2001), and Liu et al. (2008), among many others. The limitations of most 2D models are: (1) they have no capability to describe the vertical flow distribution in a cross section, and (2) they usually assume hydrostatic pressure distribution in the vertical direction. Secondary flow is critical for meander migration. However, 2D models can not predict this secondary flow circulation in a bend. Special treatment has been developed to use 2D models for secondary flows, though their applicability is limited.

The state-of-art computational fluid dynamics (CFD) simulation technique can reveal the detailed turbulent flow field in the channel and indicate the trend of erosion and channel migration. For example, 3D CFD simulation has been done for the first two bends of the St. Clair River in the Great Lakes area to investigate the erosion problem (Figure 5.3 (a), Liu et al. (2012)). The simulated shear stresses were used to calculate the erosion rate. Corresponding field measurements using ADCP have also been done the in that area. Figure 5.3 (b) shows the velocities in the primary and secondary directions at the first bend. However, 3D modeling for channel stability is very limited and it is anticipated that this situation will not change in the near future.



(a) (b)

Figure 5.3: Modeling of meandering channel in the St. Clair River: (a) 3D numerical modeling (b) ADCP velocity measurement showing secondary flow in the first bend of the St. Clair River

In practice, high-dimensional models (2D and 3D) for the prediction of channel stability, though sound attractive, are very limited due to the complicity of the problem. Some examples of three-dimensional morphological modeling efforts are Wu et al. (2000), Fischer-Antze et al. (2008), and Liu and García (2008). There are still a lot of challenges which include extremely long simulation time, large deformation of the domain, and input data uncertainties, among many others. The extremely long simulation time is partially due to the geological time scales on which the channel system evolves. As such, it is not recommended to do 3D modeling of regional channel stabilities at current stage. However, it is absolutely suitable and perhaps more reasonable nowadays to do 3D modeling for local erosion and sedimentation problems associated with channel migrations.

More practical numerical modeling approach to predict meander migration of rivers at reach-scale would be two-dimensional (2D) linear analytical models. Note that the 2D linear analytical model is different from the 2D computational model mentioned above. The basic idea behind 2D linear analytical models is that instead of solving all the 2D governing equations for flow and sediment, some assumptions are made for things such as the transverse profile in bends. The linear theory is limited to the case of mildly curved channels, for which a linearization of the governing equations is feasible. Some representative examples of linear models are Ikeda et al. (1981), Blondeaux and Seminara (1985), Johannesson and Parker (1989a), Johannesson and Parker (1989b), Zolezzi and

Seminara (2001), and Seminara et al. (2001), among many others. For small to mild curvature meander bends, the linear theroy is a good approximation for the fluvial processes and the formulations for velocity and depth given by the theory can be used to compute the rate and direction of migration. It is noted that these velocity and water depth are not from solving the governing equations numerically. The limitation of these linear models is very obvious. They can not be used for meander bends with high local curvatures.

To improve model predictions and overcome some of the weaknesses of linear theory, physically-based approaches have been proposed. For example, Motta et al. (2012) proposed a new formulation for the meander migration rate based on the physically-based streambank erosion processes and implemented in RVR Meander software (discussed next). The performance of the proposed new formulation was compared with those from the classic linear theories by using several test cases. One of the highlights of the new model is the consideration of bank erosion processes (hydraulic erosion, cantilever, and planar failure) which was originally developed in the US Department of Agriculture channel evolution model CONCEPTS. They showed that the physically-based model can capture the complex long-term migration patterns of natural channels.

The RVR Meander platform (`http://www.rvrmeander.org`) is a free software to predict channel migrations. The new development merges the functionalities of the first version of RVR Meander (Abad and Garcia, 2006; Motta et al., 2012) and CONCEPTS model(Langendoen et al., 2001). CONCEPTS stands for CONservational Channel Evolution and Pollutant Transport System. The RVR Meander platform implements a physically- and process-based method that relates channel migration to the streambank erosion processes (both hydraulic erosion and mass failure). It has a stand-alone version for Windows and Linux operating systems and an intergraded version with ArcGIS. An example simulation for the Machinaw River in Illinois is shown in Figure 5.4. The group in UTSA will use RVR Meander program for this project.

5.3 Physical models

5.3.1 Laboratory models for channel migrations

Physical models have been used to study the general laws behind channel migrations. The purposes of physical modeling in the lab are to duplicate the complicated flow processes with a small scale, examine the effectiveness of countermeasures, investigate the hydraulic performance under different flow and sediment load conditions (Julien, 2002).

If properly designed, scaled physical modeling can provide valuable information about the physical process based on similarity principle. For a physical model to represent the reality, the geometric, kinematic, and dynamic similitudes need to be considered. When not all of these similarities can be satisfied, an analysis needs to be done to take into account the critical physical processes. In Section 5.6.1 of HDS-6 (Richardson et al., 2001), a brief discussion of these similitudes is provided. It also provides additional reports and documents on particular physical modeling projects for alluvial channel flows at highway crossings.

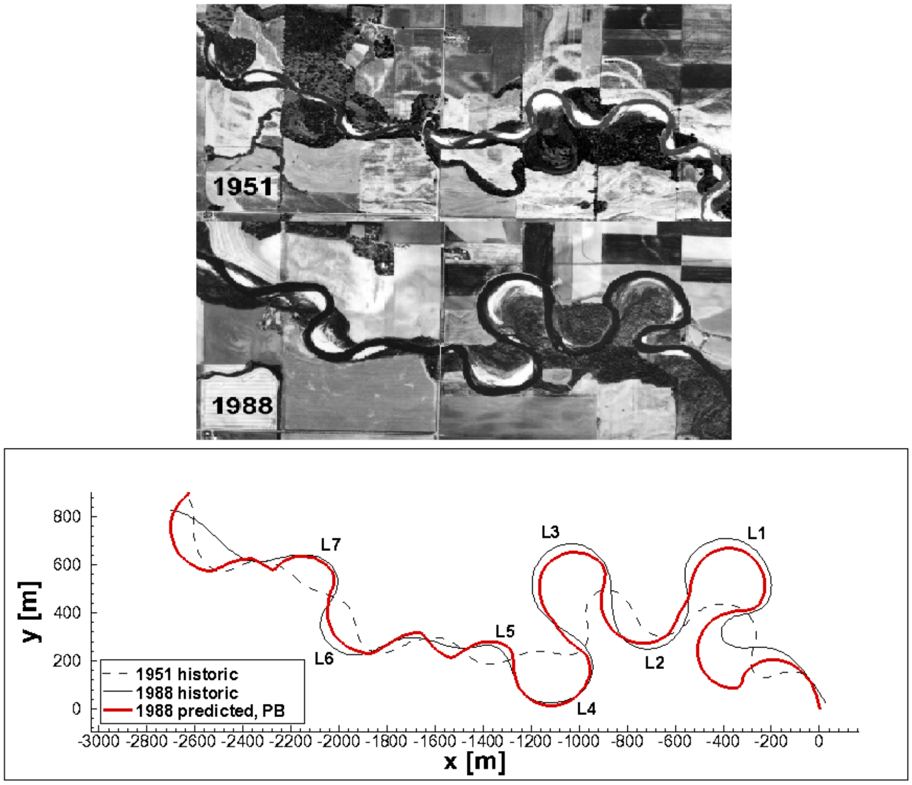
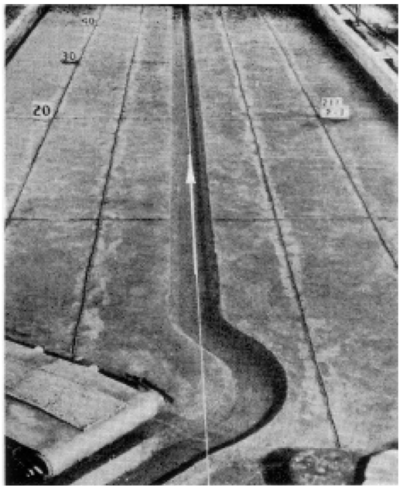


Figure 5.4: Example of results for the prediction of meander in the Machinaw River in Illinois obtained with the RVRMeander program (Motta et al., 2012)

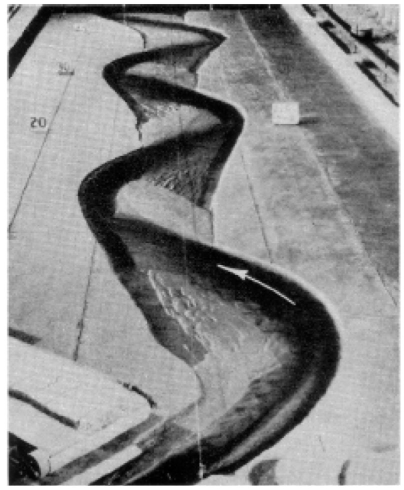
In general, there are two types of physical models for river channels: (1) fixed-bed, and (2) live-bed. For fixed-bed models, the interest is on the flow in the river and around hydraulic structures. The bed is fixed and no sediment motion is allowed. Usually the bed is paved with rigid surface or the bed shear stress is below the critical shear stress for sediment motion. On the other hand, live-bed models are useful when sediment transport is important, such as local scour and channel migration. Comparing to the fixed-bed models, one additional degree of freedom (sediment) is added to the problem. To ensure similarity between model and prototype, the dimensionless shear stress (Shields number) and the dimensionless sediment size should be similar.

The notable early work in the laboratory is in Friedkin (1945) where he studied the evolution of a channel from straight to meandering. Some of the key parameters were defined and a first attempt was made to establish qualitative relationships (García, 2008, chap. 8).

Among many other movable bed flume experiments for curved channels mimicking natural meandering rivers, a widely cited example is Odgaard and Bergs (1988), though much earlier experimental work also exist, such as Yen and Yen (1971). It has been used by many as a validation case for numerical models, such as Wu et al. (2000). In this study, they used a semi-circular recirculating channel with sand bed. Detailed measurement of individual components of the momentum equation



(a)



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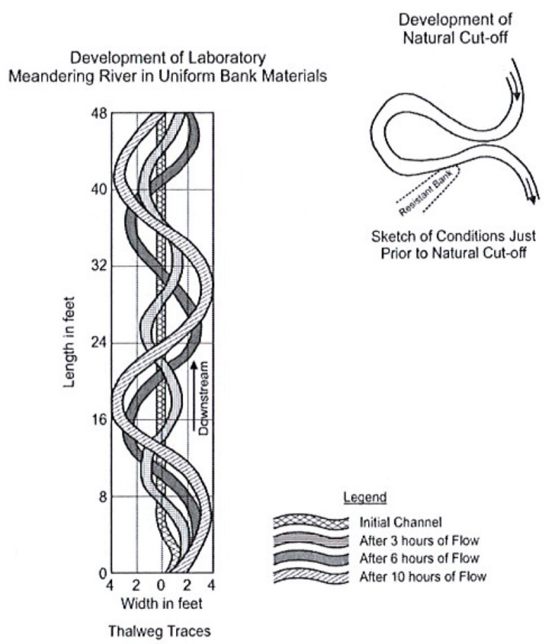


(c)

Figure 5.5: Physical model experiments reported in (Friedkin, 1945): (a) Initial straight channel, (b) Channel form after 4 hours, (c) Sketch of the meander development

was done and the relative effect of each component was evaluated.

In a previous TxDOT project, the group led by Prof. Briaud at TAMU also did laboratory experiments to develop so called soil-based guidelines to predict channel meander migrations. The highlight of their work is the application of soil erosion model to estimate migration rate. Both non-cohesive sand and cohesive clay were used as bed material. Figure 5.6 shows the artificial meandering river experiment conducted at Texas A&M University (Briaud et al., 2007).

Figure 5.6: Physical modeling of meandering channel development (Briaud et al., 2007)

There are also laboratory experiments with the bed fixed. In these studies, the focus is the turbulent flow features and the coherent structures assuming the morphological boundary is frozen in time. For example, Jin et al. (1990) used a 270^o channel to study the velocity and turbulence distributions with particular attention on the roughness effect of the banks. In natural river channels and more importantly with human interventions such as riprap protections, the roughness elements on the banks could change the flow features and consequently the channel evolutions. Another example is in Abad and García (2009) , where a fixed bed high-amplitude meandering flume was used to investigate the details of the turbulence and its implications for river bends. They also reversed the flow in the flume to investigate the effect of the bend orientations. By reversing the flow direction, the bend switches between upstream oriented and downstream oriented, both of which occur in nature.

The references given in this section is not conclusive. The meandering of a river system is very complex and our ability to predict its trajectory is limited. A recent comprehensive review on the state-of-art in this field can be found in Guneralp et al. (2012), which is an editorial paper for a special issue titled "Meandering Channels" in the journal *Geomorphology*. The dynamics in the system seems gradual with episodic abrupt events, such as meander cutoffs. Most of studies focus on

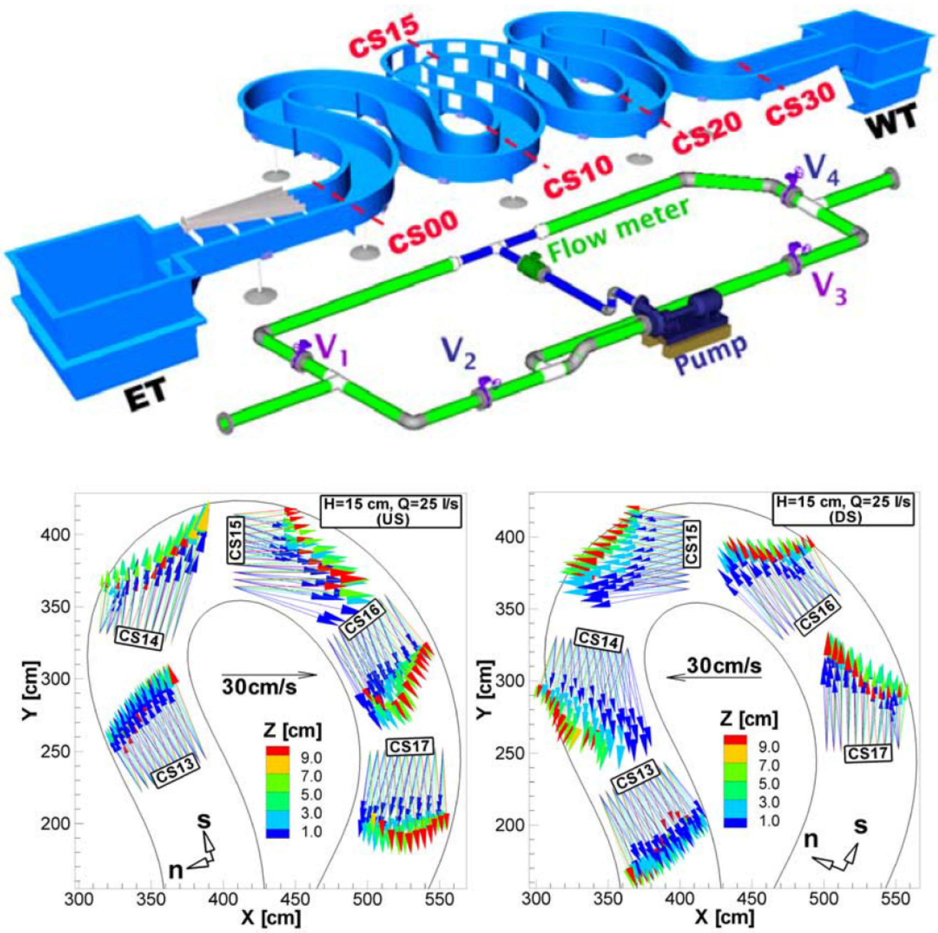


Figure 5.7: An example of flume test for hight amplitude meander bends with fixed bed (Abad and García, 2009): (a) The schematic of the flume, (b) Secondary flow in the bends which is responsible for the erosion and transportation of sediments.

the prediction of gradual evolution of the river channels without the consideration of these abrupt changes. The timing of cutoffs seems random and unpredictable. However, cutoffs are important part of the whole process. In a recent study, van Dijk et al. (2012) demonstrated in a laboratory setting that the cutoff process, which is affected by dynamic upstream perturbations, will alter the bend growth and floodplain formation. There is clearly a lot of unknowns to be explored in the future.

5.3.2 Methods to measure soil resistance to erosion

Channel aggradation/degradation and migration occur through soil erosion and transport. Therefore, the erodibility of sediment is one of the key parameters. In most of numerical models, no matter what approach they use, how easily the soil can be eroded away is important for the successful prediction of channel evolution.

There are methods available to quantify soil resistance to erosion at the element level and to predict channel degradation and migration at the global level. The measurement of soil resistance to erosion at the element level provides information for global channel stability prediction.

In the literature, there are several methods to quantify erosion at the element level. In general, they apply artificially generated flows to the soils and observe the erosion process. We briefly discuss three of the methods, i.e., soil classification based method, the Erosion Function Apparatus, and the Pocket Erodometer. The soil classification approach consists of collecting samples of the soil, classifying it according to the Unified Soil Classification System and using Figure 5.8 (a) (Briaud et al., 2007). The Erosion Function Apparatus approach is well known and leads to an erosion curve as shown in Figure 5.8 (b) (Briaud et al., 2001). From this curve, an engineer can read the critical velocity and the erosion rate for a given river velocity.

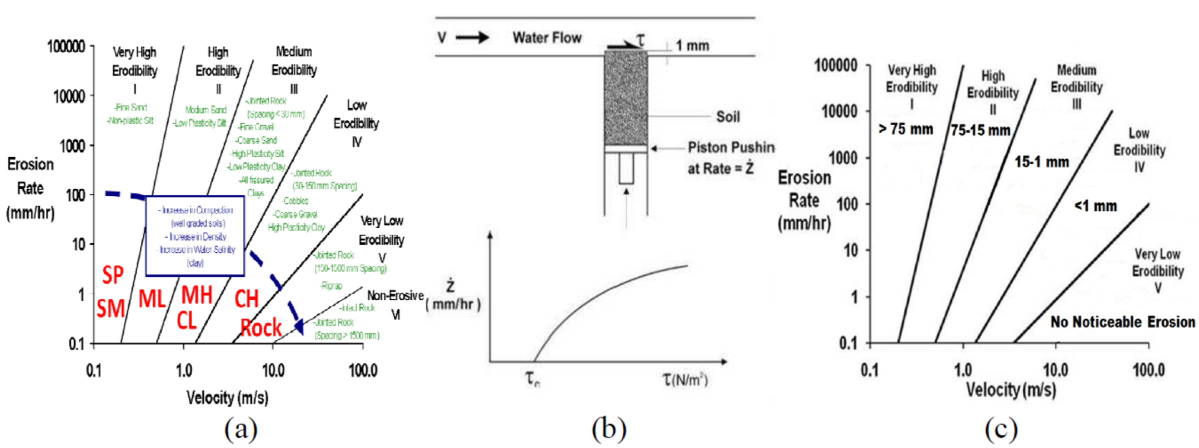


Figure 5.8: Methods to test soil erosion resistance: (a) Soil Classification Approach (b) Erosion Function Apparatus (c) Erosion chart for PET (Briaud et al., 2007)

The soil classification approach is too rudimentary and the EFA requires time and money. In order to simplify erosion testing, the Pocket Erodometer Test (PET) was developed (Figure 1.13 (c)). It consist of directing a jet to the surface of the soil sample and measuring the depth of the hole developing as a result of the test. The jet is at 8 m/s and is repeated 20 times from a distance of 50 mm from the sample face. Figure 5.9 shows a PET in progress.

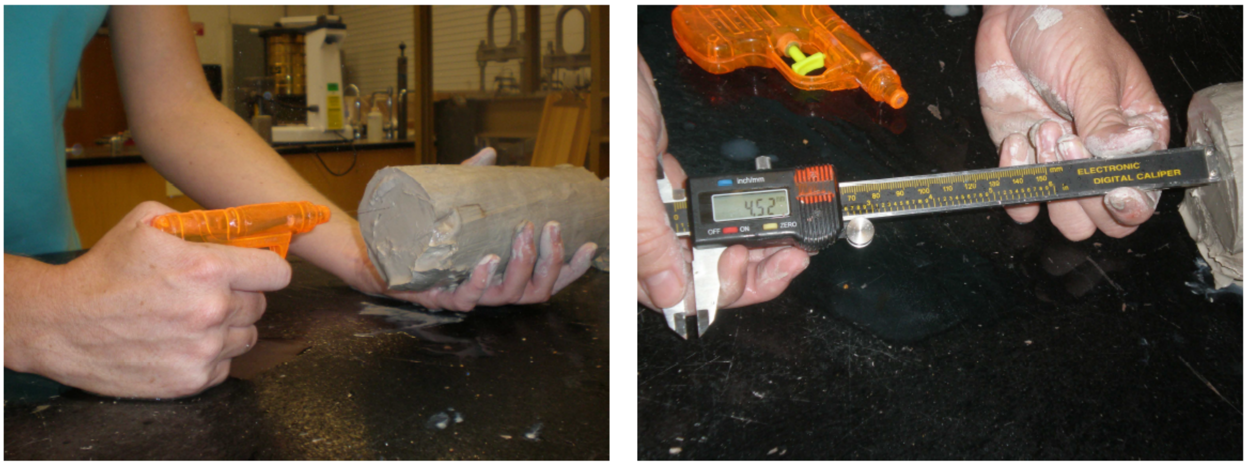


Figure 5.9: Pocket Erodometer Test (PET) in progress (Briaud et al., 2007)

5.4 Summary

This technical memorandum summarizes the survey on both numerical and physical models the research team has done on the topic of channel stability and its impact on roadway hydraulic structures. For numerical models, it was found that there are quite a lot of choices with different levels of complexities, which ranges from simple empirical migration predictions to more complicated three-dimensional computational models. For practical purpose, the research team found that perhaps it is premature to use those three-dimensional and even some of the two-dimensional numerical models at reach scale. Empirical formulas, linear theory based 1D/2D methods, and new development on 1D/2D methods based on physical processes are more suitable for engineering applications. For physical models, we surveyed the literature and found it is very hard to generalize the channel evolution in a laboratory setting. These physical models are very useful to reveal some of the key processes for channel migrations. However, for specific cases, physical models should be done on a case-by-case basis if resources are available. The physical modeling and numerical modeling techniques can be used in combination to cross check and further reduce the uncertainties.

Chapter 6

Analysis Procedures and Design Guidelines for Structures in Unstable Streams

6.1 Introduction

We have revised and modified the relevant part in the TxDOT Hydraulic Manual Chapter 7 "Channels": Section 4-"Stream Stability Issues", which is ready to be inserted into the manual.

At the beginning of the project 0-6724, we only had 2009 version. The current version is published in 2011. There are only minor changes regarding channel stability. As a result , we updated and modified the 2011 version.

The revised version of the TxDOT Hydraulic Manual is attached in the Appendix. The following of the technical memo will document the revisions and modifications regarding channel instability problems made in the manual.

6.2 List of revision and modifications

- Added a summary on the causes of channel instability This part is missing in the old manual. We added a section with the title "Causes of Channel Instability.
- Added section "Channel Instability Assessment Procedures", which is a synthesis of the HEC-18, 20, 23. We also added the three-level analysis procedure as suggested in HEC-20 and how to use the three documents in combination. We recommended analysis tools:

  First choice : TAMU MEANDER, which is funded by TxDOT. It is simple and easy to use and considers flood events and history. It is based on erodibility test and fitting of meander curve.

Second choice : RVRMeander, which is a free software with GIS-plugin and standalone versions. It considers more physics: river hydraulics, sediment transport, and bank failure. It is slightly complicated as more physics are considered.

Application examples for the sites selected using both TAMU MEANDER and RVRMeander will be documented in detail in TM7.

- Added vertical channel instability with description of the problem, causes and general river response to channelization. We also added analysis procedure and tools for vertical instability problem.
- Added regulatory mandate part for countermeasure. Relevant part is not in the original manual. However, it is mandated by National Bridge Inspection Standards (NBIS). We also added Plan of Action (POA) part.
- Added organized and more detailed section for countermeasures. Relevant part is not in the hydraulics manual. Added parts include "Countermeasure selection criteria" and "Countermeasure classification, when and how to use them". The countermeasures are grouped into: hydraulic countermeasures including river training and armoring, structural countermeasures including foundation strengthening and pier geometry modifications, biotechnical countermeasures including vegetated ripraps and root wads, and monitoring. We also added a section "Specific engineering countermeasures for channel instability problems". This section specifically deals with problem associated with meander migration, braiding and anabranching, and aggradation/ degradation.

As a general comment, since the literature on channel instability is abundant, we cannot include all. Only included concepts and analysis methods the research team deems most important Condensed and synthesized in the revised guideline References are given when details have to be left out This project contributes application examples and data in the final report, technical memos, case studies, and database.

Appendix A

Field Observation Records

A.1 Records for SH63 at the Sabine River

A.1.1 Field notes for SH63 at the Sabine River

Notes from the field visit

Site: SH63 at Sabine River

Date: 6/6/2012

Time: From 12:30am to 2:00am

Participants: Xiaofeng Liu (PI)

Rusen Sinir (Graduate student, UTSA)

Axel Montalvo (Graduate student, TAMU)

Another student from TAMU

Notes:

1. We started at the right side of the channel where public access is available. A brief examination of the river under the bridge was undertaken right away to assess the condition of the channel.

   This bridge is also right on the middle of a meander bend. This reach of the Sabine River forms the boundary between Texas and Louisiana. The outer bank (Louisiana side) shows a lot of signs for erosion. A big bar formed on the inner side (Texas side).

2. After the initial examination, we started to take samples of bed and bank materials. One group (Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials.

3. The positions of the taken samples were recorded by GPS:

   Sample #1: WP45 N30°21.781', W096°09.239' .
   Sample #2: WP46
   Sample #3: WP47
   Sample #4: WP48

(Aerial photo of the river and SH63)

We observed large dunes and ripples on the point bar and also inside the river. It seems the river is regulated a lot by the dam not far from upstream.

4. We filled out the “Stream Reconnaissance Record Sheets” suggested by HEC-21(?). It is a long form with a lot of details. However, it is less useful, time consuming, and sometime hard to make choices.

5. We also tried the “Rapid Assessment of Channel Stability” method and gave scores to each of the 13 indicators. The total score for this side was 60. Accordingly, it is classified as “Fair” in terms of channel stability.

A.2 Records for SH190 at the Sabine River

A.2.1 Field notes for SH190 at the Sabine River

Notes from the field visit

Site: SH190 at Sabine River

Date: 6/6/2012

Time: From 8:30am to 10:00am

Participants: Xiaofeng Liu (PI)

Kyle Strom (co-PI)

Rusen Sinir (Graduate student, UTSA)

Axel Montalvo (Graduate student, TAMU)

Another student from TAMU

Notes:

1. The visit of this site was due to communication mistake. We were supposed to visit SH63@Sabine instead of SH190. Both sites are close to each other (about 30 miles apart). We finished out sampling of sediment. TAMU only have one sample completed before moving to SH63 site.

   Though not originally scheduled, we found that at this site, the bridge foundation was at great risk due to its location on the meander bend. It seems a lot of efforts have been done to protect the foundation.

2. We started at the right side of the channel where public access is available. A brief examination of the river under the bridge was undertaken right away to assess the condition of the channel.

   This bridge is right on the middle of a meander bend. This reach of the Sabine river forms the boundary between Texas and Louisiana. The outer bank (Louisiana side) shows a lot of signs for erosion. A big bar formed on the inner side (Texas side).

3. After the initial examination, we started to take samples of bed and bank materials. One group (Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials.

4. The positions of the taken samples were recorded by GPS:

Sample #1: WP40 N30°21.781’, W096°09.239’ . It is about 25m from the water line on the right bank. From this side, ripraps on the left bank can be seen. This location is at the starting point of the bar upstream.

We estimated the water velocity by timing the floating object through the shovel. We recorded 5 ft/ 3 seconds (or about 1.6 ft/s). The depth at the Sample # 1 is 3.5 ft.

(Aerial photo of the river and SH190)

Sample #2: WP41 , about 25-30 m from waterline at right side. In the middle of the bar. Velocity estimated 5 ft/2.5 s (about 2 ft/s). We observed bedforms and ripples in the river near shore. Depth is about 3.5 ft.

WP42: The river experience expansion at this point and there is very strong circulation and a shear layer developed with large vorticies. In the middle of the channel, "macro-boil" type vortex shows on the free surface suggesting large bedforms on the bottom. This may be due to the expansion and recirculation zone.

Sample #3: WP43 . End of the bar on the right bank. 15 m from shore. Velocity about 2ft/s. Depth is 3 feet.

Sample #4: WP44. This is a sample taken right in the middle of the bar.

5. We filled out the “Stream Reconnaissance Record Sheets” suggested by HEC-21(?). It is a long form with a lot of details. However, it is less useful, time consuming, and sometime hard to make choices.

6. We also tried the “Rapid Assessment of Channel Stability” method and gave scores to each of the 13 indicators. The total score for this side was 60. Accordingly, it is classified as “Fair” in terms of channel stability.

A.2.2 Stream Reconnaissance Record Sheets for SH190 at the Sabine River

STREAM RECONNAISSANCE RECORD SHEETS

(Modified from Thorne, 1998) [(1)]

SECTION 1 - SCOPE AND PURPOSE

Brief Problem Statement:

Assessment of channel stability

Purpose of Stream Reconnaissance:

For TxDOT Research project 0-6724
Channel stability

Logistics of Reconnaissance Trip:

RIVER: Sabina River	LOCATION: SH 190	DATE: 6/06/2012 From: 8:30 To: 10:00.
PROJECT: 0-6724	STUDY REACH: upstream/downstream ± 100 m	
SHEET COMPLETED BY: Xiaofeng Liu (UTSA)		
RIVER STAGE: low	TIME START:	TIME FINISH:

General Notes and Comments on Reconnaissance Trip:

see field trip notes.

C.3

SECTION 2 - REGION AND VALLEY DESCRIPTION

PART 1: AREA AROUND RIVER VALLEY

Terrain
- Mountains [ ]
- Uplands [ ]
- Hills [ ]
- Plains [ ]
- Lowlands [x]

Drainage Pattern
- Dendritic [x] ?
- Parallel [ ]
- Trellis [ ]
- Rectangular [ ]
- Radial [ ]
- Annular [ ]
- Multi-Basin [ ]
- Contorted [ ]

Surface Geology
- Weathered Soils [ ]
- Glacial Moraine [ ]
- Glacio/Fluvial [ ]
- Fluvial [x]
- Lake Deposits [ ]
- Wind blown (loess) [ ]

Rock Type
- Metamorphic [ ]
- Igneous [ ]
- None [x]

Specific Rock Types (if known)

Land Use
- Managed [x]
- Cultivated [ ]
- Urban [ ]
- Suburban [ ]

Vegetation
- Temperate forest [ ]
- Boreal forest [ ]
- Woodland [x]
- Savanna [ ]
- Temperate grassland [ ]
- Desert scrub [ ]
- Extreme Desert [ ]
- Tundra or Alpine [ ]
- Agricultural land [ ]

Notes and Comments:

PART 2: RIVER VALLEY AND VALLEY SIDES

Location of River
- In Valley [x]
- On Alluvial Fan [ ]
- On Alluvial Plain [ ]
- In a Delta [ ]
- In Old Lake Bed [ ]

Height
- < 5 m [x] ?
- 5 - 10 m [ ]
- 10 - 30 m [ ]
- 30 - 60 m [ ]
- 60 - 100 m [ ]
- > 100 m [ ]

Side Slope Angle
- < 5degrees [x]
- 5-10 degrees [ ]
- 10-20 degrees [ ]
- 20-50 degrees [ ]
- >50 degrees [ ]

Valley Shape
- Symmetrical [ ]
- Asymmetrical [x]

Valley Side Failures
- None [x]
- Occasional [ ]
- Frequent [ ]

Failure Locations
- None [ ]
- Away from river [ ]
- Along river (Undercut) [ ]

Failure Type [ ] (see sketch in manual)

Notes and Comments:

PART 3: FLOOD PLAIN (VALLEY FLOOR)

Valley Floor Type
- None [ ]
- Indefinite [x]
- Fragmentary [ ]
- Continuous [ ]

Valley Floor Data
- None [ ]
- < 1 river width [ ]
- 1 - 5 river widths [ ]
- 5-10 river widths [ ]
- >10 river widths [x]

Surface Geology
- Bed rock [ ]
- Glacial Moraine [ ]
- Glacio/Fluvial [ ]
- Fluvial: Alluvium [x]
- Fluvial: Backswamp [ ]
- Lake Deposits [ ]
- Wind Blown (Loess) [ ]

Flow Resistance*
- Left Overbank Manning n value ___
- Right Overbank Manning n value ___ (* note: n value for channel is recorded in Part 6)

Land Use
- Natural [ ]
- Managed [x]
- Cultivated [ ]
- Urban [ ]
- Suburban [ ]
- Industrial [ ]

Vegetation
- None [ ]
- Unimproved Grass [ ]
- Improved Pasture [ ]
- Orchards [ ]
- Arable Crops [ ]
- Shrubs [ ]
- Deciduous Forest [x]
- Coniferous Forest [ ]
- Mixed Forest [ ]

Riparian Buffer Strip
- None [ ]
- Indefinite [ ]
- Fragmentary [x]
- Continuous [ ]

Strip Width
- None [ ]
- < 1 river width [ ]
- 1 - 5 river widths [x]
- > 5 river widths [ ]

Notes and Comments:

PART 4: VERTICAL RELATION OF CHANNEL TO VALLEY

Terraces
- None [x]
- Indefinate [ ]
- Fragmentary [ ]
- Continuous [ ]
- Number of Terraces ___

Overbank Deposits
- None [ ]
- Silt [ ]
- Fine sand [x]
- Medium sand [ ]
- Coarse sand [ ]
- Gravel [ ]
- Boulders [ ]

Levees
- None [x]
- Natural [ ]
- Constructed [ ]

Instability Status ?
- Stable [ ]
- Degrading [ ]
- Aggrading [ ]

Levee Data
- Height (m) [ ]
- Side Slope (o) [ ]

Levee Condition
- None [x]
- Intact [ ]
- Local Failures [ ]
- Frequent failures [ ]

Levee Description
- None [ ]
- Indefinite [ ]
- Fragmentary [ ]
- Continuous [ ]
- Left Bank [ ]
- Right Bank [ ]
- Both Banks [ ]

Trash Lines
- Absent [ ]
- Present [ ]
- Height above flood plain (m) ___

Notes and Comments:

PART 5: LATERAL RELATION OF CHANNEL TO VALLEY

Planform
- Straight [ ]
- Sinuous [ ]
- Irregular [ ]
- Regular meanders [x]
- Irregular meanders [ ]
- Tortuous meanders [ ]
- Braided [ ]
- Anastomosed [ ]

Planform Data
- Bend Radius ___
- Meander belt width ___
- Wavelength ___
- Meander Sinuosity ___

Lateral Activity
- None [ ]
- Meander progression [x]
- Increasing amplitude [ ]
- Progression+cut-offs [ ]
- Irregular erosion [ ]
- Avulsion [ ]
- Braiding [ ]

Floodplain Features
- None [ ]
- Meander scars [ ]
- Scroll bars+sloughs [ ]
- Oxbow lakes [ ]
- Irregular terrain [ ]
- Abandoned channel [ ]
- Braided Deposits [ ]

Location in Valley
- Left [ ]
- Middle [x]
- Right [ ]

Notes and Comments:

C.4

SECTION 3 - CHANNEL DESCRIPTION

PART 6: CHANNEL DESCRIPTION

Dimensions	Flow Type	Bed Controls	Control Types	Width Controls	Control Types
Av. top bank width (m)	None	None X	None X	None X	None X
Av. channel depth (m)	Uniform/Tranquil X	Occasional	Solid Bedrock	Occasional	Bedrock
Av. water width (m)	Uniform/Rapid	Frequent	Weathered Bedrock	Frequent	Boulders
Av. water depth (m)	Pool+Riffle	Confined	Boulders	Confined	Gravel armor
Reach slope	Steep + Tumbling	Number of controls	Gravel armor	Number of controls	Revetments
Mean velocity (m/s)	Steep + Step/pool		Cohesive Materials		Cohesive Materials
			Bridge protection		Bridge abutments
Manning's n value	(Note: Flow type on day of observation)		Grade control structures		Dykes or groines

Notes and Comments:

PART 7: BED SEDIMENT DESCRIPTION

Bed Material	Bed Armour	Surface Size Data	Bed Forms (Sand)	Bar Types	Bar Surface data
Clay	None X	D50 (mm)	Flat bed (None)	None	D50 (mm)
Silt	Static-armour	D84 (mm)	Ripples X	Pools and riffles	D84 (mm)
Sand X	Mobile-armour	D16 (mm)	Dunes	Alternate bars	D16 (mm)
Sand and gravel			Bed form height (m)	Point bars X	
gravel and cobbles	**Sediment Depth**	**Substrate Size Data**	**Island or Bars**	Mid-channel bars	**Bar Substrate data**
cobbles + boulders	Depth of loose	D50 (mm)	None	Diagonal bars	D50 (mm)
boulders + bedrock	Sediment (cm)	D84 (mm)	Occasional	Junction bars	D84 (mm)
Bed rock		D16 (mm)	Frequent	Sand waves + dunes	D16 (mm)

Notes and Comments:

Channel Sketch Map

Map Symbols
(to be determined by field crew)

Study reach limits	North point	Cut bank	Photo point
Cross-section	Flow direction	Exposed island/bar	Sediment sampling point
Bank profile	Impinging flow	Structure	Significant vegetation

Representative Cross-section

C.5

SECTION 4 - LEFT (OR RIGHT) BANK SURVEY

PART 8: LEFT (OR RIGHT) BANK CHARACTERISTICS

Type
- Noncohesive [x]
- Cohesive [ ]
- Composite [ ]
- Layered [ ]
- Even Layers [ ]
- Thick+thin layers [ ]
- Number of layers ___

Protection Status
- Unprotected [x]
- Hard points [ ]
- Toe protection [ ]
- Revetments [ ]
- Dyke Fields [ ]

Bank Materials
- Silt/clay [ ]
- Sand/silt/clay [ ]
- Sand/silt [ ]
- Sand [x]
- Sand/gravel [ ]
- Gravel [ ]
- Gravel/cobbles [ ]
- Cobbles [ ]
- Cobbles/boulders [ ]
- Boulders/bedrock [ ]

Layer Thickness
- Material 1 (m) ___
- Material 2 (m) ___
- Material 3 (m) ___
- Material 4 (m) ___

70 feet

Ave. Bank Height
- Average height (m) ___

Ave. Bank Slope
- angle (degrees) ___ 43°

Bank Profile Shape
(see sketches in manual)

Tension Cracks
- None [ ]
- Occasional [ ]
- Frequent [ ]

Crack Depth
- Proportion of bank height ___

Distribution and Description of Bank Materials in Bank Profile

	Material Type 1	Material Type 2	Material Type 3	Material Type 4
Toe	[ ]	[ ]	[ ]	[ ]
Mid-Bank	[ ]	[ ]	[ ]	[ ]
Upper Bank	[ ]	[ ]	[ ]	[ ]
Whole Bank	[ ]	[ ]	[ ]	[ ]
D50 (mm)	___	___	___	___
sorting coefficient	___	___	___	___ (sorting coef.)

Notes and Comments:

PART 9: LEFT (OR RIGHT) BANK-FACE VEGETATION

Vegetation
- None/fallow [ ]
- Artificially cleared [ ]
- Grass and flora [x]
- Reeds and sedges [ ]
- Shrubs [ ]
- Saplings [ ]
- Trees [x]

Orientation
- Angle of leaning (o) ___

Tree Types
- None [ ]
- Deciduous [x]
- Coniferous [ ]
- Mixed [ ]

Tree species (if known)

Density + Spacing
- None [ ]
- Sparse/clumps [ ]
- dense/clumps [ ]
- Sparce/continuous [ ]
- Dense/continuous [x]

Roots
- Normal [ ]
- Exposed [x]
- Adventitious [ ]

Location
- Whole bank [ ]
- Upper bank [x]
- Mid-bank [x]
- Lower bank [ ]

Diversity
- Mono-stand [ ]
- Mixed stand [x]
- Climax-vegetation [ ]

Health
- Healthy [x]
- Fair [ ]
- Poor [ ]
- Dead [ ]

Age
- Imature [ ]
- Mature [x]
- Old [ ]

Height
- Short [ ]
- Medium [ ]
- Tall [x]
- Height (m) ___ 10 m.

Lateral Extent
- Wide belt [x]
- Narrow belt [ ]
- Single row [ ]

Notes and Comments:

Bank Profile Sketches

Profile Symbols
(to be determined by field crews)

Bank Top Edge	Failed debris	Engineered Structure
Bank Toe	Attached bar	Significant vegetation
Water's Edge	Undercutting	Vegetation Limit

C.6

PART 10: LEFT (OR RIGHT) BANK EROSION

Erosion Location
General
Outside Meander
Inside Meander
Opposite a bar
Behind a bar

Opposite a structure
Adjacent to structure
Dstream of structure
Ustream of structure
Other (write in)

Present Status
Intact
Eroding:dormant
Eroding:active
Advancing:dormant
Advancing:active

Rate of Retreat
m/yr (if applicable and known) ___
Rate of Advance
m/yr (if applicable and known) ___

Dominant Processes
Parallel flow
Impinging flow
Piping
Freeze/thaw
Sheet erosion

Rilling + gullying
Wind waves
Vessel Forces
Ice rafting
Other (write in)

Notes and Comments:

PART 11: LEFT (OR RIGHT) BANK GEOTECH FAILURES

Failure Location
General
Outside Meander
Inside Meander
Opposite a bar
Behind a bar

Opposite a structure
Adjacent to structure
Dstream of structure
Ustream of structure
Other (write in)

Present Status
Stable
Unreliable
Unstable:dormant
Unstable:active

Failure Scars+Blocks
None
Old
Recent
Fresh
Contemporary

Apparent Failure Mode
Soil/rock fall
Shallow slide
Rotational slip
Slab-type block
Cantilever failure

Pop-out failure
Piping failure
Dry granular flow
Wet earth flow
Other (write in)

Notes and Copmments:

PART 12: LEFT (OR RIGHT) BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris
None
Individual grains
Aggregates+crumbs
Root-bound clumps
Small soil blocks
Medium soil blocks
Large soil blocks
Cobbles/boulders
Boulders

Vegetation
None/fallow
Artificially cleared
Grass and flora
Reeds and sedges
Shrubs
Saplings
Trees

Age
Immature
Mature
Old
Age in Years

Health
Healthy
Unhealthy
Dead

Tree species
(if known)

Roots
Normal
Adventitious
Exposed

Existing Debris Storage
No bank debris
Little bank debris
Some bank debris
Lots of bank debris

Notes and Comments:

C.7

A.2.3 Rapid Assessment Sheet for SH190 at the Sabine River

Rapid Assessment SH190 @ Sabine River

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.

Stability Indicator	Ratings				
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)	
1. Bank soil texture and coherence	Clay and silty clay; cohesive material	Clay loam to sandy clay loam	Sandy clay to sandy loam	Loamy sand to sand; non-cohesive material	11
2. Average bank slope angle	Bank slopes <3H:1V (18° or 33%) on both sides	Bank slopes up to 2H:1V (27° or 50%) on one or occasion-ally both banks	Bank slopes to 1.7H:1V (31° or 60%) common on one or both banks	Bank slopes over 60% common on one or both banks	8
3. Vegetative bank protection	Wide bank of woody vegetation with at least 90% density and cover. Primarily hard wood, leafy, deci-duous trees with mature, healthy, and diverse vegetation located on the bank. Woody vegetation oriented vertically	Medium bank of woody vegetation with 70-90% plant density and cover. A majority of hard wood, leafy, deciduous trees with maturing, diverse vegetation located on the bank. Woody vegetation oriented 80-90° from horizontal with minimal root exposure.	Small bank of woody vegetation with 50-70% plant density and cover. A majority of soft wood, piney, coniferous trees with young or old vegeta-tion lacking in diver-sity located on or near the top of bank. Woody vegetation oriented at 70-80° from horizontal often with evident root exposure.	Woody vegetation bank may vary depending on age and health with less than 50% plant den-sity and cover. Primary soft wood, piney, coniferous trees with very young, old and dying, and/or monostand vegeta-tion located off of the bank. Woody vegeta-tion oriented at less than 70° from horiz-ontal with extensive root exposure.	4
4. Bank cutting	Little or none evident. Infrequent raw banks less than 15 cm (5.9 in) high generally.	Some intermittently along channel beds and at prominent constrictions. Raw banks may be up to 30 cm (11.8 in) high.	Significant and frequent. Cuts 30-60 cm (11.8-23.6 in) high. Root mat overhangs.	Almost continuous cuts, some over 60 cm (23.6 in) high. Undercutting, sod-root overhangs, and side failures frequent.	2
5. Mass wasting or bank failure	No or little evidence of potential or very small amounts of mass wasting. Uniform channel width over the entire reach.	Evidence of infre-quent and/or minor mass wasting. Mostly headed over with vegetation. Relatively constant channel width and minimal scalloping of banks.	Evidence of frequent and/or significant occurrences of mass wasting that can be aggravated by higher flows, which may cause undercutting and mass wasting of unstable banks. Channel width quite irregular and scalloping of banks is evident.	Frequent and extensive mass wasting. The potential for bank failure, as evidenced by tension cracks, massive under-cuttings, and bank slumping, is con-siderable. Channel width is highly irregular and banks are scalloped.	7
6. Bar development	Bars are mature, narrow relative to stream width at low flow, well vegetated, and composed of coarse gravel to cobbles.	Bars may have vegetation and/or be composed of coarse gravel to cobbles, but minimal recent growth of bar evident by lack of vegetation on portions of the bar.	Bar widths tend to be wide and composed of newly deposited coarse sand to small cobbles and/or may be sparsely vegetated	Bar widths are generally greater than 1/2 the stream width at low flow. Bars are composed of exten-sive deposits of fine particles up to coarse gravel with little to no vegetation.	9
7. Debris jam potential	Debris or potential for debris in channel is negligible	Small amounts of debris present. Small jams could be formed.	Noticeable accumu-lations of all sizes. Moderate down-stream debris jam potential possible.	Moderate to heavy accumulations of various size debris present. Debris jam potential significant.	2
8. Obstructions, flow deflectors, and sediment traps	Rare or not present	Present, causing cross currents and minor bank and bottom erosion	Moderately frequent and occasionally unstable obstructions cause noticeable erosion of the chan-nel. Considerable sediment accumu-lations behind obstructions	Frequent and often unstable causing a continual shift of sediment and flow. Traps are easily filled causing channel to migrate and/or widen.	2

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.					
Stability Indicator	Ratings				
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)	
9. Channel bed material consolidation and armoring	Assorted sizes tightly packed, overlapping, and possibly imbricated. Most material >4 mm (0.16 in).	Moderately packed with some overlapping. Very small amounts of material < 4 mm (0.16 in).	Loose assortment with no apparent overlap. Small to medium amounts of material < 4 mm (0.16 in).	Very loose assortment with no packing. Large amounts of material < 4 mm (0.16 in).	11
10. Shear stress ratio (Eqs. D.1 and D.2)	$\tau_0 / \tau_c < 1.0$	$1.0 \leq \tau_0 / \tau_c < 1.5$	$1.5 \leq \tau_0 / \tau_c < 2.5$	$\tau_0 / \tau_c \geq 2.5$	11
11. ‡High flow angle of approach to bridge or culvert	$0^\circ \leq \alpha \leq 5^\circ$	$5^\circ < \alpha \leq 10^\circ$	$10^\circ < \alpha \leq 30^\circ$	$\alpha > 30^\circ$	2
12. §Bridge or culvert distance from meander impact point	$D_m > 35$ m ($D_m > 115$ ft)	$20 < D_m \leq 35$ m ($66 < D_M \leq 115$ ft)	$10 < D_m \leq 20$ m ($33 < D_m \leq 66$ ft)	$0 < D_m \leq 10$ m ($0 < D_M \leq 33$ ft)	11
13. Percentage of channel constriction	0-5%	6-25%	26-50%	> 50%	4

‡ α = approach flow angle to bridge or culvert

§ D_m = distance from bridge or culvert upstream to meander impact point

Table D.2. Stability Indicators and Weights for Stability Assessment Scheme.[1]				
Stability Indicator	Weight			
1. Bank soil texture and coherence	0.6	11	6.6	
2. Average bank slope angle	0.6	8	4.8	
3. Vegetative bank protection	0.8	4	3.2	15
4. Bank cutting	0.4	2	0.8	
5. Mass wasting or bank failure	0.8	7	5.6	11.
6. Bar development	0.6	9	5.4	
7. Debris jam potential	0.2	2	0.4	
8. Obstructions, deflectors, and sediment traps	0.2	2	0.4	9.6
9. Bed material consolidation and armoring	0.8	11	8.8	
10. Shear stress ratios	1.0	11	11	
11. High flow angle of approach to bridge	0.8	2	1.6	24.6
12. Distance from meander impact point	0.8	11	8.8	35.6
13. Percentage of channel constriction	0.8	4	3.2	60.6

Table D.3. Overall Rating Ranges.	
Description	Rating (R)
Excellent	R < 32
Good	32 ≤ R < 55
Fair	55 ≤ R < 78
Poor	R ≥ 78

Fair

A.3 Records for SH105 at the Brazos River

A.3.1 Field notes for SH105 at the Brazos River

Notes from the field visit

Site: SH105 at Brazos River

Date: 6/4/2012

Time: From 7:30am to 10:30am

Participants: Xiaofeng Liu (PI)

Kyle Strom (co-PI)

Rusen Sinir (Graduate student, UTSA)

Axel Montalvo (Graduate student, TAMU)

Another student from TAMU

Notes:

1. We started at the left side of the channel where public access is available. A brief examination of the river under the bridge was undertaken right away to assess the condition of the channel. We also talked to the TxDOT personnel (Anthony L. Garcia, Anthony.L.Garcia@txdot.gov) who assisted us at the site.

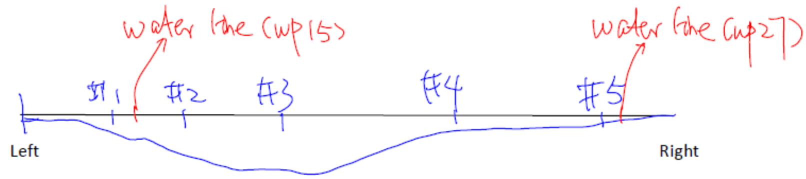
   Garcia mentioned that this bridge was built in the 1950s and is scheduled to be replaced in 2014. This replacement was due to the aging of the bridge and the meander threat right upstream. The new bridge will be located 500ft downstream from its current site. He recalled that the highest level of river stage during floods reached about 70ft below the bridge deck. We also saw water mark high up on the bridge pier and trash lines on the trees upstream which confirmed his description.

   Garcia also mentioned Doug Marino (Doug.Marino@txdot.gove) –Bridge Engineer for more detailed information, such as aerial maps, channel cross sections, and surveys.

2. After the initial examination, we started to take samples of bed and bank materials. One group (Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials.

3. The position of the cross section we examined was recorded by GPS: N30°21.781’, W096°09.239’ .

(Green arrow indicates the location of the cross section where bed sediment samples were taken)



(Sketch of the cross section and locations where sediment was sampled)

Note: Point #1 is about 50 ft from the left bank, water line on the left side (WP15 on the GPS) is about 70 ft from the bank. On the right side, water line is marked as WP27 on the GPS.

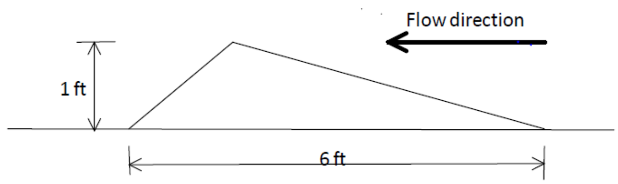
Point # 3 is the deepest point consists of sand dunes.
Point # 1, 2, 3: gravel+sand
Point # 4, 5: sand

In between, the river cross section was marked by several waypoints (WP15 to 27). The corrdinates of these waypoints are:

WP15: N 30°21.788’ W096 °09.246’
WP16: N 30°21.789’ W096 °09.247’
WP17: N 30°21.790’ W096 °09.247’
WP18: N 30°21.793’ W096 °09.246’
WP19: N 30°21.794’ W096 °09.246’
WP20: N 30°21.798’ W096 °09.246’
WP21: N 30°21.800’ W096 °09.246’
WP22: N 30°21.803’ W096 °09.246’
WP23: N 30°21.805’ W096 °09.246’

WP24: N 30°21.808' W096 °09.246'
WP25: N 30°21.810' W096 °09.246'
WP26: N 30°21.812' W096 °09.246'
WP27: N 30°21.813' W096 °09.247'

4. At the center of the channel, dunes were found when we waded across to the other side of the river. It was estimated that the height of the dune was 1 ft and width be about 6 ft.



5. On the right side of the river, ripples were present.

6. Some documentation of the way points:

Kyle's pictures: Pic. 4018-4019 to 4018-4020 -> WP#28 (N 30°21.927' W096 °09.050')
We stand on the point bar on the right side of the river and looked east to the left bank. We found the left bank (the outer bank) has sand (light color material in the pictures) is about half from the bottom and covered by dark colored cohesive material.

Pic. 4018-4021 to 4018-4027 -> WP#29 (N 30°22.095' W096 °08.969')
Again we stand on the point bar on the right side of the river and looked east to the left (outer) bank. There is absolutely no vegetation on the outer bank. We found at least one layer of coarse (gravel sized) material at the base almost flush with the water surface. Don't know how deep this coarse layer is since the river is very deep at this point and is not wadable.

Pic. 4018-4028 to 4018-4030 -> WP#30 (N 30°22.189' W096 °09.007')
Again we stand on the point bar on the right side of the river and looked east to the left (outer) bank. This is the starting point of the tree line going upstream. Downstream of this point, there is no tree nor vegetation.

7. We filled out the "Stream Reconnaissance Record Sheets" suggested by HEC-21(?). It is a long form with a lot of details. However, it is less useful, time consuming, and sometime hard to make choices.

8. We also tried the "Rapid Assessment of Channel Stability" method and gave scores to each of the 13 indicators. The total score for this side was 67. Accordingly, it is classified as "Fair" in terms of channel stability.

A.3.2 Stream Reconnaissance Record Sheets for SH105 at the Brazos River

STREAM RECONNAISSANCE RECORD SHEETS

(Modified from Thorne, 1998) (1)

SECTION 1 - SCOPE AND PURPOSE

Brief Problem Statement:

Assessment of channel stability.

Purpose of Stream Reconnaissance:

For TxDOT Research project 0-6724
Channel stability

Logistics of Reconnaissance Trip:

RIVER: Brazos	LOCATION: @ SH105	DATE: 6/4/2012 From: 8 am To: 10:30 am
PROJECT: 0-6724	STUDY REACH: upstream / downstream ± 500 m	
SHEET COMPLETED BY: Xiaofeng Liu (UTSA)		
RIVER STAGE: √ low	TIME START:	TIME FINISH:

General Notes and Comments on Reconnaissance Trip:

See field trip notes.

C.3

SECTION 2 - REGION AND VALLEY DESCRIPTION

PART 1: AREA AROUND RIVER VALLEY

Terrain	Drainage Pattern	Surface Geology	Rock Type	Land Use	Vegetation
Mountains	Dendritic	Weathered Soils	Metamorphic	Managed	Temperate forest
Uplands	Parallel	Glacial Moraine	Igneous	Cultivated [X]	Boreal forest
Hills	Trellis	Glacio/Fluvial	None [X]	Urban	Woodland
Plains	Rectangular	Fluvial [X]		Suburban	Savanna
Lowlands [X]	Radial	Lake Deposits			Temperate grassland
	Annular	Wind blown (loess)			Desert scrub
	Multi-Basin				Extreme Desert
	Contorted				Tundra or Alpine
					Agricultural land [X]

Specific Rock Types (if known)

Notes and Comments:

PART 2: RIVER VALLEY AND VALLEY SIDES

Location of River	Height	Side Slope Angle	Valley Shape	Valley Side Failures	Failure Locations
In Valley	< 5 m	< 5degrees [X]	Symmetrical [X]	None [X]	None [X]
On Alluvial Fan	5 - 10 m [X]	5-10 degrees	Asymmetrical	Occasional	Away from river
On Alluvial Plain [X]	10 - 30 m	10-20 degrees		Frequent	Along river (Undercut)
In a Delta	30 - 60 m	20-50 degrees			
In Old Lake Bed	60 - 100 m	>50 degrees			
	> 100 m				

Failure Type ____ (see sketch in manual)

Notes and Comments:

PART 3: FLOOD PLAIN (VALLEY FLOOR)

Valley Floor Type	Valley Floor Data	Surface Geology	Land Use	Vegetation	Riparian Buffer Strip
None	None	Bed rock	Natural	None	None [X]
Indefinite	< 1 river width	Glacial Moraine	Managed	Unimproved Grass	Indefinite
Fragmentary	1 - 5 river widths	Glacio/Fluvial	Cultivated [X]	Improved Pasture [X]	Fragmentary
Continuous [X]	5-10 river widths	Fluvial: Alluvium [X]	Urban	Orchards	Continuous
	>10 river widths [X]	Fluvial: Backswamp	Suburban	Arable Crops	**Strip Width**
		Lake Deposits	Industrial	Shrubs	None [X]
		Wind Blown (Loess)		Deciduous Forest	< 1 river width
				Coniferous Forest	1 - 5 river widths
				Mixed Forest	> 5 river widths

Flow Resistance*

Left Overbank Manning n value ___

Right Overbank Manning n value ___ (* note: n value for channel is recorded in Part 6)

Notes and Comments:

PART 4: VERTICAL RELATION OF CHANNEL TO VALLEY

Terraces	Overbank Deposits	Levees	Levee Data	Levee Description	Trash Lines
None	None	None [X]	Height (m)	None	Absent
Indefinate	Silt [X]	Natural	Side Slope (o)	Indefinite	Present [X]
Fragmentary	Fine sand	Constructed		Fragmentary	Height above flood plain (m) ___
Continuous	Medium sand		**Levee Condition**	Continuous	
Number of Terraces ___	Coarse sand	**Instability Status**	None	Left Bank	
	Gravel	Stable	Intact	Right Bank	
	Boulders	Degrading [X]	Local Failures	Both Banks	
		Aggrading	Frequent failures		

Notes and Comments:

PART 5: LATERAL RELATION OF CHANNEL TO VALLEY

Planform	Planform Data	Lateral Activity	Floodplain Features	Location in Valley
Straight	Bend Radius ____	None	None	Left
Sinuous	Meander belt width ____	Meander progression [X]	Meander scars	Middle
Irregular	Wavelength ____	Increasing amplitude	Scroll bars+sloughs	Right
Regular meanders	Meander Sinuosity ____	Progression+cut-offs	Oxbow lakes	
Irregular meanders [X]		Irregular erosion	Irregular terrain	
Tortuous meanders		Avulsion	Abandoned channel	
Braided		Braiding	Braided Deposits	
Anastomosed				

Notes and Comments:

C.4

SECTION 3 - CHANNEL DESCRIPTION

PART 6: CHANNEL DESCRIPTION

Dimensions	Flow Type	Bed Controls	Control Types	Width Controls	Control Types
Av. top bank width (m)	None	None (circled)	None (circled)	None (circled)	None (circled)
Av. channel depth (m)	Uniform/Tranquil X	Occasional	Solid Bedrock	Occasional	Bedrock
Av. water width (m)	Uniform/Rapid	Frequent	Weathered Bedrock	Frequent	Boulders
Av. water depth (m)	Pool+Riffle	Confined	Boulders	Confined	Gravel armor
Reach slope	Steep + Tumbling	Number of controls	Gravel armor	Number of controls	Revetments
Mean velocity (m/s) 0.3	Steep + Step/pool		Cohesive Materials		Cohesive Materials
			Bridge protection		Bridge abutments
Manning's n value	(Note: Flow type on day of observation)		Grade control structures		Dykes or groines

Notes and Comments:

PART 7: BED SEDIMENT DESCRIPTION

Bed Material	Bed Armour	Surface Size Data	Bed Forms (Sand)	Bar Types	Bar Surface data
Clay ☐	None ☒	D50 (mm) __	Flat bed (None) ☐	None ☐	D50 (mm) __
Silt ☐	Static-armour ☐	D84 (mm) __	Ripples ☒	Pools and riffles ☐	D84 (mm) __
Sand ☐	Mobile-armour ☐	D16 (mm) __	Dunes ☒	Alternate bars ☐	D16 (mm) __
Sand and gravel ☒			Bed form height (m) 0.3	Point bars ☒	
gravel and cobbles ☐	**Sediment Depth**	**Substrate Size Data**	**Island or Bars**	Mid-channel bars ☐	**Bar Substrate data**
cobbles + boulders ☐	Depth of loose	D50 (mm) __	None ☐	Diagonal bars ☐	D50 (mm) __
boulders + bedrock ☐	Sediment (cm) ?	D84 (mm) __	Occasional ☒	Junction bars ☐	D84 (mm) __
Bed rock ☐		D16 (mm) __	Frequent ☐	Sand waves + dunes ☐	D16 (mm) __

Notes and Comments:

Channel Sketch Map

Map Symbols
(to be determined by field crew)

Study reach limits	North point	Cut bank	Photo point
Cross-section	Flow direction	Exposed island/bar	Sediment sampling point
Bank profile	Impinging flow	Structure	Significant vegetation

Representative Cross-section

SECTION 4 - LEFT (OR RIGHT) BANK SURVEY

PART 8: LEFT (OR RIGHT) BANK CHARACTERISTICS

Type
- Noncohesive
- Cohesive
- Composite [X]
- Layered [X]
- Even Layers
- Thick+thin layers
- Number of layers 3

Protection Status
- Unprotected [X]
- Hard points
- Toe protection
- Revetments
- Dyke Fields

Bank Materials
- Silt/clay
- Sand/silt/clay [X]
- Sand/silt
- Sand
- Sand/gravel
- Gravel
- Gravel/cobbles
- Cobbles
- Cobbles/boulders
- Boulders/bedrock

Layer Thickness
- Material 1 (m) 5
- Material 2 (m) 5
- Material 3 (m) 5
- Material 4 (m)

Ave. Bank Height
- Average height (m) 10

Ave. Bank Slope
- angle (degrees) 4

Bank Profile Shape
(see sketches in manual)

Tension Cracks
- None
- Occasional [X]
- Frequent

Crack Depth
- Proportion of bank height 30%

Distribution and Description of Bank Materials in Bank Profile

Material Type 1	Material Type 2	Material Type 3	Material Type 4
Toe	Toe	Toe	Toe
Mid-Bank	Mid-Bank	Mid-Bank	Mid-Bank
Upper Bank	Upper Bank	Upper Bank	Upper Bank
Whole Bank	Whole Bank	Whole Bank	Whole Bank
D50 (mm)	D50 (mm)	D50 (mm)	D50 (mm)
sorting coefficient	sorting coefficient	sorting coefficient	sorting coef.

Notes and Comments:

PART 9: LEFT (OR RIGHT) BANK-FACE VEGETATION

Vegetation
- None/fallow [X]
- Artificially cleared
- Grass and flora
- Reeds and sedges
- Shrubs
- Saplings
- Trees

Orientation
- Angle of leaning (o)

Tree Types
- None [X]
- Deciduous
- Coniferous
- Mixed

Tree species (if known)

Density + Spacing
- None [X]
- Sparse/clumps
- dense/clumps
- Sparce/continuous
- Dense/continuous

Roots
- Normal [X]
- Exposed
- Adventitious

Location
- Whole bank [X]
- Upper bank
- Mid-bank
- Lower bank

Diversity
- Mono-stand [X]
- Mixed stand
- Climax-vegetation

Health
- Healthy
- Fair [X]
- Poor
- Dead

Age
- Imature
- Mature [X]
- Old

Height
- Short
- Medium [X]
- Tall [X]
- Height (m)

Lateral Extent
- Wide belt [X]
- Narrow belt
- Single row

Notes and Comments:

Bank Profile Sketches

Profile Symbols
(to be determined by field crews)

Bank Top Edge	Failed debris	Engineered Structure
Bank Toe	Attached bar	Significant vegetation
Water's Edge	Undercutting	Vegetation Limit

C.6

PART 10: LEFT (OR RIGHT) BANK EROSION

Erosion Location			Present Status		Rate of Retreat	Dominant Processes			
General	☐	Opposite a structure ☐	Intact	☐	m/yr (if applicable and known) ___	Parallel flow	☐	Rilling + gullying	☐
Outside Meander	X	Adjacent to structure ☐	Eroding:dormant	☐		Impinging flow	X	Wind waves	☐
Inside Meander	X	Dstream of structure ☐	Eroding:active	X	**Rate of Advance**	Piping	☐	Vessel Forces	☐
Opposite a bar	☐	Ustream of structure X	Advancing:dormant	☐	m/yr (if applicable and known) ___	Freeze/thaw	☐	Ice rafting	☐
Behind a bar	☐	Other (write in) ☐	Advancing:active	X		Sheet erosion	☐	Other (write in)	☐

Notes and Comments:

PART 11: LEFT (OR RIGHT) BANK GEOTECH FAILURES

Failure Location			Present Status		Failure Scars+Blocks		Apparent Failure Mode			
General	☐	Opposite a structure ☐	Stable	☐	None	☐	Soil/rock fall	☐	Pop-out failure	☐
Outside Meander	X	Adjacent to structure ☐	Unreliable	☐	Old	☐	Shallow slide	☐ ?	Piping failure	☐
Inside Meander	X	Dstream of structure ☐	Unstable:dormant	☐	Recent	☐	Rotational slip	X ?	Dry granular flow	☐
Opposite a bar	☐	Ustream of structure X	Unstable:active	X	Fresh	X	Slab-type block	X	Wet earth flow	☐
Behind a bar	☐	Other (write in) ☐			Contemporary	☐	Cantilever failure	X	Other (write in)	☐

Notes and Copmments:

PART 12: LEFT (OR RIGHT) BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris		Vegetation		Age		Health		Roots		Existing Debris Storage	
None	X	None/fallow	X	Immature	X	Healthy	☐	Normal	☐	No bank debris	☐
Individual grains	☐	Artificially cleared	☐	Mature	☐	Unhealthy	☐	Adventitious	☐	Little bank debris	X
Aggregates+crumbs	☐	Grass and flora	☐	Old	☐	Dead	X	Exposed	☐	Some bank debris	X
Root-bound clumps	☐	Reeds and sedges	☐	Age in Years	☐					Lots of bank debris	☐
Small soil blocks	☐	Shrubs	☐			**Tree species** (if known)					
Medium soil blocks	☐	Saplings	☐								
Large soil blocks	☐	Trees	☐								
Cobbles/boulders	☐										
Boulders	☐										

Notes and Comments:

C.7

A.3.3 Rapid Assessment Sheet for SH105 at the Brazos River

Rapid Assessment of Channel stability
SH105 @ Brazos River.

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.

	Stability Indicator	Ratings				
		Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)	
	1. Bank soil texture and coherence	Clay and silty clay; cohesive material	Clay loam to sandy clay loam	Sandy clay to sandy loam	Loamy sand to sand; non-cohesive material	8
	2. Average bank slope angle	Bank slopes <3H:1V (18° or 33%) on both sides	Bank slopes up to 2H:1V (27° or 50%) on one or occasionally both banks	Bank slopes to 1.7H:1V (31° or 60%) common on one or both banks	Bank slopes over 60% common on one or both banks	12
	3. Vegetative bank protection	Wide bank of woody vegetation with at least 90% density and cover. Primarily hard wood, leafy, deciduous trees with mature, healthy, and diverse vegetation located on the bank. Woody vegetation oriented vertically	Medium bank of woody vegetation with 70-90% plant density and cover. A majority of hard wood, leafy, deciduous trees with maturing, diverse vegetation located on the bank. Woody vegetation oriented 80-90° from horizontal with minimal root exposure.	Small bank of woody vegetation with 50-70% plant density and cover. A majority of soft wood, piney, coniferous trees with young or old vegetation lacking in diversity located on or near the top of bank. Woody vegetation oriented at 70-80° from horizontal often with evident root exposure.	Woody vegetation bank may vary depending on age and health with less than 50% plant den-sity and cover. Primary soft wood, piney, coniferous trees with very young, old and dying, and/or monostand vegetation located off of the bank. Woody vegetation oriented at less than 70° from horizontal with extensive root exposure.	11
?	4. Bank cutting	Little or none evident. Infrequent raw banks less than 15 cm (5.9 in) high generally.	Some intermittently along channel beds and at prominent constrictions. Raw banks may be up to 30 cm (11.8 in) high.	Significant and frequent. Cuts 30-60 cm (11.8-23.6 in) high. Root mat overhangs.	Almost continuous cuts, some over 60 cm (23.6 in) high. Undercutting, sod-root overhangs, and side failures frequent.	2
	5. Mass wasting or bank failure	No or little evidence of potential or very small amounts of mass wasting. Uniform channel width over the entire reach.	Evidence of infrequent and/or minor mass wasting. Mostly headed over with vegetation. Relatively constant channel width and minimal scalloping of banks.	Evidence of frequent and/or significant occurrences of mass wasting that can be aggravated by higher flows, which may cause undercutting and mass wasting of unstable banks. Channel width quite irregular and scalloping of banks is evident.	Frequent and extensive mass wasting. The potential for bank failure, as evidenced by tension cracks, massive under-cuttings, and bank slumping, is considerable. Channel width is highly irregular and banks are scalloped.	11
	6. Bar development	Bars are mature, narrow relative to stream width at low flow, well vegetated, and composed of coarse gravel to cobbles.	Bars may have vegetation and/or be composed of coarse gravel to cobbles, but minimal recent growth of bar evident by lack of vegetation on portions of the bar.	Bar widths tend to be wide and composed of newly deposited coarse sand to small cobbles and/or may be sparsely vegetated	Bar widths are generally greater than 1/2 the stream width at low flow. Bars are composed of extensive deposits of fine particles up to coarse gravel with little to no vegetation.	8
	7. Debris jam potential	Debris or potential for debris in channel is negligible	Small amounts of debris present. Small jams could be formed.	Noticeable accumulations of all sizes. Moderate downstream debris jam potential possible.	Moderate to heavy accumulations of various size debris present. Debris jam potential significant.	2
?	8. Obstructions, flow deflectors, and sediment traps	Rare or not present	Present, causing cross currents and minor bank and bottom erosion	Moderately frequent and occasionally unstable obstructions cause noticeable erosion of the channel. Considerable sediment accumulations behind obstructions	Frequent and often unstable causing a continual shift of sediment and flow. Traps are easily filled causing channel to migrate and/or widen.	2

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.				
Stability Indicator	Ratings			
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)
9. Channel bed material consolidation and armoring	Assorted sizes tightly packed, overlapping, and possibly imbricated. Most material >4 mm (0.16 in).	Moderately packed with some overlapping. Very small amounts of material < 4 mm (0.16 in).	Loose assortment with no apparent overlap. Small to medium amounts of material < 4 mm (0.16 in).	Very loose assortment with no packing. Large amounts of material < 4 mm (0.16 in).
10. Shear stress ratio (Eqs. D.1 and D.2)	$\tau_0 / \tau_c < 1.0$	$1.0 \leq \tau_0 / \tau_c < 1.5$	$1.5 \leq \tau_0 / \tau_c < 2.5$	$\tau_0 / \tau_c \geq 2.5$
11. ‡High flow angle of approach to bridge or culvert	$0° \leq \alpha \leq 5°$	$5° < \alpha \leq 10°$	$10° < \alpha \leq 30°$	$\alpha > 30°$
12. §Bridge or culvert distance from meander impact point	$D_m > 35$ m (Dm > 115 ft)	$20 < D_m \leq 35$ m ($66 < DM \leq 115$ ft)	$10 < D_m \leq 20$ m ($33 < Dm \leq 66$ ft)	$0 < D_m \leq 10$ m ($0 < DM \leq 33$ ft)
13. Percentage of channel constriction	0-5%	6-25%	26-50%	> 50%

‡ α = approach flow angle to bridge or culvert

§ D_m = distance from bridge or culvert upstream to meander impact point

Table D.2. Stability Indicators and Weights for Stability Assessment Scheme.[1]	
Stability Indicator	Weight
1. Bank soil texture and coherence	0.6
2. Average bank slope angle	0.6
3. Vegetative bank protection	0.8
4. Bank cutting	0.4
5. Mass wasting or bank failure	0.8
6. Bar development	0.6
7. Debris jam potential	0.2
8. Obstructions, deflectors, and sediment traps	0.2
9. Bed material consolidation and armoring	0.8
10. Shear stress ratios	1.0
11. High flow angle of approach to bridge	0.8
12. Distance from meander impact point	0.8
13. Percentage of channel constriction	0.8

Table D.3. Overall Rating Ranges.	
Description	Rating (R)
Excellent	$R < 32$
Good	$32 \leq R < 55$
Fair	$55 \leq R < 78$
Poor	$R \geq 78$

A.4 Records for FM787 at the Trinity River

A.4.1 Field notes for FM787 at the Trinity River

Notes from the field visit

Site: FM787 at Trinity River

Date: 6/5/2012

Time: From 7:30am to 10:30am

Participants: Xiaofeng Liu (PI)

Kyle Strom (co-PI)

Rusen Sinir (Graduate student, UTSA)

Axel Montalvo (Graduate student, TAMU)

Another student from TAMU

Notes:

1. We started at the left side of the channel where public access is available. A brief examination of the river under the bridge, upstream and downstream was undertaken right away to assess the condition of the channel.

2. At the upstream side, we found there were very evident signs of channel instability. Upstream very close to the bridge, the outer bank is attaching the road. The shoulder of the road starts falling off to the river. There are some sheet piles to prevent the failure. However, the effect is minimal due to the fact the sheet piles are only local protection.

   The location of shoulder failure and sheet pile failure is at WP-31: N30°25.701', W094°50.831'
   Sheet pile (on the river?): WP-32: N30°25.686', W094°50.876'

3. We also found some scour protection and river training works. Upstream adjacent to the bridge, there are some piles standing in the water close to the right bank. They are failed scour protection works. There are some more on the left side of the river more upstream.

4. Grouted ripraps were put on the outer bank and under the bridge. It seems they stay in place and are working well. Maybe they are newly installed.

5. The river is at low flow condition. Downstream of the bridge, the river experiences expansion and creates recirculation zones when the stage is high. That might be the reason for the large sand bars there. The bridge has significant contraction effect to the river.

6. Even though the river stage is low, the scour condition of the piers, especially those in the river, is not known. However, for the bridge piers on the left bank, though they were protected by grouted ripraps, one pier shows very evident erosion since it deck has been exposed (picture was taken).

7. There is evidence of debris accumulation on the bridge pier deck left during floods (pictures were taken).

8. Part of the traffic over the bridge is track-trailer for lumbers.

9. After the initial examination, we started to take samples of bed and bank materials. One group (Strom, Liu, and Sinir) focused on bed materials and the TAMU group focused on bank materials.

10. We only took sediment samples at the downstream side of the bridge since it is more accessible. The starting position we examined was recorded by GPS: N30^{o}25.458', W094^{o}50.973'.

(Green arrow indicates the location where we started to collect bed sediment samples)

Sample #1 at WP-34: N30^{o}25.438', W094^{o}50.954'. It was in the river. Gravels on bottom bedrock (limestones or marle). These bedrocks are not so hard to be broken apart. At this location and to some extend both upstream and downstream, the river bottom is on bedrock. However, all the banks are fluivial.

Sample #2 at WP-35: N30^{o}25.451', W094^{o}50.981'. This point is about 30 ft from the water line into the river from WP-33.

Sample #3 at WP-37: N30^{o}25.399', W094^{o}50.827'. At the bar.

Sample #4 at WP-39: N30^{o}25.330, W094^{o}50.713'. Sand. Litter bed rock in the center.

WP-38: N30°25.421, W094°50.736’. Bank material is sand similar to the bar. No sample was taken.

11. We also took simple survey of the left bank at WP-38. This side length is about 48 ft and height 22 ft with a side slope about 30 degrees. On the top of the bank, there were trees and the side slope is almost vertical.

12. We filled out the “Stream Reconnaissance Record Sheets” suggested by HEC-21(?). It is a long form with a lot of details. However, it is less useful, time consuming, and sometime hard to make choices.

13. We also tried the “Rapid Assessment of Channel Stability” method and gave scores to each of the 13 indicators. The total score for this side was 78. Accordingly, it is classified as “Poor” in terms of channel stability.

A.4.2 Stream Reconnaissance Record Sheets for FM787 at the Trinity River

FM 787 @ Trinity River

STREAM RECONNAISSANCE RECORD SHEETS

(Modified from Thorne, 1998) (1)

SECTION 1 - SCOPE AND PURPOSE

Brief Problem Statement:

Assessment of channel stability.

Purpose of Stream Reconnaissance:

For TxDOT Research Project 0-6724
channel stability.

Logistics of Reconnaissance Trip:

RIVER: Trinity	LOCATION: FM 787	DATE: 6/5/2012 From: 8am To: 10:30AM
PROJECT: 0-6724	STUDY REACH: upstream/down stream ± 200 m	
SHEET COMPLETED BY: Xiaofeng Liu (UTSA)		
RIVER STAGE: low	TIME START:	TIME FINISH:

General Notes and Comments on Reconnaissance Trip:

see field trip notes.

C.3

SECTION 2 - REGION AND VALLEY DESCRIPTION

PART 1: AREA AROUND RIVER VALLEY

Terrain: Mountains [ ] Uplands [ ] Hills [ ] Plains [ ] Lowlands [X]

Drainage Pattern: Dendritic [ ] Parallel [ ] Trellis [ ] Rectangular [ ] Radial [ ] Annular [ ] Multi-Basin [ ] Contorted [ ] ?

Surface Geology: Weathered Soils [ ] Glacial Moraine [ ] Glacio/Fluvial [ ] Fluvial [X] Lake Deposits [ ] Wind blown (loess) [ ]

Rock Type: Metamorphic [ ] Igneous [ ] None [ ]

Specific Rock Types (if known): sedimentary river + bottom

Land Use: Managed [ ] Cultivated [X] Urban [ ] Suburban [ ]

Vegetation: Temperate forest [ ] Boreal forest [ ] Woodland [X] Savanna [ ] Temperate grassland [ ] Desert scrub [ ] Extreme Desert [ ] Tundra or Alpine [ ] Agricultural land [ ]

Notes and Comments:

PART 2: RIVER VALLEY AND VALLEY SIDES

Location of River: In Valley [X] On Alluvial Fan [ ] On Alluvial Plain [ ] In a Delta [ ] In Old Lake Bed [ ]

Height: < 5 m [ ] 5 - 10 m [ ] 10 - 30 m [ ] 30 - 60 m [ ] 60 - 100 m [ ] > 100 m [ ] ?

Side Slope Angle: < 5degrees [ ] 5-10 degrees [ ] 10-20 degrees [ ] 20-50 degrees [ ] >50 degrees [ ] ?

Valley Shape: Symmetrical [ ] Asymmetrical [ ] ?

Valley Side Failures: None [ ] Occasional [ ] Frequent [ ] ?

Failure Locations: None [ ] Away from river [ ] Along river (Undercut) [ ] ?

Failure Type [ ] (see sketch in manual)

Notes and Comments:

PART 3: FLOOD PLAIN (VALLEY FLOOR)

Valley Floor Type: None [ ] Indefinite [ ] Fragmentary [ ] Continuous [X]

Valley Floor Data: None [ ] < 1 river width [ ] 1 - 5 river widths [ ] 5-10 river widths [ ] >10 river widths [X]

Flow Resistance*
Left Overbank Manning n value
Right Overbank Manning n value ___ (* note: n value for channel is recorded in Part 6)

Surface Geology: Bed rock [ ] Glacial Moraine [ ] Glacio/Fluvial [ ] Fluvial: Alluvium [X] Fluvial: Backswamp [ ] Lake Deposits [ ] Wind Blown (Loess) [ ]

Land Use: Natural [ ] Managed [ ] Cultivated [X] Urban [ ] Suburban [ ] Industrial [ ]

Vegetation: None [ ] Unimproved Grass [ ] Improved Pasture [X] Orchards [X] Arable Crops [ ] Shrubs [ ] Deciduous Forest [ ] Coniferous Forest [ ] Mixed Forest [ ]

Riparian Buffer Strip: None [ ] Indefinite [ ] Fragmentary [ ] Continuous [X]

Strip Width: None [ ] < 1 river width [X] 1 - 5 river widths [ ] > 5 river widths [ ]

Notes and Comments:

PART 4: VERTICAL RELATION OF CHANNEL TO VALLEY

Terraces: None [ ] Indefinate [ ] Fragmentary [ ] Continuous [ ] Number of Terraces 1

Overbank Deposits: None [ ] Silt [X] Fine sand [X] Medium sand [ ] Coarse sand [ ] Gravel [ ] Boulders [ ]

Levees: None [X] Natural [ ] Constructed [ ]

Instability Status: Stable [ ] Degrading [X] Aggrading [ ]

Levee Data: Height (m) [ ] Side Slope (o) [ ]

Levee Condition: None [ ] Intact [ ] Local Failures [ ] Frequent failures [ ]

Levee Description: None [ ] Indefinite [ ] Fragmentary [ ] Continuous [ ] Left Bank [ ] Right Bank [ ] Both Banks [ ]

Trash Lines: Absent [X] Present [ ] Height above flood plain (m) ___

Notes and Comments:

PART 5: LATERAL RELATION OF CHANNEL TO VALLEY

Planform: Straight [ ] Sinuous [ ] Irregular [ ] Regular meanders [ ] Irregular meanders [X] Tortuous meanders [ ] Braided [ ] Anastomosed [ ]

Planform Data: Bend Radius ___ Meander belt width ___ Wavelength ___ Meander Sinuosity ___

Lateral Activity: None [ ] Meander progression [X] Increasing amplitude [ ] Progression+cut-offs [ ] Irregular erosion [ ] Avulsion [ ] Braiding [ ]

Floodplain Features: None [ ] Meander scars [ ] Scroll bars+sloughs [ ] Oxbow lakes [X] Irregular terrain [ ] Abandoned channel [X] Braided Deposits [ ]

Location in Valley: Left [ ] Middle [ ] Right [ ] ?

Notes and Comments:

C.4

SECTION 3 - CHANNEL DESCRIPTION

PART 6: CHANNEL DESCRIPTION

Dimensions	Flow Type	Bed Controls	Control Types	Width Controls	Control Types
Av. top bank width (m)	None	None	None	(None)	(None)
Av. channel depth (m)	(Uniform/Tranquil)	(Occasional)	~~Solid Bedrock~~	Occasional	Bedrock
Av. water width (m)	Uniform/Rapid	Frequent	(Weathered Bedrock)	Frequent	Boulders
Av. water depth (m)	Pool+Riffle d/s	Confined	Boulders	Confined	Gravel armor
Reach slope	Steep + Tumbling	Number of controls	Gravel armor	Number of controls	Revetments
Mean velocity (m/s)	Steep + Step/pool		Cohesive Materials		Cohesive Materials
			Bridge protection		Bridge abutments
Manning's n value	(Note: Flow type on day of observation)		Grade control structures		Dykes or groines

Notes and Comments:

PART 7: BED SEDIMENT DESCRIPTION

Bed Material		Bed Armour		Surface Size Data		Bed Forms (Sand)		Bar Types		Bar Surface data	
Clay	☐	None	☒	D50 (mm)		Flat bed (None)	☐	None	☐	D50 (mm)	__
Silt	☒	Static-armour	☐	D84 (mm)	__	Ripples	☒	Pools and riffles	☐	D84 (mm)	__
Sand	☒	Mobile-armour	☐	D16 (mm)	__	Dunes	☐	Alternate bars	☐	D16 (mm)	__
Sand and gravel	☐					Bed form height (m)	__	Point bars	☒		
gravel and cobbles	☐	**Sediment Depth**		**Substrate Size Data**		**Island or Bars**		Mid-channel bars	☒	**Bar Substrate data**	
cobbles + boulders	☐	Depth of loose		D50 (mm)		None	☐	Diagonal bars	☒	D50 (mm)	__
boulders + bedrock	☐	Sediment (cm) 7 2' 0		D84 (mm)	__	Occasional	☒	Junction bars	☐	D84 (mm)	__
Bed rock	☐	deep. Bedrock		D16 (mm)	__	Frequent	☐	Sand waves + dunes	☐	D16 (mm)	__

Notes and Comments:

Channel Sketch Map

Map Symbols
(to be determined by field crew)

Study reach limits	North point	Cut bank	Photo point
Cross-section	Flow direction	Exposed island/bar	Sediment sampling point
Bank profile	Impinging flow	Structure	Significant vegetation

Representative Cross-section

C.5

SECTION 4 - LEFT (OR RIGHT) BANK SURVEY

PART 8: LEFT (OR RIGHT) BANK CHARACTERISTICS

Type
- Noncohesive [X]
- Cohesive [ ]
- Composite [ ]
- Layered [ ]
- Even Layers [ ]
- Thick+thin layers [ ]
- Number of layers ___

Protection Status
- Unprotected [ ]
- Hard points [ ]
- Toe protection [ ] ?
- Revetments [ ]
- Dyke Fields [ ]

Bank Materials
- Silt/clay [ ]
- Sand/silt/clay [ ]
- Sand/silt [X]
- Sand [ ]
- Sand/gravel [ ]
- Gravel [ ]
- Gravel/cobbles [ ]
- Cobbles [ ]
- Cobbles/boulders [ ]
- Boulders/bedrock [ ]

Layer Thickness
- Material 1 (m) ___
- Material 2 (m) ___
- Material 3 (m) ___
- Material 4 (m) ___

Ave. Bank Height
- Average height (m) 20'-30'

Ave. Bank Slope
- angle (degrees) ~30°

Bank Profile Shape (see sketches in manual) ___

Tension Cracks
- None [ ]
- Occasional [ ]
- Frequent [X]

Crack Depth
- Proportion of bank height 2'

Distribution and Description of Bank Materials in Bank Profile

	Material Type 1	Material Type 2	Material Type 3	Material Type 4
Toe	[ ]	[ ]	[ ]	[ ]
Mid-Bank	[ ]	[ ]	[ ]	[ ]
Upper Bank	[ ]	[ ]	[ ]	[ ]
Whole Bank	[ ]	[ ]	[ ]	[ ]
D50 (mm)	___	___	___	___
sorting coefficient	___	___	___	___

Notes and Comments:

PART 9: LEFT (OR RIGHT) BANK-FACE VEGETATION

Vegetation
- None/fallow [ ]
- Artificially cleared [ ]
- Grass and flora [ ]
- Reeds and sedges [X]
- Shrubs [X]
- Saplings [X]
- Trees [ ]

Orientation
- Angle of leaning (o) ___

Tree Types
- None [ ]
- Deciduous [X]
- Coniferous [ ]
- Mixed [ ]

Tree species (if known) ___

Density + Spacing
- None [ ]
- Sparse/clumps [ ]
- dense/clumps [X]
- Sparce/continuous [ ]
- Dense/continuous [ ]

Roots
- Normal [ ]
- Exposed [X]
- Adventitious [ ]

Location
- Whole bank [X]
- Upper bank [ ]
- Mid-bank [ ]
- Lower bank [ ]

Diversity
- Mono-stand [ ]
- Mixed stand [X]
- Climax-vegetation [ ]

Health
- Healthy [X]
- Fair [ ]
- Poor [ ]
- Dead [ ]

Age
- Imature [ ]
- Mature [X]
- Old [ ]

Height
- Short [ ]
- Medium [X]
- Tall [X]
- Height (m) 15'

Lateral Extent
- Wide belt [ ]
- Narrow belt [X]
- Single row [ ]

Notes and Comments:

Bank Profile Sketches

Profile Symbols
(to be determined by field crews)

Bank Top Edge	Failed debris	Engineered Structure
Bank Toe	Attached bar	Significant vegetation
Water's Edge	Undercutting	Vegetation Limit

C.6

PART 10: LEFT (OR RIGHT) BANK EROSION

Erosion Location
- General [ ]
- Outside Meander [X]
- Inside Meander [ ]
- Opposite a bar [ ]
- Behind a bar [ ]
- Opposite a structure [ ]
- Adjacent to structure [ ]
- Dstream of structure [ ]
- Ustream of structure [ ]
- Other (write in) [ ]

Present Status
- Intact [ ]
- Eroding:dormant [ ]
- Eroding:active [X]
- Advancing:dormant [ ]
- Advancing:active [ ]

Rate of Retreat
m/yr (if applicable and known) ___

Rate of Advance
m/yr (if applicable and known) ___

Dominant Processes
- Parallel flow [ ]
- Impinging flow [X]
- Piping [ ]
- Freeze/thaw [ ]
- Sheet erosion [ ]
- Rilling + gullying [X]
- Wind waves [ ]
- Vessel Forces [ ]
- Ice rafting [ ]
- Other (write in) [ ]

Notes and Comments:

PART 11: LEFT (OR RIGHT) BANK GEOTECH FAILURES

Failure Location
- General [ ]
- Outside Meander [X]
- Inside Meander [ ]
- Opposite a bar [ ]
- Behind a bar [ ]
- Opposite a structure [ ]
- Adjacent to structure [ ]
- Dstream of structure [ ]
- Ustream of structure [ ]
- Other (write in) [ ]

Present Status
- Stable [ ]
- Unreliable [ ]
- Unstable:dormant [ ]
- Unstable:active [X]

Failure Scars+Blocks
- None [ ]
- Old [ ]
- Recent [X]
- Fresh [ ]
- Contemporary [ ]

Apparent Failure Mode
- Soil/rock fall [ ]
- Shallow slide [ ]
- Rotational slip [ ]
- Slab-type block [X]
- Cantilever failure [ ]
- Pop-out failure [ ]
- Piping failure [ ]
- Dry granular flow [ ]
- Wet earth flow [ ]
- Other (write in) [ ]

Notes and Copmments:

PART 12: LEFT (OR RIGHT) BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris
- None [ ]
- Individual grains [X]
- Aggregates+crumbs [ ]
- Root-bound clumps [ ]
- Small soil blocks [ ]
- Medium soil blocks [ ]
- Large soil blocks [ ]
- Cobbles/boulders [ ]
- Boulders [ ]

Vegetation
- None/fallow [ ]
- Artificially cleared [ ]
- Grass and flora [X]
- Reeds and sedges [ ]
- Shrubs [ ]
- Saplings [ ]
- Trees [ ]

Age
- Immature [ ]
- Mature [X]
- Old [ ]
- Age in Years [ ]

Health
- Healthy [X]
- Unhealthy [ ]
- Dead [ ]

Tree species (if known) ___

Existing Debris Storage
- No bank debris [ ]
- Little bank debris [X]
- Some bank debris [ ]
- Lots of bank debris [ ]

Roots
- Normal [ ]
- Adventitious [ ]
- Exposed [ ]

Notes and Comments:

A.4.3 Rapid Assessment Sheet for FM787 at the Trinity River

Rapid Assessment FM 787 at Trinity River

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.

Stability Indicator	Ratings				
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)	
1. Bank soil texture and coherence	Clay and silty clay; cohesive material	Clay loam to sandy clay loam	Sandy clay to sandy loam	Loamy sand to sand; non-cohesive material	11
2. Average bank slope angle	Bank slopes <3H:1V (18° or 33%) on both sides	Bank slopes up to 2H:1V (27° or 50%) on one or occasionally both banks	Bank slopes to 1.7H:1V (31° or 60%) common on one or both banks	Bank slopes over 60% common on one or both banks	8
3. Vegetative bank protection	Wide bank of woody vegetation with at least 90% density and cover. Primarily hard wood, leafy, deciduous trees with mature, healthy, and diverse vegetation located on the bank. Woody vegetation oriented vertically	Medium bank of woody vegetation with 70-90% plant density and cover. A majority of hard wood, leafy, deciduous trees with maturing, diverse vegetation located on the bank. Woody vegetation oriented 80-90° from horizontal with minimal root exposure.	Small bank of woody vegetation with 50-70% plant density and cover. A majority of soft wood, piney, coniferous trees with young or old vegetation lacking in diversity located on or near the top of bank. Woody vegetation oriented at 70-80° from horizontal often with evident root exposure.	Woody vegetation bank may vary depending on age and health with less than 50% plant den-sity and cover. Primary soft wood, piney, coniferous trees with very young, old and dying, and/or monostand vegetation located off of the bank. Woody vegetation oriented at less than 70° from horizontal with extensive root exposure.	10
4. Bank cutting	Little or none evident. Infrequent raw banks less than 15 cm (5.9 in) high generally.	Some intermittently along channel beds and at prominent constrictions. Raw banks may be up to 30 cm (11.8 in) high.	Significant and frequent. Cuts 30-60 cm (11.8-23.6 in) high. Root mat overhangs.	Almost continuous cuts, some over 60 cm (23.6 in) high. Undercutting, sod-root overhangs, and side failures frequent.	2
5. Mass wasting or bank failure	No or little evidence of potential or very small amounts of mass wasting. Uniform channel width over the entire reach.	Evidence of infrequent and/or minor mass wasting. Mostly headed over with vegetation. Relatively constant channel width and minimal scalloping of banks.	Evidence of frequent and/or significant occurrences of mass wasting that can be aggravated by higher flows, which may cause undercutting and mass wasting of unstable banks. Channel width quite irregular and scalloping of banks is evident.	Frequent and extensive mass wasting. The potential for bank failure, as evidenced by tension cracks, massive under-cuttings, and bank slumping, is considerable. Channel width is highly irregular and banks are scalloped.	11
6. Bar development	Bars are mature, narrow relative to stream width at low flow, well vegetated, and composed of coarse gravel to cobbles.	Bars may have vegetation and/or be composed of coarse gravel to cobbles, but minimal recent growth of bar evident by lack of vegetation on portions of the bar.	Bar widths tend to be wide and composed of newly deposited coarse sand to small cobbles and/or may be sparsely vegetated	Bar widths are generally greater than 1/2 the stream width at low flow. Bars are composed of extensive deposits of fine particles up to coarse gravel with little to no vegetation.	10
7. Debris jam potential	Debris or potential for debris in channel is negligible	Small amounts of debris present. Small jams could be formed.	Noticeable accumulations of all sizes. Moderate downstream debris jam potential possible.	Moderate to heavy accumulations of various size debris present. Debris jam potential significant.	2
8. Obstructions, flow deflectors, and sediment traps	Rare or not present	Present, causing cross currents and minor bank and bottom erosion	Moderately frequent and occasionally unstable obstructions cause noticeable erosion of the channel. Considerable sediment accumulations behind obstructions	Frequent and often unstable causing a continual shift of sediment and flow. Traps are easily filled causing channel to migrate and/or widen.	7

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.				
Stability Indicator	Ratings			
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)
9. Channel bed material consolidation and armoring	Assorted sizes tightly packed, overlapping, and possibly imbricated. Most material >4 mm (0.16 in).	Moderately packed with some overlapping. Very small amounts of material < 4 mm (0.16 in).	Loose assortment with no apparent overlap. Small to medium amounts of material < 4 mm (0.16 in).	Very loose assortment with no packing. Large amounts of material < 4 mm (0.16 in).
10. Shear stress ratio (Eqs. D.1 and D.2)	$\tau_0 / \tau_c < 1.0$	$1.0 \leq \tau_0 / \tau_c < 1.5$	$1.5 \leq \tau_0 / \tau_c < 2.5$	$\tau_0 / \tau_c \geq 2.5$
11. ‡High flow angle of approach to bridge or culvert	$0° \leq \alpha \leq 5°$	$5° < \alpha \leq 10°$	$10° < \alpha \leq 30°$	$\alpha > 30°$
12. §Bridge or culvert distance from meander impact point	$D_m > 35$ m ($D_m > 115$ ft)	$20 < D_m \leq 35$ m ($66 < DM \leq 115$ ft)	$10 < D_m \leq 20$ m ($33 < Dm \leq 66$ ft)	$0 < D_m \leq 10$ m ($0 < DM \leq 33$ ft)
13. Percentage of channel constriction	0-5%	6-25%	26-50%	> 50%

‡ α = approach flow angle to bridge or culvert

§ D_m = distance from bridge or culvert upstream to meander impact point

Table D.2. Stability Indicators and Weights for Stability Assessment Scheme.[1]	
Stability Indicator	Weight
1. Bank soil texture and coherence	0.6
2. Average bank slope angle	0.6
3. Vegetative bank protection	0.8
4. Bank cutting	0.4
5. Mass wasting or bank failure	0.8
6. Bar development	0.6
7. Debris jam potential	0.2
8. Obstructions, deflectors, and sediment traps	0.2
9. Bed material consolidation and armoring	0.8
10. Shear stress ratios	1.0
11. High flow angle of approach to bridge	0.8
12. Distance from meander impact point	0.8
13. Percentage of channel constriction	0.8

Table D.3. Overall Rating Ranges.	
Description	Rating (R)
Excellent	R < 32
Good	32 ≤ R < 55
Fair	55 ≤ R < 78
Poor	R ≥ 78

A.5 Records for US90 at the Nueces River

A.5.1 Field notes for US90 at the Nueces River

Notes from the field visit

Site: US90 at Nueces River

Date: 6/11/2012

Time: From 7:30am to 11:30am

Participants: Xiaofeng Liu (PI)

Rusen Sinir (Graduate student, UTSA)

Axel Montalvo (Graduate student, TAMU)

Another student from TAMU

Notes:

1. We started at the left side of the channel where public access is available. A brief examination of the river under the bridge was undertaken right away to assess the condition of the channel. The river was dry with no water. However, according to the TxDOT engineer, the water level was very high during floods. There are two long bridges across the river, with each in one direction of US90.

2. The right bank of the bridges is problematic which is evident from the heavy bank protection work we saw. Large riprap rocks were dumped to the banks to protect them. These rocks were also grouted with concrete. However, at some segments of the ripraps, they already show signs of failure. The toe of the ripraps has been eroded away. The rocks are hanging there due the grout.

3. On the right bank, scour of the pile foundations is severe. There is a big scour hole under the first span of the bridge to the right bank. Piles have been exposed by about 6-7 feet. However, TxDOT engineer told us that the foundation pile might be very deep and that erosion does not pose a threat. He is more concerned about the concrete corrosion described below.

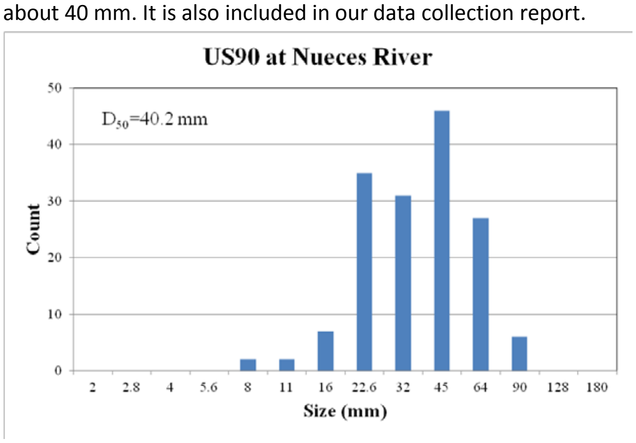
4. There are also signs of bridge foundation pile deterioration (corrosion). Grouting and retrofitting work has been done. However, the deterioration is still ongoing. No sure it is related to floods.

5. After the initial examination, we started to take samples of bed and bank materials. One group (Liu and Sinir) focused on bed materials and the TAMU group focused on bank materials.

6. The position of the cross section we examined was recorded by GPS:
WP56: N33°27.382’, W095°56.532’ . At this location, we did the pebble count.

(Google map view of the location: US90 at Nueces River)

The following figure shows the pebble count result. The mean sediment size for the gravels on the river bed is about 40 mm. It is also included in our data collection report.



We also took a sample for sediment under the gravel armor. This sample is much finer than the surface sediment. The GPS location of this sample is
WP57: N 29°12.397’ W099 °54.163’

7. At the center of the channel, several large gravel dunes were found. These dunes seem isolated and not connected with each other. It was estimated that the height of the dune was 6 ft. Width of the dunes are not estimable.

8. Samples were also taken at the banks. We walked upstream where there is a big meander bend. At the bend, the bank material is much finer. The bank is almost vertical and shows lots of sign of bank erosion and failure.

A.6 Records for SH34 at the N. Sulphur River

A.6.1 Field notes for SH34 at the N. Sulphur River

Notes from the field visit

Site: SH34 at N. Sulphur River

Date: 6/7/2012

Time: From 7:30am to 11:30am

Participants:

Rusen Sinir (Graduate student, UTSA)

Axel Montalvo (Graduate student, TAMU)

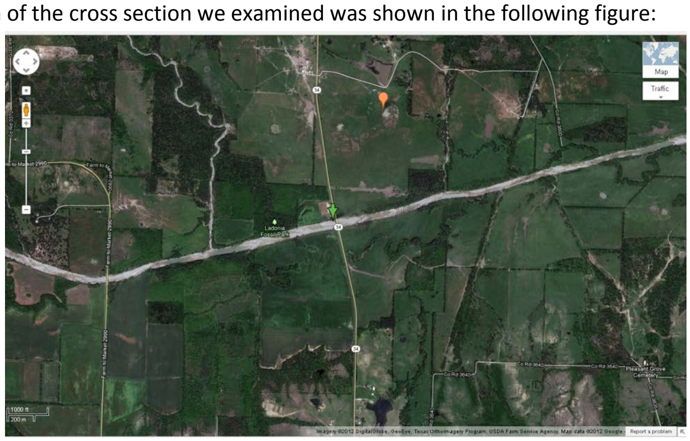
Another student from TAMU

Notes:

1. PI-Liu was absent due to other duties.

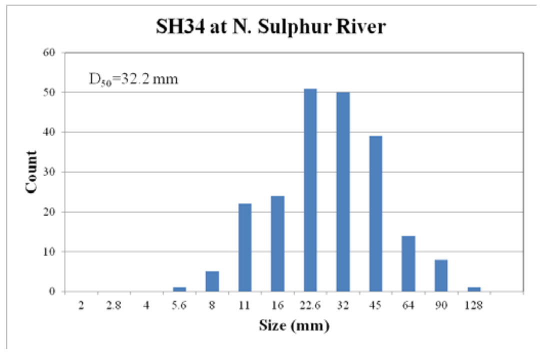
2. This bridge crossing is experiencing severe erosion problem due to channelization. It was very evident from the pictures taken.

3. The position of the cross section we examined was shown in the following figure:



(Google map view of the location: SH34 at N. Sulphur River)

4. The sediment in the river bed and its banks are very fine, except several places we saw scattered gravels. Gravel count was done at one location where the gravels accumulate. The following figure shows the pebble count result. It is also recorded in data collection report.



We took several samples for sediment. The GPS locations of these samples are
Sample #1: WP49: N 32°04.900’ W095°17.129’
Sample #2: WP50: N 33°27.369’ W095°56.536’
Sample #3: WP51: N 33°27.380’ W095°56.537’
Sample #4: WP52: N 33°27.363’ W095°56.480’
Sample #5: WP53: N 33°27.368’ W095°56.492’
Sample #6: WP54: N 33°27.388’ W095°56.490’
Sample #7: WP55: N 33°27.371’ W095°56.504’

5. At the center of the channel, large amount of debris accumulated in front of the bridge pier, which is a sign of bank failure upstream.

6. The banks at the site on both sides are very steep (almost vertical). Very severe bank erosion is going on.

A.6.2 Rapid Assessment Sheet for SH34 at the N. Sulphur River

Rapid Assessment SH34 @ N. Sulphur River

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.					
Stability Indicator	Ratings				
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)	
1. Bank soil texture and coherence	Clay and silty clay; cohesive material	Clay loam to sandy clay loam	Sandy clay to sandy loam	Loamy sand to sand; non-cohesive material	2
2. Average bank slope angle	Bank slopes <3H:1V (18° or 33%) on both sides	Bank slopes up to 2H:1V (27° or 50%) on one or occasionally both banks	Bank slopes to 1.7H:1V (31° or 60%) common on one or both banks	Bank slopes over 60% common on one or both banks	12
3. Vegetative bank protection	Wide bank of woody vegetation with at least 90% density and cover. Primarily hard wood, leafy, deciduous trees with mature, healthy, and diverse vegetation located on the bank. Woody vegetation oriented vertically	Medium bank of woody vegetation with 70-90% plant density and cover. A majority of hard wood, leafy, deciduous trees with maturing, diverse vegetation located on the bank. Woody vegetation oriented 80-90° from horizontal with minimal root exposure.	Small bank of woody vegetation with 50-70% plant density and cover. A majority of soft wood, piney, coniferous trees with young or old vegetation lacking in diversity located on or near the top of bank. Woody vegetation oriented at 70-80° from horizontal often with evident root exposure.	Woody vegetation bank may vary depending on age and health with less than 50% plant den-sity and cover. Primary soft wood, piney, coniferous trees with very young, old and dying, and/or monostand vegetation located off of the bank. Woody vegetation oriented at less than 70° from horizontal with extensive root exposure.	11
4. Bank cutting	Little or none evident. Infrequent raw banks less than 15 cm (5.9 in) high generally.	Some intermittently along channel beds and at prominent constrictions. Raw banks may be up to 30 cm (11.8 in) high.	Significant and frequent. Cuts 30-60 cm (11.8-23.6 in) high. Root mat overhangs.	Almost continuous cuts, some over 60 cm (23.6 in) high. Undercutting, sod-root overhangs, and side failures frequent.	? 6
5. Mass wasting or bank failure	No or little evidence of potential or very small amounts of mass wasting. Uniform channel width over the entire reach.	Evidence of infrequent and/or minor mass wasting. Mostly headed over with vegetation. Relatively constant channel width and minimal scalloping of banks.	Evidence of frequent and/or significant occurrences of mass wasting that can be aggravated by higher flows, which may cause undercutting and mass wasting of unstable banks. Channel width quite irregular and scalloping of banks is evident.	Frequent and extensive mass wasting. The potential for bank failure, as evidenced by tension cracks, massive under-cuttings, and bank slumping, is considerable. Channel width is highly irregular and banks are scalloped.	8
6. Bar development	Bars are mature, narrow relative to stream width at low flow, well vegetated, and composed of coarse gravel to cobbles.	Bars may have vegetation and/or be composed of coarse gravel to cobbles, but minimal recent growth of bar evident by lack of vegetation on portions of the bar.	Bar widths tend to be wide and composed of newly deposited coarse sand to small cobbles and/or may be sparsely vegetated	Bar widths are generally greater than 1/2 the stream width at low flow. Bars are composed of extensive deposits of fine particles up to coarse gravel with little to no vegetation.	? 7
7. Debris jam potential	Debris or potential for debris in channel is negligible	Small amounts of debris present. Small jams could be formed.	Noticeable accumulations of all sizes. Moderate downstream debris jam potential possible.	Moderate to heavy accumulations of various size debris present. Debris jam potential significant.	9
8. Obstructions, flow deflectors, and sediment traps	Rare or not present	Present, causing cross currents and minor bank and bottom erosion	Moderately frequent and occasionally unstable obstructions cause noticeable erosion of the channel. Considerable sediment accumulations behind obstructions	Frequent and often unstable causing a continual shift of sediment and flow. Traps are easily filled causing channel to migrate and/or widen.	9

D.5

Table D.1. Stability Indicators, Descriptions, and Ratings.[1] Range of Values in Ratings Columns Provide Possible Rating Values for Each Factor.					
Stability Indicator	Ratings				
	Excellent (1-3)	Good (4-6)	Fair (7-9)	Poor (10-12)	
9. Channel bed material consolidation and armoring	Assorted sizes tightly packed, overlapping, and possibly imbricated. Most material >4 mm (0.16 in).	Moderately packed with some overlapping. Very small amounts of material < 4 mm (0.16 in).	Loose assortment with no apparent overlap. Small to medium amounts of material < 4 mm (0.16 in).	Very loose assortment with no packing. Large amounts of material < 4 mm (0.16 in).	10
10. Shear stress ratio (Eqs. D.1 and D.2)	$\tau_0 / \tau_c < 1.0$	$1.0 \leq \tau_0 / \tau_c < 1.5$	$1.5 \leq \tau_0 / \tau_c < 2.5$	$\tau_0 / \tau_c \geq 2.5$	9
11. ‡High flow angle of approach to bridge or culvert	$0° \leq \alpha \leq 5°$	$5° < \alpha \leq 10°$	$10° < \alpha \leq 30°$	$\alpha > 30°$	10
12. §Bridge or culvert distance from meander impact point	$D_m > 35$ m ($D_m > 115$ ft)	$20 < D_m \leq 35$ m ($66 < D_M \leq 115$ ft)	$10 < D_m \leq 20$ m ($33 < D_m \leq 66$ ft)	$0 < D_m \leq 10$ m ($0 < D_M \leq 33$ ft)	10
13. Percentage of channel constriction	0-5%	6-25%	26-50%	> 50%	9

‡ α = approach flow angle to bridge or culvert

§ D_m = distance from bridge or culvert upstream to meander impact point

Table D.2. Stability Indicators and Weights for Stability Assessment Scheme.[1]			
Stability Indicator	Weight		
1. Bank soil texture and coherence	0.6	2	1.2
2. Average bank slope angle	0.6	12	7.2
3. Vegetative bank protection	0.8	11	8.8
4. Bank cutting	0.4	6	2.4
5. Mass wasting or bank failure	0.8	8	6.4
6. Bar development	0.6	7	4.2
7. Debris jam potential	0.2	9	1.8
8. Obstructions, deflectors, and sediment traps	0.2	9	1.8
9. Bed material consolidation and armoring	0.8	10	8
10. Shear stress ratios	1.0	9	9
11. High flow angle of approach to bridge	0.8	10	8
12. Distance from meander impact point	0.8	10	8
13. Percentage of channel constriction	0.8	9	7.2
		Σ =	74

Table D.3. Overall Rating Ranges.	
Description	Rating (R)
Excellent	R < 32
Good	$32 \leq R < 55$
Fair	$55 \leq R < 78$
Poor	$R \geq 78$

Fair

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