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16. Abstract
Scour of bridge foundations is the most common cause of bridge failures. The overall goal of this project was to evaluate the applicability of the existing Hydraulic Engineering Circular (HEC-18) documents method to Louisiana bridges that are mostly situated on cohesive soils and hence develop a more reliable design method for scour depth and scour rate prediction.

The errors of scour depth prediction of the HEC-18 method are mainly from three sources: (1) the driving force of scour, i.e., the hydrologic and hydraulic properties of flood flow causing scour development; (2) the resistive force of scour, i.e., the geotechnical properties of streambed soils or sediments that are removed by stream flow; and (3) the geometry, size, and shape of the obstacles (e.g., piers and pile caps). The third error source is not a focus of this study. Due to the availability of the geotechnical data on streambed soils, the second error source was investigated at a secondary priority, and the primary priority of this study was to evaluate the existing method's applicability to cohesive soils in Louisiana using real hydrological data derived from archived satellite remote sensing data.

A total of seven bridges situated on clays, silts, and sands were selected as case studies for scour analysis over a 10- to 15-year period. The hydraulic properties were determined by analyzing satellite sensing data, which were then used as inputs to the HEC-18 method via a software program WASPRO. The recorded scour survey data were also analyzed and compared with data predicted by the HEC-18 using the real flood data. Significant discrepancy existed among the HEC-18 prediction and surveyed scour depth, and the predicted values were always greater than the surveyed depth. Therefore, for cohesive soils, the HEC-18 method usually provides a more conservative design. Although the bridges were safe for the final scour depth, the method typically yields a more costly design.

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LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

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Evaluation of Design Methods to Determine Scour Depths for Bridge Structures

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IMPLEMENTATION STATEMENT

Based on a literature review, those scour prediction methods developed by other states or for soils of different categories may not be applicable to the Louisiana cohesive soils, because of different climatic conditions (e.g., rate of precipitation, storms, and hurricanes) and soil geotechnical properties.

The existing HEC-18 method yields a conservative design for bridges in cohesive soils. However, to achieve a more economical design, HEC-18 can be modified by using flood hydraulic properties and soil geotechnical properties to correct the errors from using assumed virtual flood events to determine the scour driving force and experimental data from sandy soils to derive the scour equations. The study also demonstrated that the developed hydrological and hydraulic analyses using archived satellite data can yield accurate hydraulic and hydrological data. Moreover, the scour survey data were useful assets for the validation of most scour design or prediction methods.

According to the analysis of the scour survey database, a scour survey should be conducted immediately after a large flood event to avoid misleading long-term aggradation from small floods and flows, which eliminates the need to perform scour depth measurements one to two times per year. Reduced scour survey frequency can reduce the costs associated with a scour survey. In addition, real-time scour monitoring and flood measurements during flooding events for selected bridges are more useful for accurate calibration of the HEC-18 method and for future research.

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INTRODUCTION

The Federal Highway Administration (FHWA) has developed design manuals, published as HEC (Hydraulic Engineering Circular) documents (including HEC-18, HEC-20, and HEC-23) for the state Departments of Transportation (DOTs) to evaluate the scour potential of existing bridges and estimate or predict the scour depths for new bridges [*1*]. The scour models in the manual HEC-18 were based on a number of empirical equations that were developed primarily from laboratory flume studies with limited field data verification. These small-scale models simplify the complexities of field conditions by assuming uniform hydraulic parameters and streambed sediment properties. Moreover, these laboratory investigations typically simulate straight, rectangular channels with uniform approach-flow velocities, approach-flow depths, and non-cohesive bed materials. The floodplains represented in the model studies are often of uniform roughness and are typically of a roughness similar to the main channel. However, variable width compound channels, floodplains with highly non-uniform roughness, and heterogeneous sediments with varying degrees of cohesiveness are typical of most bridge sites.

Because of the complex nature of the scour process, these scour-prediction equations recommended in HEC-18 may tend to provide conservative scour depth estimates to ensure that an adequate factor of safety is considered for bridge scour design. To obtain reasonable bridge scour prediction using the HEC-18 method, the designers must be well trained and have years of design experience. They have to carefully evaluate the field conditions and make sound assumptions. The accurate prediction of scour depths for new bridges under design floods is very important. Underestimation of scour depths may result in costly bridge repairs or even catastrophic bridge failures, while overestimation may cause costly, unnecessarily deep foundations. The scour potential evaluation for existing bridges is also important. Overestimation of scour depths causes more bridges to be misclassified as “scour critical” thus resulting in unnecessary installation of scour countermeasures or bridge replacements. In fact, some of those screened “scour-critical” bridges may be from scour-overestimation due to improper use of assumptions or engineering judgments and the inaccuracy of scour prediction equations.

Currently, LADOTD uses the HEC-18 method provided by FHWA for bridge scour design. Costs associated with the current design methods that usually lead to conservative estimation of scour depths can be very high. On the other hand, LADOTD has developed and maintained a large database for a large number of bridge structures that are prone to scour. Those bridges were monitored and hydrologic and hydraulic data collected. As the load resistance factor design (LRFD) approach is being implemented, a large emphasis is placed on the reliability of the estimated scour data and the actual time it takes to reach those estimated scour profiles, since such data are needed for predicting scour depth for those bridges. In addition, different bed materials scour at a different rate, and because of this fact, HEC-18 does not always accurately predict the scour depth at a certain time. A more reliable scour prediction method is needed, especially for the clay and silty clay soils common in Louisiana, with distinct local climatic characteristics (e.g., heavy downpours, severe storms, and hurricanes).

According to the literature review of scour prediction, there are several limitations with the current design method: (1) the HEC-18 method only predicts the scour depth, but not the scour rate or time to scour; (2) the method was developed mainly based on data from cohesionless soils/sediments, but not cohesive soils (e.g., clays and silty clays); (3) the method uses an assumed hydrological data (e.g., 100 year or 500 year return floods), but without the consideration of special hydrological characteristics of a given geographical or climatologic region; and (4) the method lacks long-term (i.e., > 10 years) field scour survey data to verify the assumptions and to calibrate the models, particularly the coefficients used in these models. In fact, this method overestimates scour depths around bridge abutments and in contracted openings at many locations [*2*]. Such excessive prediction of scour depth typically results in construction of unnecessarily deep foundations or installation of unnecessary countermeasures. Therefore, the need for an improved scour prediction and evaluation method with better accuracy is apparently urgent. Resulting from this need, this project aims to develop a new scour prediction and evaluation method, with a specific focus on Louisiana bridges and climatic settings.

OBJECTIVES

The overall goal of the project was to develop a more reliable tool for scour depth and scour rate prediction in the state of Louisiana, with the consideration of LA′s special meteorological and climatic characteristics and soil/sediment properties. The newly developed scour prediction method is still based on the fundamental framework set by FHWA-approved HEC-18, but includes some statistically derived new components and/or selected parameters in the prediction models.

To achieve the project's goal, specific objectives were proposed as follows:

- To analyze historical scour data obtained from field measurements;
- To evaluate the current LADOTD scour prediction method – the HEC-18 method- through comparing the field survey scour data and the predicted results;
- To evaluate alternative design methodologies used in other states for the prediction of bridge scour depths;
- To evaluate available scour rate prediction methods developed by academic researchers;
- To develop a site-specific scour prediction method, based on the frameworks of the current scour prediction models, by using multi-variant statistical analysis of long-term field survey scour data, long-term (> 10 years) continuously recorded hydrometeorologic/hydraulic data.

SCOPE

The scope of the project was limited to the evaluation of “pile-bent” supported bridges, but not including those bridges with footings. In addition to the total scour depth, it also considered the rate of scour and time to scour. The total scour depth included the long-term degradation or aggradation, general scour (particularly contraction scour), and local scour (pier or abutment scour). In terms of the soil types for bridge pile/pier foundations, both cohesionless and cohesive soils were considered, based on the types of soil recorded in the LADOTD bridge scour database. In particular, this project selected appropriate bridges from the LADOTD bridge scour database by considering the availability of scour survey data, stream/rain gauge and weather data, and variable soil types. The target case studies were 8-10 bridges, preferably with 2-3 bridges from each of the three major soil types considered: sand, clay, and silty-clay.

METHODOLOGY

Overview of Research Methodology

Bridge scour is a complex natural process involving three components: the soil (or rock) through its properties (e.g., erosional resistance, particle size distribution or gradation, and cohesive strength or cohesion); the water through its flow velocity; and the geometry of the obstacle (e.g., bridge piers and abutments) through its size and shape. As such, multidisciplinary fundamental knowledge of these three components is needed for studying and solving a bridge scour problem. The research methods selected by the multidisciplinary research team mainly included: (1) a review of existing knowledge and the literature on bridge scour; (2) analysis of historical field measurements on scour depths in the LADOTD scour database and comparison with the LADOTD design/prediction scour data obtained via HEC-18 design method; (3) re-development of the hydrological data through current or archived meteorological data obtained by satellite remote sensing and through GIS data for the selected watersheds; (4) hydraulic analysis of the hydrometeorological data for each selected bridge site; (5) geotechnical analysis and laboratory testing of soil properties in the bridge site; and (6) development of a scour depth and scour rate prediction method by using multi-variants statistical analysis of field survey scour data, continuous hydrometeorological/hydraulic data, and soil geotechnical properties. Figure 1 illustrates graphically the proposed methodology for this project.

Three comparisons were necessary to evaluate the current design methods and to form the basis of significant improvement in scour prediction accuracy. First, a comparison of scour depth predicted by the current guidance with field measured (or survey) scour depth was needed to provide an overall assessment of the state-of-practice. Second, a comparison of the hydraulics from one-dimensional numerical models with the measured hydraulics was required to evaluate the adequacy of those models for estimating the hydraulics at the contracted bridge sites. Third, a comparison of scour computed using measured hydraulics with the observed depth of scour was needed to provide a direct evaluation of the scour-prediction equations. These comparisons were the basis for determining the source of inaccuracies associated with the scour-prediction methods.

In summary, the research methodology adopted in this study consisted of a series of analyses, including:

- Selection of bridges for case studies
- Surveyed scour data analysis
- Building watershed model for the selected bridges
- Archived satellite data analysis for rainfall events

- Hydrological analysis based on the watershed model and rainfall events
- Hydraulic analysis based on the hydrological data
- Scour analysis based on hydraulic data and river bed morphology and bridge parameters
- Comparison of the predicted scour depth with the surveyed scour depth.

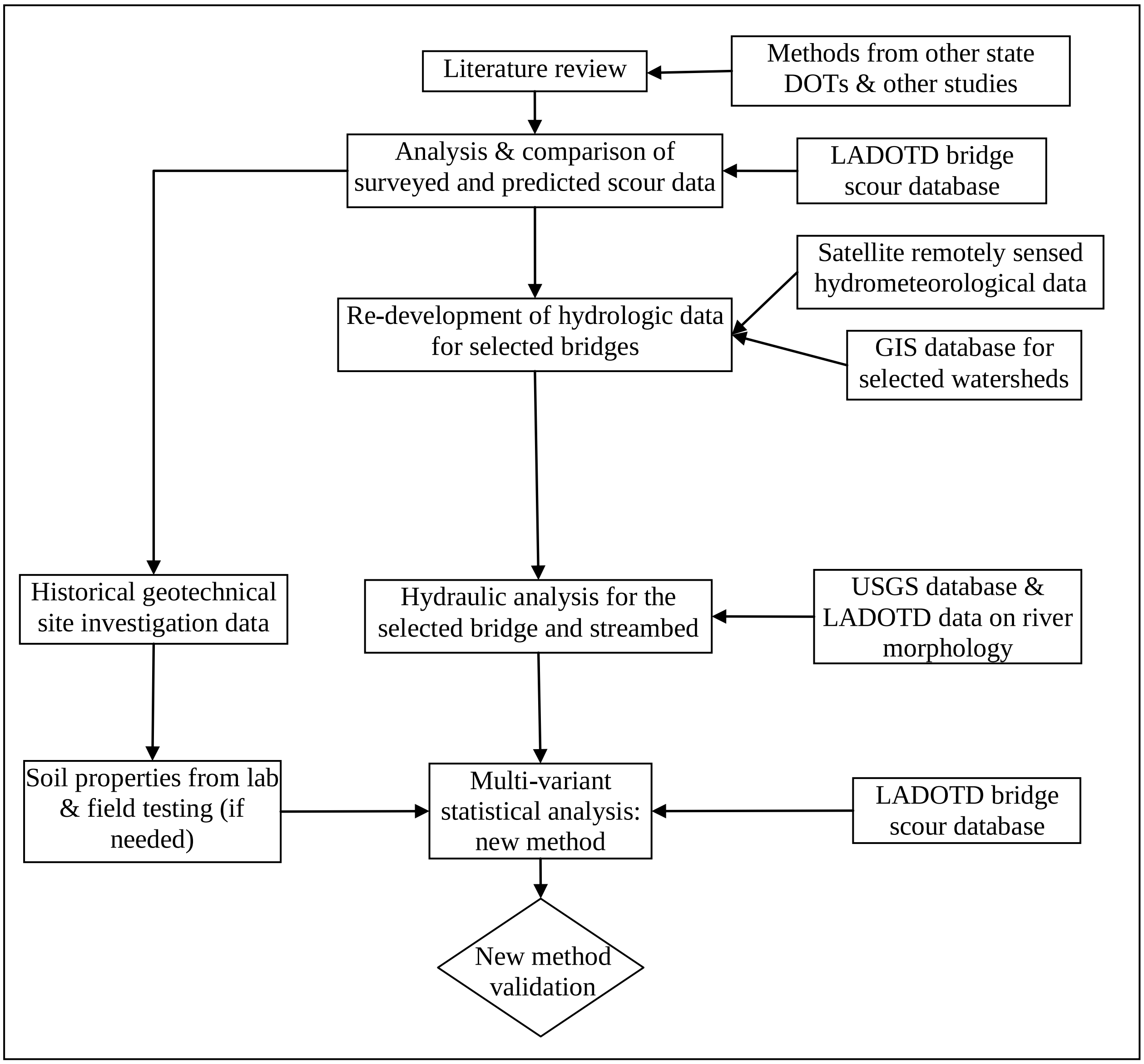


Figure 1
Graphical illustration of the overall research methodology

Research Tasks

This section briefly describes the research tasks carried out according to the research objectives and methodology. Originally a total of 12 tasks were proposed. However, due to the lack of sufficient geotechnical data, eight major tasks were carried out, including:

Task 1: Review of literature and available scour prediction techniques
Task 2: Analysis and evaluation of historical field scour survey data
Task 3: Reporting of interim progress
Task 4: Re-development of historical hydrometeorological forcing and hydrologic analysis
Task 5: Validation and calibration of hydrometeorological data using United States Geological Survey (USGS) data
Task 6: Hydraulic analysis of floods and water flow velocities
Task 7: Analysis of water surface elevations
Task 8: Preparation of a final report

Selection of Bridges for Detailed Case Studies

Clayey soils are one of the most abundant types of soils in Louisiana's stream and river beds. The design, construction, and maintenance of Louisiana's bridges, buildings, and other public facilities require an understanding of these soils' engineering properties and performance. In the past years, the LA government and researchers have devoted a significant effort to take care of this kind of material. As a result, a widely covered soil survey database for Louisiana parishes has been set up in LADOTD. This database plays an important role in the development of Louisiana's transportation, public service, and hydraulic systems. According to the database, cohesive soils are mainly in the southwest of Louisiana, extending through Beauregard, Allen, Evangeline, Calcasieu, Jefferson Davis, and Acadia parishes. According to this database, the river flow direction, and the flow basin conditions, the following seven bridges are chosen for this project as detailed case studies.

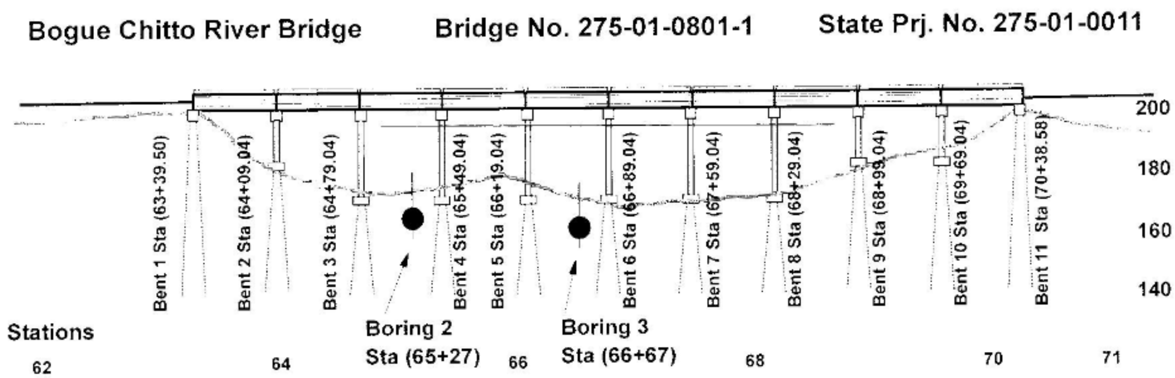
Bogue Chitto River Bridge

This bridge is located on LA438 in Washington parish, northeast of Louisiana, across the Bogue Chitto River. Table 1 summarizes its basic data, and Figures 2 and 3 show a picture of the bridge and soil properties of the bridge site, respectively.

Table 1
Basic information for Bogue Chitto Bridge

Bridge name	LA0438 over BOGUE CHITTO RIVER
Structure number	625902750108011
Location	LA0438
Purpose	Carries two-lane highway over waterway
Length of largest span	69.9 ft.
Total length	700.2 ft.
Roadway width between curbs	24.0 ft.
Deck width edge-to-edge	29.2 ft.
Design load	M 13.5 / H 15
Number of main spans	10
Main spans material	Prestressed concrete
Main spans design	Stringer/Multi-beam or girder
Deck type	Concrete Cast-in-Place

Figure 2
Bogue Chitto River Bridge (built in 1967)



Boring # 2

Soil Type & Color	qu	ω	LL	PI	Elevation
Gray Fine to Med. to Coarse Sand and Gravel		14	NP	N=2/18"	175 - 172
Gray Fine Sand w/ Traces Pea Gravel		25	NP	N=7	158
Yellow Brown Sandy Loam		29	NP	N=2	155
Pink Sandy Loam				N=18	152
Pink Silty Clay, Alt. Lenses Sandy Loam		27	NP	N=3	149
Pink Fine Sand		19	NP	N=43	146
Yellow Brown Coarse Sand and Gravel		13	NP	N=49	131
				N=23	128
Blue Gray and Brown Silty Clay w/ Traces Sand		20	54	38	125
	3.27	25	31	12	121
Gray and Brown Silty Clay & Traces Fine Sand	3.17	26	46	28	116
Yellow Brown and Gray Sandy Clay	3.63	23	35	20	113
Blue Green Silty Clay and Silty Clay Loam	3.31	16	35	23	92
Blue Green Sandy Loam		23	NP		87
Sand				N=5	85

Boring # 3

Soil Type & Color	qu	ω	LL	PI	Elev.
Coarse Sand and Pea Gravel; Traces Roots		20	NP	N=2	174 - 165
Light Gray Coarse Sand and Pea Gravel		13	NP	N=13	162
Coarse Sand and Gravel		7	NP	N=29	156
Coarse Sand and Gravel w/ Sandy Clay		19	29	N=14	153
Gray Brown Sandy Loam		22	NP	N=13	150
Brown Coarse Sand and Pea Gravel		12	NP	N=8	147
Red Brown Fine to Med. Sand w/ Tr. Gravel		20	NP	N=26	144
Pink and Yellow Fine to Med. Sandy Loam		24	NP	N=9	141
Red Brown Fine to Medium Sand		17	NP	N=26	138
Brown Med. to Coarse Sand w/ Traces Gravel		19	NP	N=50	135
Brown Fine to Med. to Coarse Sand & Gravel		14	NP	N=25	126
Light Gray and Brown Silty Clay; Organic 9%	2.90	29	53	36	115
Gray Silty Loam and Silty Clay Loam	1.72	24	29	14	102
Gray Silty Clay Loam, Silty Clay & Fine Sand		22	39	27	93
Blue Green Silty Clay and Fine Sand		22	29	16	86
Blue Green Fine Silty Sand		19	NP	N=75/10"	77

Figure 3
Bogue Chitto River Bridge soil properties

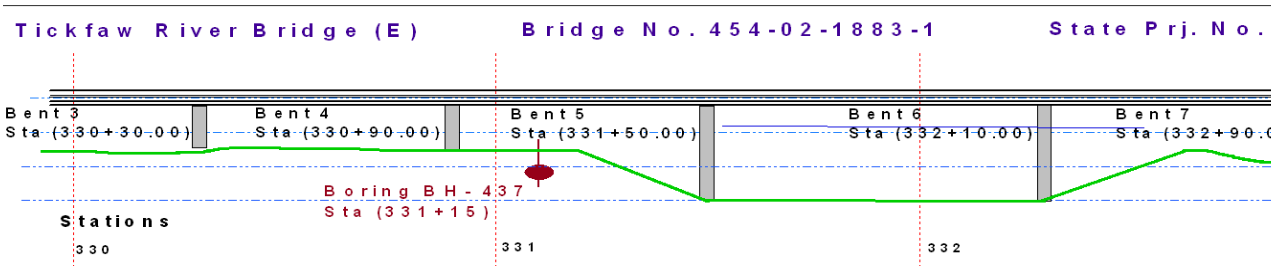
Tickfaw River Bridge on I-12

This bridge is located on I-12 in Livingston parish, crossing the Tickfaw River. Table 2 summarizes the basic information for this bridge. Figures 4 and 5 show a picture of the bridge and the soil properties of the bridge site.

Table 2
Basic information for Tickfaw River Bridge

Bridge name	I0012 over TICKFAW RIVER
Structure number	623204540218831
Location	I0012
Purpose	Carries two-lane highway over waterway
Length of largest span	80.1 ft.
Total length	562.0 ft.
Roadway width between curbs	27.9 ft.
Deck width edge-to-edge	33.5 ft.
Design load	MS 18 / HS 20
Number of main spans	9
Main spans material	Prestressed concrete
Main spans design	Stringer/Multi-beam or girder
Deck type	Concrete Cast-in-Place

Figure 4
Tickfaw River Bridge on I-12 (built in 1969)



Boring # BH-437

Soil Type & Color	qu	ω	LL	PI	Elev.
Light Brown Silty Loam		18	NP	N = 12	25 to 22
Light Brown and Gray Sandy Loam		17	NP	N = 14	14
White Sand		17	NP	N = 15	10
White and Gray Sandy Loam		28		N = 15	6
Gray Medium Silty Clay	1.49	44	58	44	2
Gray Light Silty Clay		25		N = 9	-2
Light Brown and Gray Silty Clay	1.14	26	38	29	-10
Light Brown and Gray Clay Loam	1.99	26	NP		-14
Gray Light Silty Clay		26		N = 17	-18
Light Brown and Gray Silty Clay		26	51	33	-22
No Recovery				N = 37	-26
Light Brown and Gray Sandy Clay Loam		16	NP	N = 19	-30
Gray Silty Clay		15	24	8	-34
White Silt		18		N = 50/10"	-39
White Sand		19	NP	N = 50/9.5"	-52

Figure 5
Tickfaw River Bridge soil properties

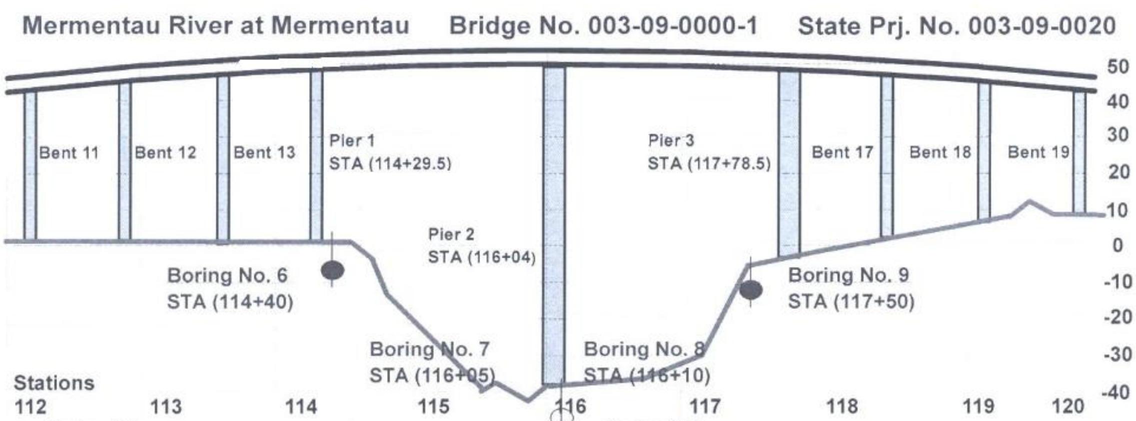
Mermentau River Bridge

The Mermentau River Bridge is on US90 over the Mermentau River, across Jefferson Davis and Acadia parishes. The soil type is identified as clay material from the boring logs. Table 3 summarizes its basic information, while Figures 6 and 7 show a picture of the bridge and the soil boring data of the bridge site, respectively.

Table 3
Basic information for Mermentau River Bridge

Bridge name	US0090 over MERMENTAU RIVER
Structure number	030100030900001
Location	1.1 MI. WEST OF LA 92
Purpose	Carries two-lane highway over waterway
Length of largest span	149.9 ft.
Total length	2030.9 ft.
Roadway width between curbs	40.0 ft.
Deck width edge-to-edge	42.7 ft.
Design load	MS 18 / HS 20
Number of main spans	31
Main spans material	Steel continuous
Main spans design	Girder and floor beam system
Deck type	Concrete Cast-in-Place

Figure 6
Mermentau River Bridge on US 90 (built in 1980)



Boring # 6

Soil Type & Color	qu	ω	LL	PI	Elevation
11' Water at Surface					-2
Gray Silty Clay; Organic 10%		86			-28
Gray Silty Clay with Trace Organic	0.52		42	19	-41
Gray Silty Clay with Traces Rotten Wood	1.27	36	55	29	-80
Gray Fine Sand			NP		-88
Gray Brown Medium-Coarse Sand			NP		-112

Boring # 7

Soil Type & Color	qu	ω	LL	PI	Elevation
36.7' Water at Surface					-29
Gray Silty Clay; Organic 11 %			58	21	-55
Gray Silty Clay	1.05		38		-79
Gray Fine Sand			NP		-84
Gray Medium - Coarse Sand			NP		-139

Boring # 8

Soil Type & Color	qu	ω	LL	PI	Elevation
46' Water at Surface					-39
Gray Silty Clay ; Organic 10%			58	25	-57
Gray Silty Clay	1.11	56	84	52	-77
Brown Medium Sand with Strata Silty Sand		27	NP		-84
Gray Fine - Medium Sand			NP		-96
Gray Coarse Sand with Traces Gravel			NP		-122

Boring # 9

Soil Type & Color	qu	ω	LL	PI	Elevation
Gray Silty Clay with Traces Rotten Wood			30	9	4 to -5
Gray Clayey Silt			NP		-17
Gray Clayey Sandy Silt withTraces Organic			24	4	-26
Gray Sandy Silty Clay		33			-29
Gray Clayey Sandy Silt			29	9	-32
Gray Clayey Silt	1.23		25	3	-65

Figure 7
Mermentau River Bridge soil properties

Saline Bayou Bridge (built in 1956)
This bridge is on US71 in Natchitoches Parish. Table 4 shows the basic information of this bridge, while Figures 8 and 9 show a picture of this bridge and the soil boring data of the bridge site, respectively.

Table 4
Basic information for Saline Bayou Bridge

Bridge name	US0071 over SALINE BAYOU
Structure number	083500090500001
Location	0.7 MI. N OF INT LA477
Purpose	Carries two-lane highway over waterway
Length of largest span	49.9 ft.
Total length	280.9 ft.
Roadway width between curbs	27.9 ft.
Deck width edge-to-edge	30.8 ft.
Design load	MS 18 / HS 20
Number of main spans	6
Main spans material	Concrete
Main spans design	Tee beam
Deck type	Concrete Cast-in-Place

Figure 8
Saline Bayou Bridge (built in 1956)

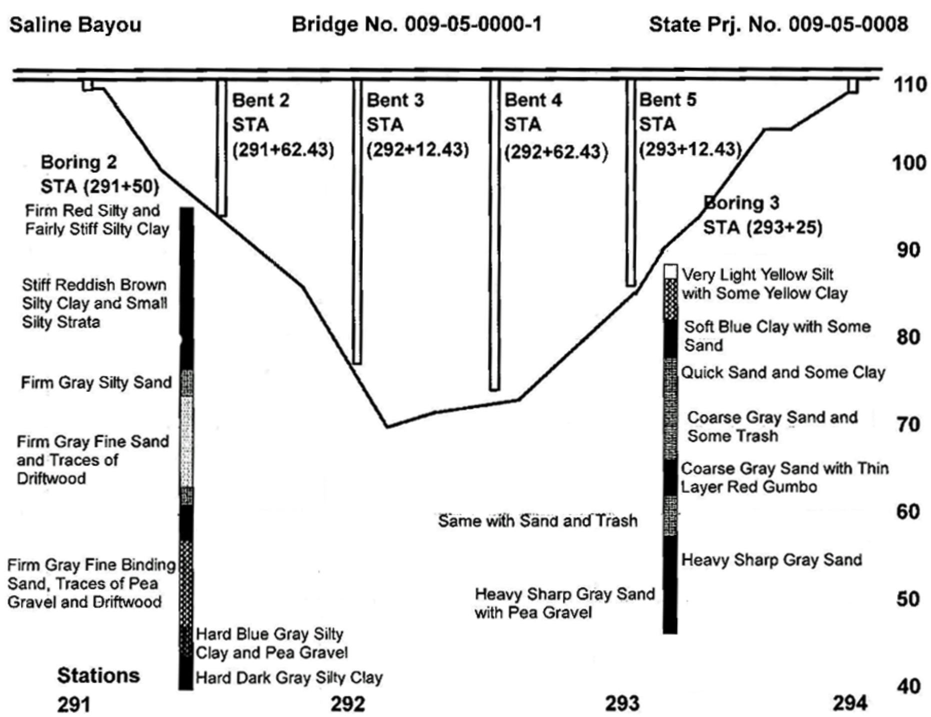


Figure 9
Saline Bayou Bridge soil properties

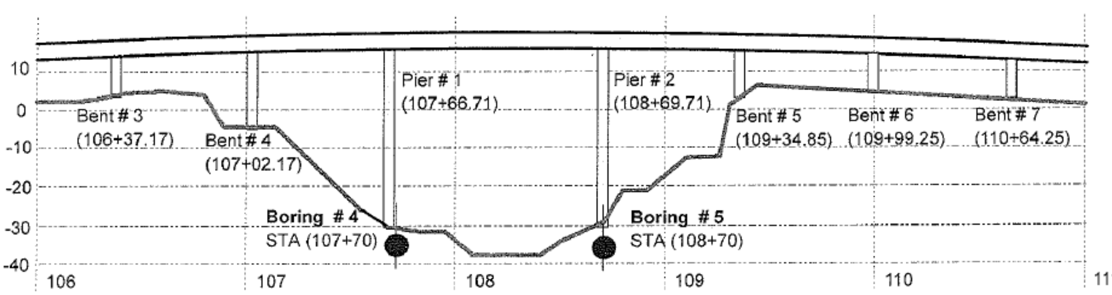
West Fork Calcasieu River Bridge
This bridge is located on LA378 in Calcasieu parish across the West Fork Calcasieu River.

Table 5
Basic information for West Fork Calcasieu River Bridge

Bridge name	LA0378 over W FORK CALCASIEU RIVER
Structure number	071008101204221
Coordinates	+30.29640, -93.24905
Purpose	Carries two-lane highway over waterway
Length of largest span	100.1 ft.
Total length	624.0 ft.
Roadway width between curbs	28.5 ft.
Deck width edge-to-edge	33.8 ft.
Vertical clearance below bridge	52.8 ft.
Design load	MS 18 / HS 20
Number of main spans	9
Main spans material	Steel
Main spans design	Movable - Lift
Deck type	Wood or Timber

Figure 10
West Fork Calcasieu River Bridge (built in 1968)

West Fork Calcasieu River | Bridge No. 810-12-0422-1 | State Prj. No. 713-21-0017



Boring # 4

Soil Type	qu	ω	LL	PI	Elev.
37' Water at Surface					-31
Dark Gray Silty Clay; 11% Organic		71	39	16	-37
Blue Gray Silty Clay; 4% Organic		50	37	18	-40
Gray Medium Sand and Silty Clay		26	20	6	-43
Gray Silty Clay; 10% Organic		54	45	23	-46
Brown Silty Clay; Strata of Silty Loam	0.95	27	32	12	-52
Brown Gray Silty Clay	1.23	32	92	57	-55
Brown Silty Clay; Lenses of Silty Loam	0.98	25	46	27	-58
	1.62	31	74	47	-61
Brown Silty Clay and Silty Loam	2.35	23	37	13	-65
Brown Silty Loam; Lenses of Clay		26	NP		-69
Brown Gray Silty Clay	3.35	21	60	41	-77
Brown Gray Silty Clay; Lenses of Loam	2.77	25	53	31	-81
	2.04	24	43	22	-89
Brown Fine-Medium Silty Sand		27	NP		-93
Brown Fine Silt Sand; Silt; Silty Loam		29	NP	N=74	-103
Gray Fine-Medium Sand		40	NP	N=51	-133

Boring # 5

Soil Type	qu	ω	LL	PI	Elev.
29' Water at Surface					-29
Gray Silty Clay;Rotten Wood; 6% Org.	0.10	41	37	17	-34
Green Gray and Brown Silty Clay	1.30	19	30	14	-35
Blue Gray Silty Clay and Loam		20	40	22	-44
Light Green Gray Silty Clay Loam	1.65	21	34	18	-47
	2.07	20	26	8	-50
	1.32	21	30	13	-58
Brown and Blue Gray Silty Clay	2.82	27	63	42	-66
Brown and Gray Silty Clay and Loam	2.49	23	38	19	-74
Brown and Blue Gray Silty Clay	1.93	24	68	49	-78
Gray Brown Silty Clay;Strata Silty Loam	1.88	23	47	27	-90
Gray Brown Silty Loam; Lenses Clay		26	32	10	-99
Brown and Gray Silty Clay and Clay Loam		28	41	15	-104
Gray Silty Loam and Silty Sand		20	27	6	-109
Gray Fine Silty Sand		26	NP		-119
Blue Gray Silty Clay; Light Lenses Loam		32	44	20	-124
Gray Fine Silty Sand		25	NP	N=58	-132

Figure 11
West Fork Calcasieu River Bridge soil properties

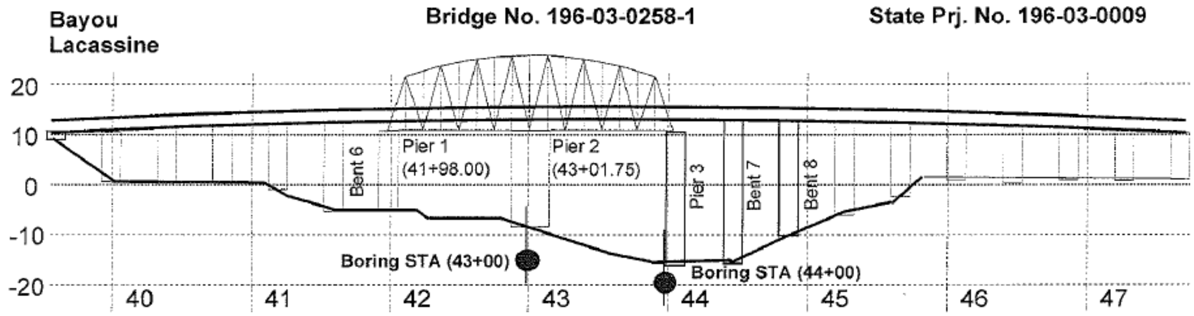
Bayou Lacassine Bridge

This bridge is on LA14 in Jefferson Davis parish, over Bayou Lacassine. Table 6 shows the basic information of this bridge, while Figures 12 and 13 show a picture of this bridge and the soil boring data of the bridge site, respectively.

Table 6
Basic information for Bayou Lacassine bridge

Bridge name	LA0014 over BAYOU LACASSINE
Structure number	072701960302581
Location	5.4 MI EAST OF LA 101
Purpose	Carries two-lane highway over waterway
Length of largest span	204.1 ft.
Total length	811.1 ft.
Roadway width between curbs	24.0 ft.
Deck width edge-to-edge	30.2 ft.
Design load	MS 18 / HS 20
Number of main spans	9
Main spans material	Steel
Main spans design	Movable - Swing
Deck type	Concrete Cast-in-Place

Figure 12
Bayou Lacassine Bridge (built in 1959)



Boring STA (43+00)

Soil Type & Color	Group	Consist.	ω	LL	PI	Elev.
Black Silty Loam, Organic	A-4	Soft	116.6	30	3	-28.5
Gray Silty Clay, Organic	A-7	Soft	90.3	46	18	-38.5
Gray Brown Light Silty Clay	A-6	Hard	29.8	56	35	-43.5
		V. Stiff	29.3	55	30	-48.5
Brown Medium Silty Clay	A-6	V. Stiff	33.9	67	39	-53.5
Gray Brown Heavy Clay	A-6	V. Stiff	46.4	71	34	-58.5
Gray Brown Silty Clay	A-6	V. Stiff	30.5	48	28	-64
	A-7	Hard	29.9	46	27	-69
	A-6	Hard	18.2	31	12	-74
Gray Brown Sandy Clay	A-7	Hard	15.9	37	17	-79
Gray Light Silty Clay	A-6	Hard	24.0	46	26	-84
		Hard	22.8	37	18	-89
Gray Medium Silty Clay	A-7	Hard	32.0	59	30	-99

Boring STA (44+00)

Soil Type & Color	Group	Consist.	ω	LL	PI	Elev.
Black Mucky Clay		Soft				-27.5
Blue Gray Medium Silty Clay	A-7	Firm	26.9	38	19	-31
Blue Gray Light Silty Clay	A-4	Spongy	24.4	36	14	-35
Blue Gray Silty Loam	A-4	Firm	20.8	29	9	-40
Blue Gray Clay Loam	A-4	Spongy	22.0	28	14	-45
Brown Gray Medium Silty Clay	A-6	V. Stiff	27.6	61	39	-50
			26.6	71	36	-55
Brown Gray Heavy Clay	A-6	V. Stiff	40.9	83	48	-60
Gray Brown Heavy Clay	A-6	V. Stiff	48.7	92	53	-65
			38.3	48	20	-70
Gray Brown Light Silty Clay	A-7	Hard	21.6	46	25	-75
Brown Gray Medium Silty Clay	A-6	Hard	35.0	64	33	-85
Gray Loam	A-4	Hard	19.4	22	2	-90
Gray Brown Light Silty Clay	A-6	Hard	28.0	47	21	-100

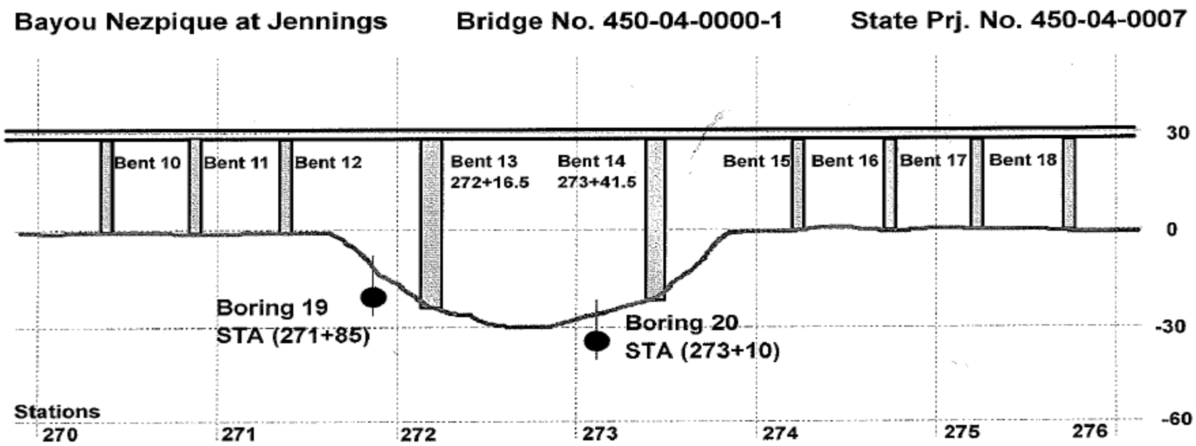
Figure 13
Bayou Lacassine Bridge soil properties

Bayou Nezpique Bridge
This bridge is on I-10 in Acadia parish, over Bayou Nezpique. This bridge was built in 1961 and reconstructed in 1974.

Table 7
Basic information for Bayou Nezpique Bridge

Bridge name	I0010 over BAYOU NAZPIQUE
Structure number	030104500400002
Location	0.4 MI EAST OF LA 97
Purpose	Carries two-lane highway over waterway
Length of largest span	125.0 ft.
Total length	1486.9 ft.
Roadway width between curbs	36.7 ft.
Deck width edge-to-edge	40.7 ft.
Vertical clearance below bridge	28.9 ft.
Design load	MS 18 / HS 20
Number of main spans	27
Main spans material	Steel
Main spans design	Stringer/Multi-beam or girder
Deck type	Concrete Cast-in-Place

Figure 14
Bayou Nezpique Bridge (built in 1961, reconstructed in 1974)



Boring 19

Soil Type & Color	Group	Consist.	ω	LL	PI	Elev.
Gray Brown Silty Clay Loam		Packed				4
Brown and Gray Silty Clay	A-6	Medium	21.9	33	14	-10
Blue Gray Silty Clay	A-4	Stiff	23.1	31	9	-15
Blue Gray Silty Clay	A-6	V. Stiff	21.5	29	11	-20
Gray Silty Clay	A-4	Stiff	23.4	28	6	-25
Gray Silty Loam	A-4	Medium	26.9	26	7	-30
Brown Blue Gray Silty Loam	A-4	Medium	23.4	NP		-35
Brown Graysil silty Clay Loam	A-6	Medium	31.9	31	11	-40
Red Brown Silty Loam	A-4	Dense	27.8	NP		-50
Red Brown Sand		Loose				-55
Red Brown Silty Loam	A-4	V. Dense	27.4	NP		-65
Brown Sandy Loam	A-4	Dense	27.9	NP		-70
Gray Sandy Loam	A-4	Dense	19.8	NP		-75
Blue Gray Medium Silty Clay	A-7-6	V. Stiff	40.9	52	30	-80

Boring 20

Soil Type & Color	Group	Consist.	ω	LL	PI	Elev.
Clay & Rotten Logs		Soft				-21
Light Gray Silty Clay	A-6	Soft	45.7	37	17	-28
Light Gray Silty Clay	A-6	V. Soft	75.8	38	18	-33
Gray Organic 16.8%	A-8	V. Soft	161.5			-38
Gray Organic 16.4%	A-8	Soft	101.5			-43
Gray Sandy Loam and Clay		Loose				-48
Gray and Brown Heavy Clay	A-7-5	Stiff	45.9	59	29	-53
Brown Sand	A-2-4	Medium	44.1	NP		-58
Brown Silty Loam	A-4	Medium	24.1	NP		-68
Gray Light Silty Clay	A-7-6	Dense	39.6	62	36	-73
Gray Heavy Clay	A-7-6	Stiff	51.8	77	50	-78
Gray Heavy Clay	A-7-5	Stiff	52.9	77	43	-83
Gray Sand	A-2-4	Dense	18.6	NP		-88
Gray Sand	A-3	Dense	17.4	NP		-93

Figure 15
Bayou Nezpique Bridge soil properties

Summary
Figure 16 summarizes the geographysical locations of the seven selected bridges as case studies. The watersheds of these bridges defined by the local topography are also shown in Figure 16. Table 8 also provides a summary of the basic information of all the seven selected bridges. As shown in Figure 16, all the selected bridges are situated north of I-10, in order to avoid the influenuce of coastal weather conditions and surge, wave, and tide on bridge scour. The near-coast weather conditions may result in different flow or flood patterns, thus no bridges were selected from the area south of I-10 in Louisiana to make the scour studies more accurate.

Also as shown in Table 8, of the seven bridges, two bridges are situated on cohesionless soils, such as sand and silty sand, while the other five bridges are all situated on cohesive soils, including stiff clay and silty clay.

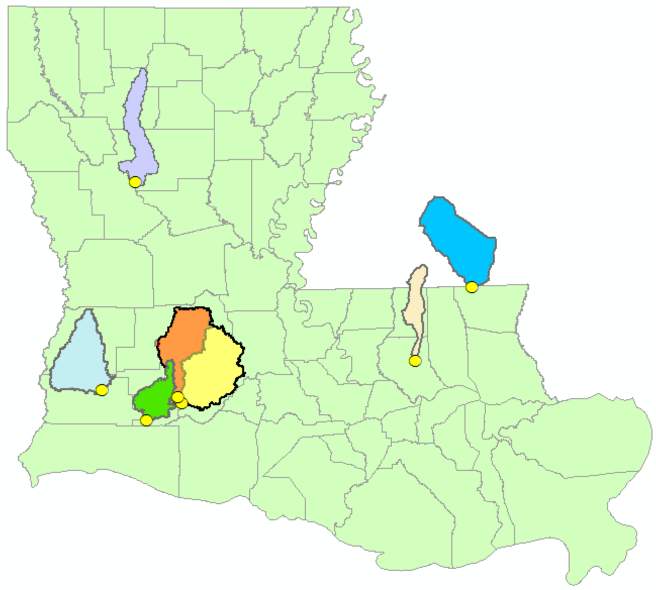


Figure 16
The locations of the seven selected bridges

Table 8
Summary of the basic information for all seven selected bridges

Bridge	Bridge No.	Latitude	Longitude	Route	Crossing	Year built	Major soil type
Bogue Chitto Bridge	275-01-0801-1	30.9904	-90.1959	LA 438	Bogue Chitto	1967	sand
Bayou Lacassine Bridge	196-03-0258-1	30.0702	-92.8786	LA 14	Bayou Lacassine	1959	Silty clay
Bayou Nezpique at Jennings	450-04-0000-1	30.2401	-92.6225	I10	Bayou Nezpique	1961	Silty clay
Mermentau River @ Mermentau	003-09-0000-1	30.1910	-92.5941	US 90	Mermentau River	1980	Gray silty clay
Saline Bayou @ St. Maurice	009-05-0000-1	31.7682	-92.9692	US 71	Saline Bayou	1956	stiff clay
Tickfaw River Bridge	454-02-1883-1	30.4748	-90.6754	I12	Tickfaw River	1969	Silty sand
West Fork Calcasieu River Bridge	810-12-0422-1	30.2904	-93.2497	LA 378	West Fork Calcasieu River	1968	Silty clay

DISCUSSION OF RESULTS

Summary of Literature Review on Bridge Scour Prediction Methods

An extensive literature review was conducted to study the current state-of-the-art understanding of issues related to bridge scour, including the concepts of bridge scour, the underlying theories, and the current design methods recommended by FHWA, and other recent research and development on bridge scour prediction in state DOTs, federal DOT, and FHWA. Although the theories underlying scour and soil erosion are of superior importance for the understanding of bridge scour processes, they are not very pertinent to this project. Additionally, it would be impractical to summarize all aspects of bridge scour in a simple report. Therefore, this section provides a summary of existing bridge scour prediction methods based on more recent literature (i.e., papers, reports, and monographs published in the past decade or so).

Introduction

About 500,000 out of the 600,000 bridges in the United States are over water. A study by Murillo shows that scour has been identified as the main cause of bridge failure in the United States [*3*]. A report conducted by Chang for the Federal Highway Administration gave that 25 percent of the 383 bridge failures due to catastrophic floods involved pier damage; whereas, 72 percent involved abutment damage [*4*]. During the past 30 years, in the United States, over 1000 bridges have collapsed and 60 percent of the failures were due to scour [*5*]. During the 1993 flood in the upper Mississippi and lower Missouri river basin, at least 22 of the 28 bridges that failed were due to scour at an estimated cost of more than $8,000,000 [*6*]. In 1994, flooding from Storm Alberto in Georgia (GA) damaged over 500 bridges. Thirty-one state-owned bridges experienced 15-20 ft. of scour and thus had to be replaced. The total damage to the GADOT highway system was approximately $130 million. These bridges or some portion of their structure will have to be replaced with new foundations that are under condition of scour.

Bridge scour is a major factor that contributes to the total construction and maintenance costs of bridges in the United States. Under-prediction of design scour depths can result in costly bridge failures and possibly in the loss of lives; while over-prediction can result in wasting millions of dollars on a single bridge. For these reasons, the proper prediction of the amount of scour anticipated at a bridge crossing during design conditions is essential.

During the past years many methods were developed to predict the scour of bridges: FHWA has developed design manuals, including HEC-18, HEC-20, and HEC-23, for the state DOTs to evaluate the scour potential of existing bridges and estimate the scour depths for new bridges; the Florida Department of Transportation developed a new method based on the HEC-20 method; the Maryland State Highway Administration developed the ABSCOUR program based on the research and development of Chang and Davis, which differs slightly from the HEC-18 methods; the Texas Department of Transportation developed a scour rate based method; and Texas A&M University developed the SCICOS-EFA method focus on pier and contraction scour in cohesive soil [*1*] [*7][8*] [*9*]. This report compares and analyzes these prediction methods available in the literature and hence develops a new and less conservative method for LADOTD to predict the bridge scour for bridge design and repair.

Background on Bridge Scour

Bridge scour is the loss of soil or sediments by erosion due to water flowing around bridge supports. Bridge scour consists of two major categories: **general scour** and **local scour**. General scour is the aggradation (accumulation) or degradation (removal) of the riverbed material and is not related to the bridge or the presence of local obstacles. Aggradation refers to the gradual and general accumulation of sediments on the riverbed. In contrast, degradation is the gradual and general removal of sediments from the riverbed. Local scour is the erosion of soil around obstacles to the water flow, such as those imposed by a bridge. Local scour includes three components (Figure 17): **pier scour, abutment scour, and contraction scour**. Pier scour is the removal of the soil around the foundation of a pier; abutment scour is the removal of soil around an abutment at the junction between a bridge and embankment; contraction scour is the removal of soil from the riverbed due to the narrowing of the stream channel either naturally or created by the bridge approach embankments and bridge piers (Figure 18). Two conditions exist for general and local scour: clear-water and live-bed scour. Clear-water scour occurs when no movement of the bed material is involved in the flow upstream of the structure, while live-bed scour takes place when there is transport of bed material from the upstream into the bridge crossing [*1*].

An additional mechanism, bed form propagation through the bridge site, may also play an important role. Bed forms refer to the pattern of regular or irregular waves that may result from water flow over a sediment bed. These forms may propagate either in the same or in the opposite direction of the flow. Since these undulations in the sediment bed may have large amplitudes, one must also take into account their contribution to the lowering of the bed near the bridge piles. Additionally, their presence contributes to the calculation of the overall roughness of the bed, and hence the vertical structure of the flow over the bed.

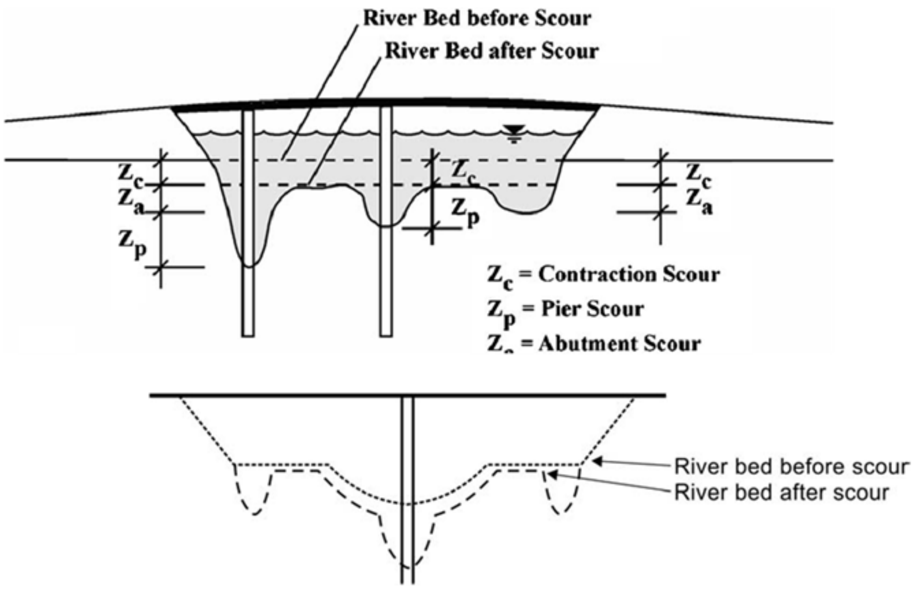


Figure 17
Illustration of the three components of local scour [*9*]

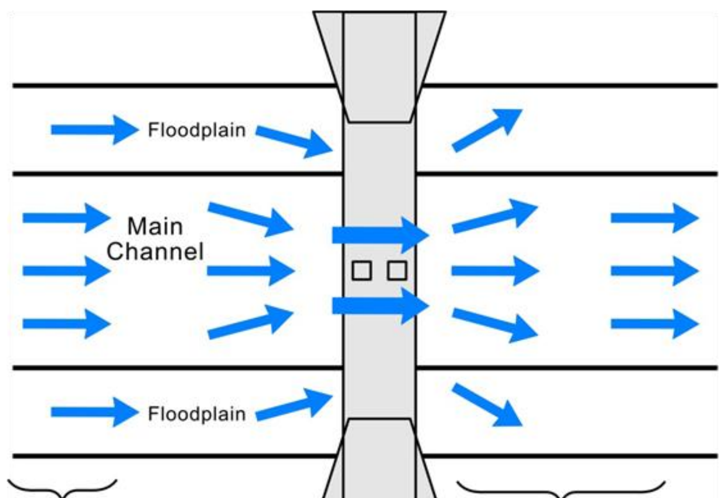


Figure 18
Illustration of the influence of bridge on river flow patterns [*10*]

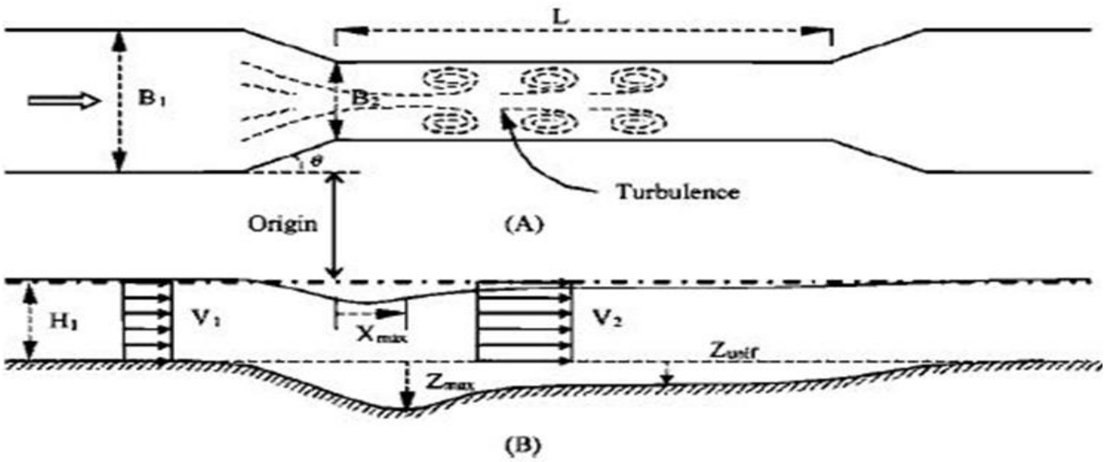


Figure 19
Illustration of mechanisms for contraction scour

The main mechanisms of local scour are: (1) increased mean flow velocities and pressure gradients in the vicinity of the structure (Figure 19), (2) the creation of secondary flows in the form of vortices, and (3) the increased turbulence in the local flow field. Two kinds of vortices may occur (Figure 20): (1) wake vortices, downstream of the points of flow separation on the structure, and (2) horizontal vortices at the bed and free surface due to stagnation pressure variations along the face of the structure and flow separation at the edge of the scour hole. Local scour is divided into two different scour regimes that depend on the flow and sediment conditions upstream of the structure. Figure 21 shows an example of local scour around a bridge pier.

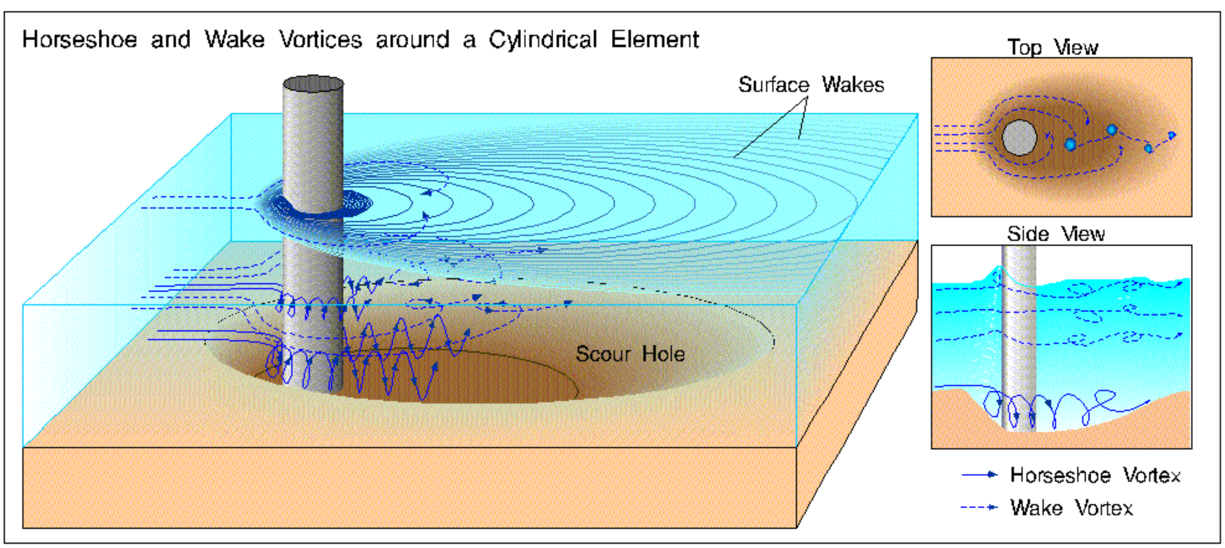


Figure 20
Schematic illustration of scour at a cylindrical pier by vortices

Figure 21
A picture showing the local scour around a bridge pier

Errors in Scour Predictions
Errors in the prediction of scour components stem from three sources:

- Estimation of hydraulic forcing, typically through hydraulic modeling but not real-time measurements;
- Selection of scour-prediction parameters, including the inadequate representation of erosion resistance of soils or sediments
- Scour-prediction equations

The hydraulic parameters usually are estimated from a one-dimensional hydraulic model that distributes flow across the approach and bridge opening by conveyance (combination of roughness and flow area). However, the flow distribution at a bridge or in its approach is typically non-uniform because of cross-stream flow caused by channel bends, complex roughness patterns, irregular valley topography, and obstructions in the floodplains. Bridges and approach embankments not aligned perpendicular to the approach flow further complicate flow patterns and velocity distributions.

The empirical scour-prediction equations developed from laboratory flume studies use average flow parameters such as approach velocity, flow depth, and embankment length. A high degree of subjectivity is often required to select these parameters. The simplifications involved in using laboratory experiments to develop scour-prediction methods and the subjectivity required to extract average representative parameters from non-uniform and heterogeneous field conditions contribute to the uncertainty and error of scour-depth predictions.

Another well-recognized source of scour-prediction error is the inadequate representation of erosion resistance or erodibility of soils or riverbed sediments. The scour-prediction equations recommended by HEC-18 were developed from uniform, unstratified, non-cohesive sediments that are representative of the most severe scour conditions. The erosional resistance of typical soils found at a bridge site is a combination of stratified soils with varying degrees of cohesiveness. In addition, the surface soils often are protected and reinforced by vegetation or armored by the largest size fractions of the bed material. The complexity of the erosion resistance of bed material has been marginally included into scour-prediction equations.

Complete and reliable field data sets are rare, although there have been more than 100 laboratory studies in which detailed and complete data sets have been published [*11*]. A survey of the literature located 30 references with potential field data for abutment and contraction scour. Of the 30 references reviewed, 4 are potential sources of data for abutment scour and 22 are potential sources for contraction scour. Most of the scour data presented in these references were collected during post-flood investigations, and flow conditions that created the scour were estimated from hydraulic models (but not from real-time measurements). Nearly all of the sites identified in the literature review required the compilation of raw data and additional analysis to obtain complete abutment and contraction-scour data sets. An exception to this is data collected by the USGS at 146 bridges in South Carolina. Hydraulic models were developed for these sites and hydraulic variables were compiled into a database and associated with field observations of scour. This database was developed to assess clear-water contraction and abutment scour equations. It should be noted that the South Carolina data were not just post-flooding measurements, but were often remnant scour after several years or decades of recovery and there was often no knowledge of what flood event caused the scour.

Studies found in some of the references compare field observations with computed scour. Contraction and abutment scour comparisons frequently predict scour depths greater than those observed and often this bias can be three to four times the measured scour depth; however, some comparisons indicate that there are conditions under which some equations will predict scour depths less than those observed. These comparisons indicate that the current methods for predicting contraction and abutment scour at bridges are unreliable.

Overview of Scour Evaluation Process

According to the literature, total bridge scour is divided into various components that are considered independent and additive, including general scour and local scour. The latter is further subdivided into contraction scour, abutment scour, and pier scour [*10*]. Most research has focused on the three components of local scour. Therefore, this section provides an overview of the scour evaluation process for contraction scour and pier or abutment scour.

Contraction scour is the erosion of material from the bed and banks across all or most of the channel width, resulting from the contraction of flow area imposed by the bridge abutments and piers. The literature presents various methods for estimating contraction scour, including (1) regime equations, (2) hydraulic-geometry equations, (3) numerical sediment-transport models, and (4) contraction scour equations.

Regime and hydraulic-geometry equations are empirical equations that are used to assess changes in channel geometry for given hydraulic conditions. Although originally developed to assist in the design or assessment of channel shape, these methods can be used for estimating contraction scour at bridges. The assumption implied by the use of these equations is that *changes in unit discharge cause a unique change in channel depth*. These equations must be calibrated with local or regional field data, which limits their application to sites with characteristics similar to those used for calibration.

Numerical sediment-transport models combine various sediment-transport equations with numerical hydraulic models to simulate scour processes in streams. Hydraulic conditions estimated with these models are used to drive the sediment-transport equations. The literature shows that the various sediment transport equations provide significantly different estimates of sediment discharge for the same site. Given adequate topographic and channel data, numerical models have been shown to provide reasonable estimates of hydraulic parameters at some sites. Adequate representation of sediment transport and scour requires selection of specific sediment transport equations developed for the specific conditions of the site and may require site calibration. To assure that the results from the sediment-transport numerical model are reasonable, the model should be calibrated and verified with observed field data. However, sediment transport models are rarely used to estimate contraction scour because of the time and costs associated with data collection necessary to construct, calibrate, and verify these models.

The literature describes a number of semi-empirical contraction-scour equations that were developed by the use of conservation of flow and sediment in a control volume in conjunction with laboratory derived concepts of sediment transport. These equations can be readily applied to a given site, which may account for their common use. Laboratory researchers have found that the transport or lack of transport of sediment in the flow approaching an obstruction or contraction is critical in assessing scour at bridges.

Contraction scour has traditionally been classified as live-bed or clear-water, which reflects the bed material sediment-transport conditions of approaching flows. Researchers have used similar approaches to derive the various equations. In the case of live-bed scour, the common assumption is that scour will cease when the load of sediment transported into the contraction is equal to or greater than the load of sediment transported from the contraction. The major difference in the various equations stems from the use of different sediment-transport relations. Though differences exist within the derivations, the format and exponents of the various live-bed equations generally are similar. In the case of clear-water scour, the common assumption is that scour will cease when the bottom hydraulic shear stress in the contraction equals to or less than the critical shear stress for the bed material. The critical shear stress is typically determined from Shield's diagram that represents a laboratory-derived shear stress for incipient motion of uniform, non-cohesive sediments. The Shield's relation and other similar relations represent laboratory-derived shear stress for incipient motion of uniform, non-cohesive sediments. Other common assumptions used in the derivation of live-bed and clear-water contraction-scour equations include steady-uniform flow, non-cohesive bed material, and sufficient time to achieve equilibrium conditions. To the degree that field conditions deviate from these and other assumptions, it is likely that the contraction-scour equations may not provide reasonable scour depths under field conditions.

Local pier or abutment scour is the removal of bed material from around flow obstructions such as piers, abutments, spurs, and embankments caused by the local flow field induced by a pier or abutment. Analytical equations for predicting abutment scour primarily have been derived from observations obtained from small-scale physical-model studies conducted in laboratory flumes.

As with contraction scour, abutment-scour equations have been classified as live-bed or clear-water, reflecting the approaching sediment-transport conditions. The equations can be subdivided further into empirical and semi-empirical equations. The empirical equations were developed from envelope curves or a regression analysis of dimensionless variables obtained from laboratory investigations. The semi-empirical equations were derived in a similar manner to the contraction scour equations by use of conservation of flow and sediment in a control volume in conjunction with laboratory-derived concepts of sediment transport. Abutment-scour depth is often assumed to be a function of contraction-scour depth and the contraction-scour equation is adjusted to reflect the increased scour potential at the abutment. In addition to laboratory-derived equations, there are several abutment-scour equations derived from field observations. These field-derived equations were developed from limited data sets for site-specific conditions; therefore, they may not be applicable to other sites. Numerical sediment-transport models also have been used to investigate abutment scour, and results from these models are subject to the same limitations described for contraction scour.

Evaluation of Existing Methods

This section briefly summarizes several recently developed scour-prediction methods individually. In the last four decades, to improve the understanding of scour mechanisms and develop more reliable models for scour prediction, significant efforts and resources have been devoted by the FHWA, state DOTs, and academic institutions to studying bridge scour. Research has been conducted in the following areas: (a) prediction of local scour at bridge piers and abutments, (b) selection and design of bridge-scour countermeasures, (c) stream-bank protection, (d) tidal scour, and (e) analysis of river systems and methodologies for predicting channel instability. Due to the complex nature of bridge scour, a universally applicable design method for determining scour depth and scour rate has yet to be developed. The scour depth and rate depend on stream flow conditions, erosive power of the flow, bed material properties, and a balance between sediment transported into and out of a bridge section. No relationship between the critical shear stress or the initial slope of the erosion function of soil column and common soil geotechnical properties indicated that the scour development is site specific [*12*].

Total scour depths at a bridge cross-section are the function of stream hydraulic conditions, sediment transport by flowing water, streambed sediment properties, bridge structure dimensions, and times. Also, the complex interactions among those variables complicate the scour development. Numerous studies have been conducted on various bridge scour topics and resulted in many physical and numerical models/equations. None of them can predict the ultimate scour depths accurately without the aid of the engineering judgment. Among then, the mostly widely used one is the HEC-18 recommended by FHWA. HEC-18 was developed by assuming uniform, unstratified, non-cohesive sediments that are representative of the most severe scour condition, but the erosional resistance of typical soils found at the bridge site is a combination of stratified soils with varying degrees of cohesiveness. The hydraulic parameters used in HEC-18 are estimated by a one-dimensional hydraulic model such as WSPRO or HEC-RAS that distributes flow across the approach and bridge opening by conveyance (combination of roughness and flow area); however, the flow distribution at a bridge or in its approach is non-uniform because of cross stream flow caused by channel bed conditions, channel bends, irregular valley topography, and obstructions in the floodplain. There are also other discrepancies between HEC-18 and the real world. However, it is difficult to find scour estimation models that can predict accurate scour depths because the scour development processes are very complex and difficult to analyze. To date, HEC-18 is still a very useful tool to estimate the total scour depths if appropriate engineering judgment is used. The pier scour and contraction scour of some selected models (including HEC-18 models) will be discussed here.

To help the team's future development, the summary focuses primarily on: (1) the methods to determine the hydraulic forcing for scour development, (2) the types of bed materials considered in the scour models, (3) validation with real-time hydraulic measurements, (4) validation with long-term scour survey data, and (5) costs and implementability of the methods. The methods evaluated mainly include:

- HEC-18 [*1*]
- Scour Rate in Cohesive Soil-Erosion Function Apparatus (SRICOS-EFA) for Cohesive Soils [*12*]
- Simplified SRICOS method [*10*]
- NCHRP 24-14 Method [*2*]
- FLDOT Method [*13*]
- ABSCOUR method [*7*]

HEC-18 Method. The fourth edition of HEC-18 was released in May 2001. It represented the state of knowledge and practice for the design, evaluation, and inspection of bridge scour at that time. Recommended by FHWA, this method is currently widely used by most US state DOTs for scour prediction, design, and inspection. If this research results in a recommendation to use an improved or alternative method, approval by state DOTs and FHWA may be required.

This method uses an assumed flood event to derive the hydraulic parameters involved in scour analysis. Typically, the 100-year or over-topping flood is used, since prior experience indicates that this is likely to produce the most severe scour conditions. Yet a superflood event on the order of a 500-year flood needs to be checked for design safety (at least with a factor of safety of 1.0). Once flood discharge data are obtained, for example, from the U.S. Geological Survey Water Resources District office, hydraulic analysis is performed by using either USGS or FHWA's Water Surface Profile (WSPRO) computer program or U.S. Army Corps of Engineers (USACE) HEC-RAS (Hydrologic Engineering Center River Analysis System). The scour prediction equations are more empirical in nature and were developed based primarily on laboratory small-scale flume studies on uniform cohesionless soils. Thus, this method has no consideration of the variability and heterogeneity of riverbed material.

Since a small rate of scour has been observed in cohesive soil (e.g., clays) and rock, the HEC-18 method tends to overestimate the scour depth in these two kinds of materials, leading to costly, conservative design of bridge foundations.

In this method, the hydraulic forcing is usually validated by the USGS water gauge data (e.g., surface, discharge, and flow velocity) if they are available. If not, extrapolation or reference data will be obtained from nearby watershed where gauge data are available. Moreover, this method has not been validated by long-term real-scour data. For a given flood, it assumes a sufficiently long duration of flood to develop the ultimate final scour depth. Since this method is based on one single flood event (without the consideration of flood duration), it cannot predict or estimate the rate of scour (i.e., the development of scour depth vs. time). In fact, a current general agreement is that the HEC-18 method tends to result in a conservative design for most cases.

SRICOS-EFA Method. This method was developed by Briaud and co-workers at Texas A&M University under the sponsorship of TxDOT and FHWA [*9, 12*]. A particular advancement is that this method considers the variability in the erosion resistance and rate of erosion (defined as "erodibility" therein) of riverbed soils. Therefore, it is applicable to cohesive bed material and can provide more accurate prediction of scour in clayey soils. Since the new term "erodibility" considers the rate of erosion (dz/dt) vs. flow velocity or resultant shear stress, this method can also be used to predict the rate of erosion, in addition to the depth of erosion.

With respect to the hydraulic forcing, this method made some, but limited, advancement. It still relies on the sparse, limited gauge station data to develop the past discharge hydrograph (i.e., discharge vs. time) or future hydrograph via extrapolation and statistical analysis. Therefore, this method has a significant advancement in considering the bed material variations, but significant errors may still result from the inaccurate flood data.

Characterization of the variation in erosion resistance and erodibility requires in-situ sampling and subsequent laboratory testing [e.g., via an Erosion Function Apparatus (EFA)]. As usual, sampling and specialized laboratory testing are costly operations and time-consuming. Therefore, this method has significant economic limitations, as pointed out by Briaud et al., which leads to the development of a simplified SRICOS method [*10*].

Simplified SRICOS Method. Recently Briaud et al. published a simplified method for scour estimation, using similar concepts and procedures developed in the SRICO-EFA method [*10*]. This method again can predict the scour rate and maximum scour depth, similar to the SRICOS-EFA method. However, it doesn't require field sampling and laboratory testing to characterize the soil erosional parameters, but utilizes erosion classification charts to replace the site-specific erosion testing and sampling for preliminary evaluations. The erosion classification charts were developed based on prior research data obtained by Briaud and co-workers. The published report also included 11 case studies to validate this simplified method.

Another significant advancement is that this method uses three levels of assessments to evaluate the current status of scour development (e.g., screening of scour critical bridges), determine the maximum scour depths, and finally calculate the time-dependent scour depth rather than simply using the maximum scour depth. As such, it can be used to predict the future development of scour within the lifetime of a bridge.

NCHRP Method. Wagner et al. published an NCHRP Document 83 (Project 24-14) that presents some improvements of the HEC-18 method resulting from a study funded by FHWA and AASHTO [*2*]. A particular advancement was that real-time hydraulics was instrumented during flood events, which is probably the first study utilizing real-time hydraulic data for scour evaluation. Numerical simulations were also used to quantify the differences between the real-time hydraulics and the simulated data derived from gauge station measurements or other statistical results. Such comparison helps assess the errors resulting from assumed hydraulic discharges and numerically derived hydraulic parameters (such as approach velocity, water flow depth upstream). As a result, modifications to the existing HEC-18 method were developed and recommended.

However, field instrumentation and monitoring of real-time hydraulic data are costly and time-consuming. Broad extension of the research of its kind is difficult. The method also points out the importance of characterizing properly and accurately the erosion resistance of bed materials in scour prediction. Another limitation of this method is that it cannot evaluate the rate of scour.

The FLDOT Method (2005). This method is very similar to the HEC-18 method, with a slight modification to consider the influence of coastal waters and tidal effects. This method tends to be conservative. A special consideration of this method is the introduction of the consideration of a new parameter – the ratio of pier width to sediment diameter. It is claimed that the inclusion of this parameter may alleviate the degree of over-prediction.

ABSCOUR Method (MD SHA, 2007). The Maryland State Highway Administration (MD SHA) developed the ABSCOUR program based on the research and development of Chang and Davis, which differs slightly from the HEC-18 method [*4, 7, 8*]. The ABSCOUR method is based on Laursen's contraction scour equation as presented in the

FHWA Publication HEC-18. This equation was originally derived by Straub considering that the shear stress in a non-contracted section and a contracted section are the same [*14*]. The flow of a long contracted channel is considered to be uniform and the scour depth is constant across the channel section. The fact is the contracting flow at the corner of a channel differs significantly from the condition as assumed. Velocity variations caused by the flow contraction and spiral flow at the toe of the abutment are considered in developing the equations.

The Scour-prediction Equations and Models

HEC-18 Models. Contraction scour equations are based on the principle of conservation of sediment transport. For the live-bed scour, the fully developed scour in the bridge cross section reaches equilibrium when sediment transported into the contracted section equals to the sediment transported out. **Live-bed contraction scour** is calculated by the modified Laursen's equation, which assumes that bed material is being transported from the upstream section [*15*]:

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{\frac{6}{7}} \left(\frac{W_1}{W_2}\right)^{k_1} \qquad (1)$$

$y_s = y_2 - y_o$ = (average contraction scour depth)

where,

y_1 = Average depth in the upstream main channel, ft.;

y_2 = Average depth in the contracted section, ft.;

y_o = Existing depth in the contracted section before scour, ft.;

Q_1 = Flow in the upstream channel transporting sediment, ft^3/s;

Q_2 = Flow in the contracted channel, ft^3/s;

W_1 = Bottom width of the upstream main channel that is transporting bed material, ft.;

W_2 = Bottom width of the main channel in the contracted section less pier widths, ft.;

k_1 = Exponent determined below:

V_*/ω	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

$V_* = (\tau_0/\rho)^{1/2} = (gy_1S_1)^{1/2}$, shear velocity in the upstream section, m/s;

ω = Fall velocity of bed material based on the D_{50}, m/s;

G = Acceleration of gravity;

S_1 = Slope of energy grade line of main channel, m/m;

τ_0 = Shear stress on the bed, Pa; and
ρ = Density of water.

Live-bed contraction scour is a function of hydraulic parameters only; therefore, the ratio of scour depths under different storms is the function of hydraulic parameters and can be calculated by either WSPRO or HEC-RAS.

For the clear water scour, the maximum scour occurs when the shear stress reduces to the critical shear stress of the bed material in the section. **Clear-water contraction scour** is calculated based on the equation developed by Laursen [*15*]:

$$y_2 = \left[\frac{K_u Q^2}{D_m^2 W^2} \right]^{\frac{3}{7}} \qquad (2)$$

$y_s = y_2 - y_o$ = (average contraction scour depth)

where,
y_2 = Average equilibrium depth in the contracted section after contraction scour, ft.;
Q = Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W, ft^3/s;
D_m = Diameter of the smallest non-transportable particle in the bed material ($1.25D_{50}$) in the contracted section, ft.;
D_{50} = Median diameter of bed material, ft.;
W = Bottom width of the contracted section less pier widths, ft.;
y_o = Average existing depth in the contracted section, ft.;
K_u = 0.025 SI units; and
K_u = 0.0077 English units.

For an existing bridge, the streambed soil conditions and pier dimension are approximately constant; therefore, the ratio of scour depths under different storms is the function of hydraulic parameters only [equation (3)] and can be calculated by either WSPRO or HEC-RAS.

$$\frac{(y_1)_1}{(y_2)_{12}} = \left(\frac{Q_2^2 W_1^2}{Q_1^2 W_2^2} \right)^{\frac{3}{7}} \qquad (3)$$

Local scour at piers is a function of bed material characteristics, bed configuration, flow characteristics, fluid properties, and the geometry of the pier and footing. **Local pier scour** can be calculated by the equation developed by Richardson and Davis [*1*]:

$$\frac{y_s}{a} = 2.0K_1K_2K_3K_4\left(\frac{y_1}{a}\right)^{0.35} Fr_1^{0.43} \qquad (4)$$

where,

y_s = Scour depth, ft.;

y_1 = Flow depth directly upstream of the pier, ft.;

K_1 = Correction factor for pier nose shape;

K_2 = Correction factor for angle of attack of flow;

K_3 = Correction factor for bed condition;

K_4 = Correction factor for armoring by bed material size;

a = Pier width, ft.;

L = Length of pier, ft.;

Fr_1 = Froude Number directly upstream of the pier = $V_1/(gy_1)^{1/2}$;

V_1 = Mean velocity of flow directly upstream of the pier, ft/s; and

g = Acceleration of gravity (32.2 ft/s^2).

For an existing bridge, the stream bed soil conditions and pier dimension are approximately constant; therefore, the ratio of scour depths for different storms is the function of hydraulic parameters only [equation (5)] and can be calculated by either WSPRO or HEC-RAS.

$$\frac{y_{s1}}{y_{s2}} = \left(\frac{y_1}{y_2}\right)^{0.35}\left(\frac{Fr_1}{Fr_2}\right)^{0.43} \qquad (5)$$

SRICOS-EFA Method. SRICOS stands for Scour Rate In Cohesive Soil; the SRICOS method is a new method proposed in 1999 to predict the scour depth z versus t curve around a cylindrical bridge pier of diameter D for a constant velocity flow, uniform soil, and water depth greater than two times the pier diameter both in clay and sand. This method is based on the calculation of two basic parameters: the maximum depth of pier scour and the initial rate of scour. The maximum depth of scour is based on an equation obtained from flume tests and the initial rate is based on an equation giving the initial shear stress obtained from numerical simulations. The initial rate of scour is read on the EFA erosion function at the corresponding value of the calculated initial shear stress.

The HEC-18 and HEC-20 gives the bridge scours by equation (4), which is based on model scale experiments in sand and has recently evaluated against full-scale observations for 56 bridges founded primarily on sand [*16*]. No guidance in HEC-18 gives to calculate the rate of scour in clay and it is implicit that equation (4) should also be used for the final depth of scour for bridges on clay. Common sense tells us that clays scour much more slowly than sand and using equation (4) for clays regardless of time appears to be overly conservative and therefore expensive.

The scour rate $\dot{z}$ is established to describe the scour depth versus time t; this scour rate is rapid in sand, slow in clay, and extremely in rack. The scour rate $\dot{z}$ versus shear stress τ curve is used to quantify the scour rate of a soil as a function of the flow velocity in a stream. Several researchers have measured the rate of erosion in cohesive soils; most have proposed a straight line, while some have found "S" shape curves. This "S" shape would indicate that different physical phenomena take place as the water velocity increases.

The scour process is highly dependent on the shear stress τ developed by the flowing water at the soil-water interface. The present study found that for large water depth, τ_{max} was dependent on the Reynold's number *R*, the mean flow velocity *V*, and the mass density of water ρ:

$$\tau_{max} = 0.094 \rho V^2 \left(\frac{1}{\log R} - \frac{1}{10} \right) \tag{6}$$

where,
R is defined as VD/ν;
V = mean flow velocity, m/s;
D = pier diameter, m; and
ν = the kinematic viscosity of water (1026 m^2/s at 20^{o}C), m^2/s.

If this value of τ_{max} is greater than the critical shear stress τ_c that the soil can resist, scour is initiated (Figure 22). As the scour hole deepens around the cylinder, the shear stress at the bottom of the hole decreases. A profile of the shear stress at the bottom of the scour hole τ_{bot} as a function of the depth of the scour hole can then be determined, using the same numerical analysis. Once the scour hole becomes deep enough, τ_{bot} becomes equal to τ_c (the critical shear stress for the soil), the soil stops scouring, and the final depth of scour z_{max} is reached.

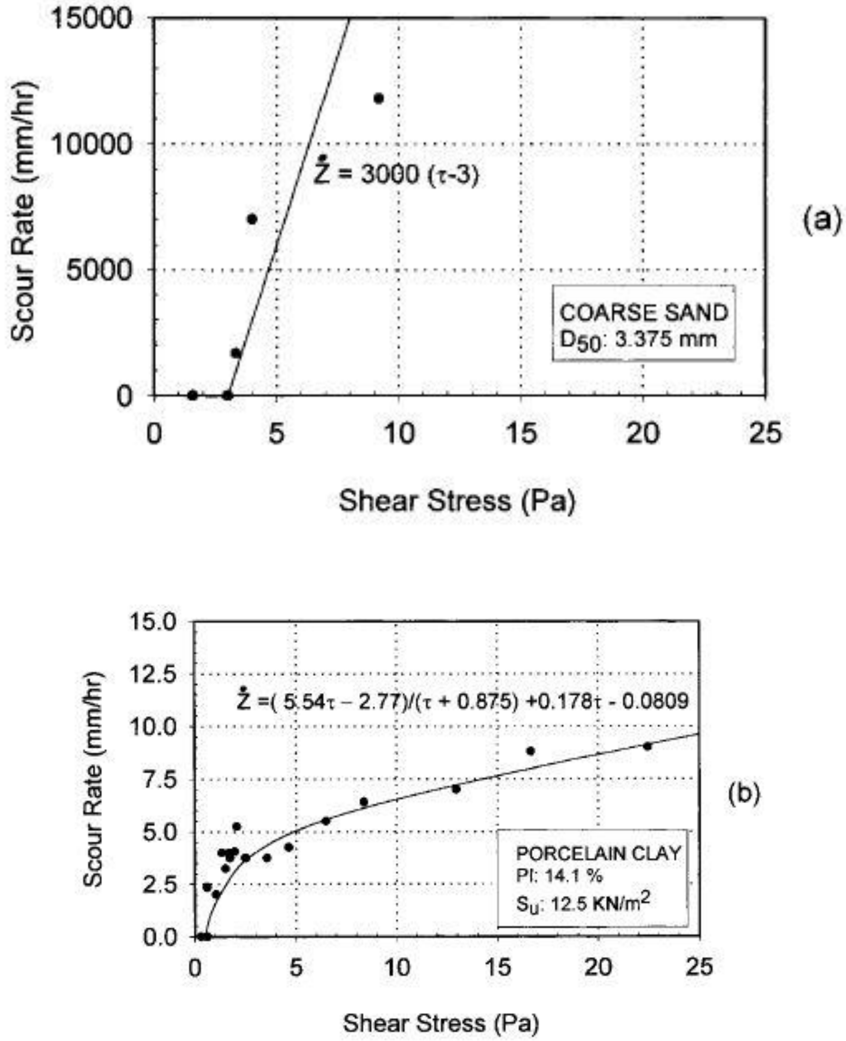


Figure 22

Shear stress and scour rate curve for a sand and a clay

SRICOS-EFA Method for Cylindrical Piers in Deep Water. For a given velocity hydrograph at a bridge, a given soil exhibiting a multilayered stratigraphy with an erosion function defined for each layer and a given cylindrical pier in deep water (water depth larger than 1.6 times the pier diameter), the SRICOS-EFA Method (program) gives the scour depth as a function of time for the period covered by the hydrograph. A hyperbola is used to connect the initial scour rate to the maximum or asymptotic scour depth and describes the complete scour-depth-versus-time curve. Robust algorithms are used to incorporate the effect of varying velocities and multilayered soil systems. This earlier method was developed by the authors under a TxDOT sponsorship and was verified by satisfactory comparison between predicted scour and measured scour at eight bridges in Texas. The scour depth *z* is given as:

$$Z = \frac{t}{\frac{1}{\dot{z}_i} + \frac{t}{z_{\max}}} \quad (7)$$

This hyperbolic equation was chosen because it fits the curves obtained in the flume tests well. Once the duration *t* of the flood to be simulated is known, the corresponding *z* value is calculated using equation (7). If *z* is large, as it is in clean fine sands, then *z* is close to z_{max} even for small *t* values. But if *z* is small, as it can be in clays, then *z* may only be a small fraction of z_{max}.

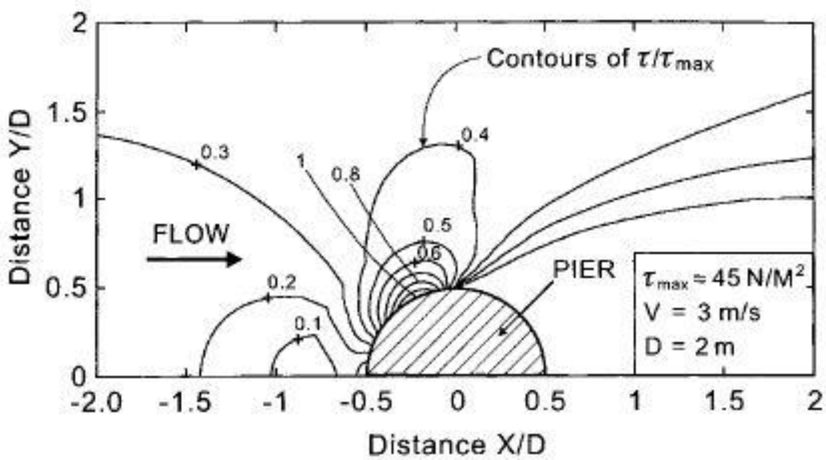


Figure 23
Maximum shear stress around a cylindrical pier

SRICOS-EFA Method for Maximum Scour Depth at Complex Piers. To study the maximum depth of scour for a pier, a set of flume experiments was conducted including the effects of shallow water depth, rectangular shapes, the angle of attack on rectangular shapes, and spacing between piers positioned in a row perpendicular to the flow. The proposed equation for the maximum depth of scour is in the form of the equation for the cylindrical pier in deep water with correction factors based on the results of the flume tests:

$$Z_{\max}(pier) = 0.18 k_w k_{sp} k_{sh} R_e^{0.635} \quad (8)$$

where,

Z_{max} (pier) = the maximum depth of pier scour, mm;

R_e = the Reynolds number equal to VB/ν;

V = the mean depth velocity at the location of the pier if the bridge is not there, m/s;

ν = the water viscosity, 1026 m^2/s; and

The *k* factors take the shallow water depth, spacing, and shape into account.

SRICOS-EFA Method for Initial Scour Rate at Complex Piers. The proposed equation for calculating the maximum shear stress for a complex pier before the scour process starts is

$$\tau_{\max} = k_w k_{sp} k_{sh} k_a \bullet 0.094 \rho V^2 \left[\frac{1}{\log R_e} - \frac{1}{10} \right] \tag{9}$$

where,

ρ is the density of water, kg/m^3;

R_e is the Reynolds Number, defined as $R_e = VB/\nu$,

ν is the kinematic viscosity, 1026 m^2/s

B is the pier width, m;

H is the water depth, m;

V is the upstream velocity, m/s;

k_w is the correction factor for the effect of water depth,

k_{sp} is the correction factor for the effect of pier spacing,

k_{sh} is the correction factor for the effect of pier shape, and

k_a is the correction factor for the effect of attack angle.

SRICOS-EFA Method for Maximum Contraction Scour Depth. A set of flume experiments was conducted to study the depth of scour associated with the contraction of a channel, including the effects of the ratio of the contracted channel width over the approach channel width, contracted channel length, and transition angle. The proposed equation for the maximum depth of contraction scour is

$$Z_{\max}(Cont) = 1.90 K_\theta K_L H_1 \left(\frac{1.49 V_{hec}}{\sqrt{g H_1}} - \frac{\left(\frac{\tau_c}{\rho} \right)^{0.5}}{g n H_1^{1/3}} \right) \geq 0 \tag{10}$$

where,

$Z_{\max}(Cont)$ = the maximum depth of contraction scour, m;

H_1 = the water depth along the center line of the non-contracted channel after scour has occurred, m;

V_{hec} = the mean depth water velocity at the location of the pier in the contracted channel, m/s;

τ_c = the critical shear stress of the soil, kPa;

ρ = the mass density of water, kg/m^3;

g = the acceleration due to gravity, m/s^2;

n = the Manning's Coefficient; and

The K factors take the transition and contracted channel length into account.

The FLDOT Method. (a) Local scour at a single pile—The Florida Department of Transportation developed a bridge scour prediction manual based on the HEC-18 and HEC-20.The equation to predict local scour depth for single pile structure were developed by Dr. Sheppard and his students at the University of Florida. These equations were first published in 1995, and have been modified and updated over the years as more laboratory data became available [*13*]. As the flow field in the immediate vicinity of a structure is quite complex, even for simple structure such as circular piles, the formation of secondary flows in the form of vortices is believed as one of the dominant features of the local flow field.

Equilibrium local scour depth depends on a number of fluid, sediment, and structure parameters, and can be expressed mathematically as:

$$y_s \equiv f\left(\rho, \mu, g, D_{50}, \sigma, \rho_s, y_0, V, D^*, \Theta\right) \tag{11}$$

where,

y_s = the equilibrium scour depth (maximum local scour depth after the flow duration that the depth is no longer changing), ft;

f = symbol meaning “function”;

ρ and ρ_s = density of water and sediment, lb/ft^3, respectively;

μ = dynamic viscosity of water (depends primarily on temperature), ft^2/s;

g = acceleration of gravity, ft/s^2;

D_{50} = median diameter of the sediment, ft;

σ = gradation of sediment, ft;

y_o = depth of flow upstream of the structure, ft;

V = depth average velocity upstream of the structure, ft/s;

D^*= effective diameter of structure (ft), i.e. the diameter of circular pile that would experience the same scour depth as the structure for the same sediment and flow conditions. For a circular pile D^* is simply the diameter of the pile; and

Θ = parameter quantifying the concentration of fine sediments in suspension, %.

Based on the importance of the Froude Number in open channel flows, a wide variety of groups and combinations of groups have been proposed over the years, and researchers found that the parameters in equation (11) can describe equilibrium scour depths for a wide range of conditions, an can be expressed as:

$$\frac{y_s}{D^*} = f\left(\frac{y_0}{D^*}, \frac{V}{V_c}, \frac{D^*}{D_{50}}, \sigma, \Theta\right) \tag{12}$$

In the clear water scour range ($0.47 < V/V_c < 1$)

$$\frac{y_s}{D^*} = 2.5\tanh\left[\left(\frac{y_0}{D^*}\right)^{0.4}\right]\left\{1-1.75\left[\ln\left(\frac{V}{V_c}\right)\right]^2\right\}\left[\frac{D^*/D_{50}}{0.4\left(D^*/D_{50}\right)^{1.2}+10.6\left(D^*/D_{50}\right)^{-0.18}}\right] \quad (13)$$

In the live-bed scour range up to the live-bed peak ($1 < V/V_c < V_{lp}/V_c$)

$$\frac{y_s}{D^*} = \tanh\left[\left(\frac{y_0}{D^*}\right)^{0.4}\right]\left\{2.2\left(\frac{\frac{V}{V_c}-1}{\frac{V_{lp}}{V_c}-1}\right)+2.5\left[\frac{D^*/D_{50}}{0.4\left(D^*/D_{50}\right)^{1.2}+10.6\left(D^*/D_{50}\right)^{-0.18}}\right]\left(\frac{\frac{V_{lp}}{V_c}-V/V_c}{\frac{V_{lp}}{V_c}-1}\right)\right\} \quad (14)$$

In the live-bed scour range above the live-bed peak ($V/V_c > V_{lp}/V_c$)

$$\frac{y_s}{D^*} = 2.5\tanh\left[\left(\frac{y_0}{D^*}\right)^{0.4}\right] \quad (15)$$

(b) Local Scour at Complex Piers- The prediction of local scour at complex piers based on the assumption that a complex pier can be represented (for the purpose of scour depth estimate) by a single circular pile with an "effective diameter" denoted by D^*.The magnitude of D^* is such that the scour depth at a circular pile with this diameter is the same as the scour depth at the complex pier for the same sediment and flow conditions. The problem of computing equilibrium scour depth at the complex pier is therefore reduced to one of determining the value of $D^*$for that pier and applying the single pile equations to this pile for the sediment and flow conditions of interest.

The total D^* for the structure can be approximated by the sum of the effective diameters of the components making up the structure;

$$D^* \equiv D^*_{col} + D^*_{pc} + D^*_{pg} \quad (16)$$

where,
D^* = effective diameter of the complex pier, ft;
D^*_{col} = effective diameter of the column, ft;
D^*_{pc} = effective diameter of the pile cap, ft;
D^*_{pg} = effective diameter of the pile group, ft.
.

where,

$$D_{col}^{*} = K_s K_\alpha K_f b_{col}\left[0.1162\left(\frac{H_{col}}{y_{0(\max)}}\right)^2 - 0.3617\left(\frac{H_{col}}{y_{0(\max)}}\right) + 0.2467\right], \text{ for } 0 \le \frac{H_{col}}{y_{0(\max)}} \le 1$$

$$D_{col}^{*} = 0, \text{ for } \frac{H_{col}}{y_{0(\max)}} > 1 \qquad (17)$$

$$D_{pc}^{*} = K_s K_\alpha b_{col} \exp\left[-1.04 - 1.77\exp\left(\frac{H_{pc}}{y_{0(\max)}}\right) + 1.695\left(\frac{T}{y_{0(\max)}}\right)^{\frac{1}{2}}\right] \qquad (18)$$

$$D_{pg}^{*} = K_{sp} K_h K_m K_s W_p \qquad (19)$$

where,
K_s = shape factor;
K_α = flow skew angle coefficient;
K_f = pile cap extension coefficient;
b_{col} = column width, ft;
H_{col} = distance between the bed and the bottom of the column, ft;
$y_{0(max)}$ = limiting value for the effective diameter calculation, ft;
b_{pc} = pile cap width, ft;
H_{pc} = distance between the bed and the bottom of the pile cap, ft;
T = pile cap thickness, ft;
K_{sp} = pile spacing coefficient,
K_h = coefficient that accounts for the height of the pile group above the adjusted bed,
K_m = number of piles in the direction of the unskewed flow; and
W_p = projected width of the piles in the pile group, ft.
The *K*-series coefficients are influenced by the external dimension of all components and their vertical positions relative to the pre-local scoured bed.

Hydrometeorological Analysis

Introduction

The basis of the hydrometeorological analysis is comprised of three main components: basin model derivation, satellite precipitation estimation, and HEC-HMS model execution (Figure 24). The first step requires the use of a variety of geophysical data within a GIS environment. The second stage involves utilizing of Geostationary Operational Environmental Satellite (GOES) satellite imagery along with quantitative procedures for estimating rainfall for a designated region and time period. Lastly, a successful model run involves inputting results from the previous two stages into USACE HEC-HMS software and determining the appropriate model parameters and making the necessary adjustments as needed within the modeling software.

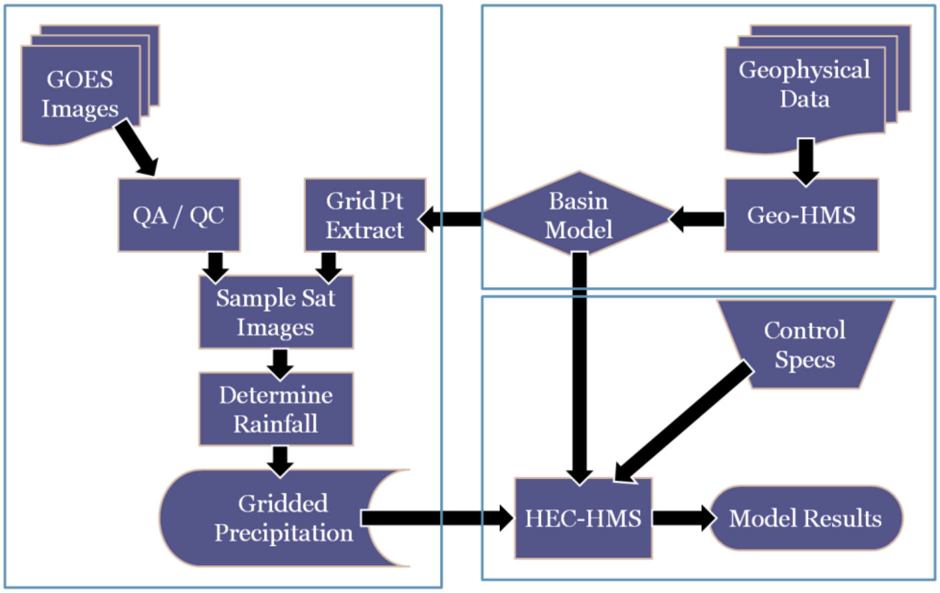


Figure 24

Overview of the flow of information throughout the hydrometeorological analysis

Basin Hydrologic Model Derivation

In this stage of the study, it is necessary to utilize data from a variety of sources and forms of geophysical data. The primary data components include a digital elevation model, land use, hydrographs, and soil information. Other related geospatial data used in the analysis include political boundaries and road network information.

This data is then processed using the functionality of ESRI's ArcGIS software and the USACE HEC-GeoHMS extension software. HEC-GeoHMS takes as input the appropriate geophysical data and through a series of GIS procedures produces a hydrologic model representative of the flow of water runoff within the targeted watershed. This model network is outputted in a format that is easily imported into HEC-HMS for further modeling efforts.

Satellite Precipitation Estimation

Usually, rainfall gauge records are used as the precipitation for the targeted area to calculate the discharge for a specific river. The following figure shows the gauges location of Louisiana (Figure 25). We can see from the figure that a very large part of the state does not have a gauge set up at all; this is because in some places it is difficult to build a station.

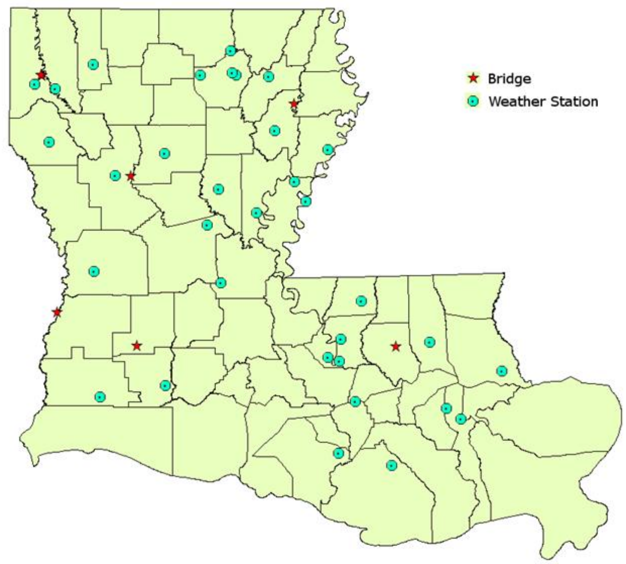


Figure 25
Rainfall gauges in Louisiana

Since the gauges are only located in limited areas, to get the precipitation value for the places with no gauges, weighted values from several nearby gauges were used, which makes the results of precipitation less precise. To increase the accuracy of the results, real-time rainfall events gained from satellite data were introduced.

Estimates of precipitation from satellite data can provide timely information about rainfall in regions where data from rain gauge networks are sparse or entirely unavailable and for which radar data are unavailable or are compromised by range effects and beam blockage. Real-time rainfall estimation using geosynchronous infrared satellite imagery has several applications in meteorology and hydrology. Precipitation estimates from satellite data are a valuable source of information for flood forecasting, weather prediction, moisture budget calculations, and numerous other applications in the hydrometeorological sciences. Although the estimates are indirect, the high frequency and high spatial resolution of the measurements, as well as the broad area that they cover, make them uniquely complementary to rain gauge and radar measurements.

High-quality estimates of the amount and spatial distribution of precipitation at various time scales are very important for a wide range of applications, such as the climatic description of rainfall over ocean areas, river forecasting, flood control, and water resource management. Accurate estimation of rainfall areas is also of great interest in numerical weather prediction studies. Satellite-based rainfall rate estimates are available every 15 minutes at a 4-km spatial resolution over North America and thus can provide assistance in the detection of flash flood and precipitation area in real time.

To apply the rainfall data directly from satellite IR imagery is really difficult; the most important reason is the difficulty in distinguishing between precipitating and non-precipitating clouds. Several computational techniques have been developed to improve the estimated rain rate by adjusting the satellite data for atmospheric (sub-cloud) conditions, cloud growth characteristics, and cloud particle size. These include the Automated Satellite Rainfall Rate Estimation technique (auto-estimator or AE); the GOES Multispectral Rainfall Algorithm (GMRSA), and the Self-Calibrating Multivariate Precipitation Retrieval Algorithm (SCaMPER) [*17*] [*18*] [*19*].

The auto-estimator technique described by Vicente uses GOES cloud-top temperature to estimate the rainfall rate based on the assumption that clouds with cold tops in the *IR* imagery produce more rainfall than those with warmer tops. Since rain tends to be a discontinuous variable, the correct computation of the estimates depends not only on the accurate determination of the instantaneous rainfall rates for every pixel, but also on the effective screening of the non-raining pixels.

The auto-estimator initially computes rainfall rates based on a nonlinear, power-law regression relationship between cloud-top temperature (10.7-μm brightness temperature) and radar-derived rainfall estimates. The auto-estimator uses National Centers for Environmental Prediction (NCEP) Eta Model–generated relative humidity (RH) and precipitable water (PW) to analyze the environmental moisture and scale the rainfall amounts accordingly. In that case, half-hourly satellite IR images are used to indicate a vertically growing and decaying cloud system, and a finite difference analysis of the cloud-top temperature on a single IR image is used as a gradient correction factor. Previously, Adler and Negri used the application of spatial gradient analyses to remove thin, non-precipitating cirrus cloud in the development of the convective stratiform technique [*20*].

Pairs of GOES-12 IR images of 4-km resolution and allocated instantaneous radar rainfall estimates from the U.S. operational network of 5- and 10-cm radar (WSR-57S, WSR-74C, WSRFS-88D) in the central Great Plains and the areas adjacent to the Gulf of Mexico were used to compute the relationship between the rainfall rate and cloud-top temperature. The following figure shows the relationship between the rainfall rate and temperature (Figure 26).

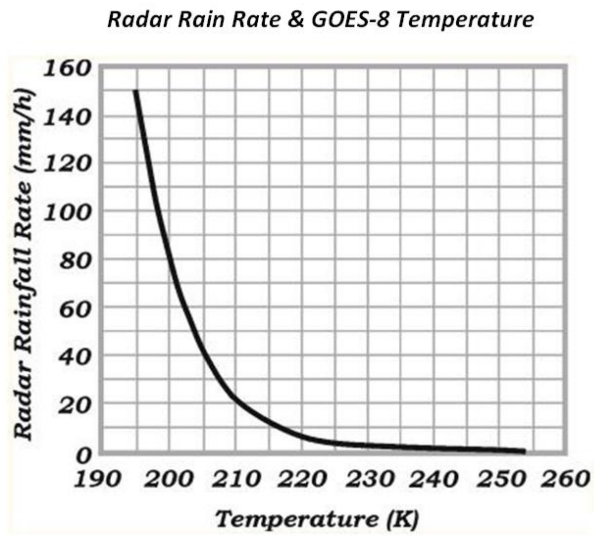


Figure 26
Power-law fit between radar-derived rainfall estimates and cloud-top temperature [*17*]

The major challenge in estimating rainfall rate using IR measurements is to distinguish non-precipitating cirrus from active cold convective clouds. To remove cirrus clouds, an empirical procedure developed by Adler and Negri was adapted for areas smaller than originally applied, and a slope (S) and a temperature gradient (G_t) are computed for each local temperature minimum in a window of all GOES pixels [*20*].

The application of geosynchronous infrared satellite imagery used to estimate the surface precipitation is based on the basic but important factor that clouds with cold tops in the IR imagery produce more rainfall than those with warmer tops [*21*, *22*]. The data used in this case are satellite data from GOES-12, from channel4-the infrared channel (10.7µm). The original satellite images were collected during the days from the largest four rainfall events during the past ten years, hourly.

Cloud-top temperature based rainfall estimates were computed using a 4-km resolution, and the results were given by Vicente et al. [*17*]:

$$R = 4.4027 \times 10^{9} \exp\left[-3.6382 \times 10^{-2} (T + 273.16)^{1.2}\right] \qquad (20)$$

where,
R is rainfall rate in in/hr, and
T is cloud-top brightness temperature Celsius.

Although satellite-based estimates of rainfall rate may have uncertainties and need to be adjusted before use, they are improving with time and can be used to estimate the rainfall amount of an area without gauges after a series of corrections already bringing benefits to the practice and research.

Bridge Scour Analysis: An Example Analysis

This section presents a detailed bridge scour analysis as an example to show the process of determining the scour depth from the satellite remotely sensed cloud top temperature. The Mermentau River Bridge was chosen to fulfill this purpose (Figure 27). For the rest six selected bridges, only the results are shown in the next section.

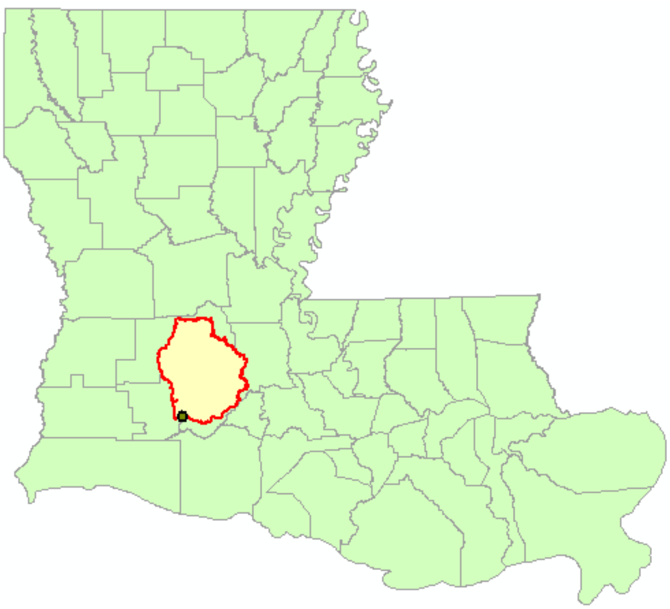


Figure 27
Location of Mermentau Bridge on US-90, Mermentau River at Mermentau, LA

Once a bridge with appropriate soil conditions was selected, it was necessary to obtain the required geophysical data representative of the region. Elevation data was obtained online from the National Map Seamless Server (http://seamless.usgs.gov) managed by the U.S. Geological Survey (USGS). This results in a digital elevation model (DEM) file, which is a simple, regularly spaced grid of elevation points. DEM is a digital model or 3-D representation of a terrain's surface that is created from terrain elevation data. The quality of a DEM is a measure of how accurate the elevation is at each pixel (absolute accuracy) and how accurate the morphology presented (relative accuracy) is at the same pixel. Several factors play important roles for the quality of DEM-derived products:

- terrain roughness;
- sampling density (elevation data collection method);
- grid resolution or pixel size;
- interpolation algorithm;
- vertical resolution; and
- terrain analysis algorithm.

In this study, the data consisted of a DEM with a spatial resolution of 10 meters. Information regarding the land use in the region of interest was also obtained from the USGS seamless server. Land use refers to the human activities that are directly related to the land, and the interpretations are based on a land use and land cover system developed for use with remotely sensed data. Land cover describes the vegetation, water, natural surface, and manmade features of the land. Land use and land cover areas are classified into nine major categories: urban or built-up land, agricultural, rangeland, forest, water areas, wetland, barren land, tundra, and perennial snow or ice. Each general class is subdivided into several detailed level-2 classes. In this project, this information was specified by the USGS 2001 Land Cover data.

The other two main data sources necessary to use with HEC-GeoHMS are hydrography and soil data. The flow line or stream network was available online from the National Hydrography Dataset (http://nhd.usgs.gov). Soil data was available online from the SSURGO Soil Database (http://soildatamart.nrcs.usda.gov). The national hydrography dataset provides hydrographic data for the United States. The flow-line feature class in the national hydrography dataset (NHD) is the fundamental flow network consisting predominantly of stream/river and artificial path vector features (Figure 28). It represents the spatial geometry, carries the attributes, models the water flow, and contains linear referencing measures for locating events on the network. Additional NHD flowline features are canal/ditch, pipeline, connector, underground conduit, and coastline. These data help to develop and analyze the surface water system of aimed area and location.

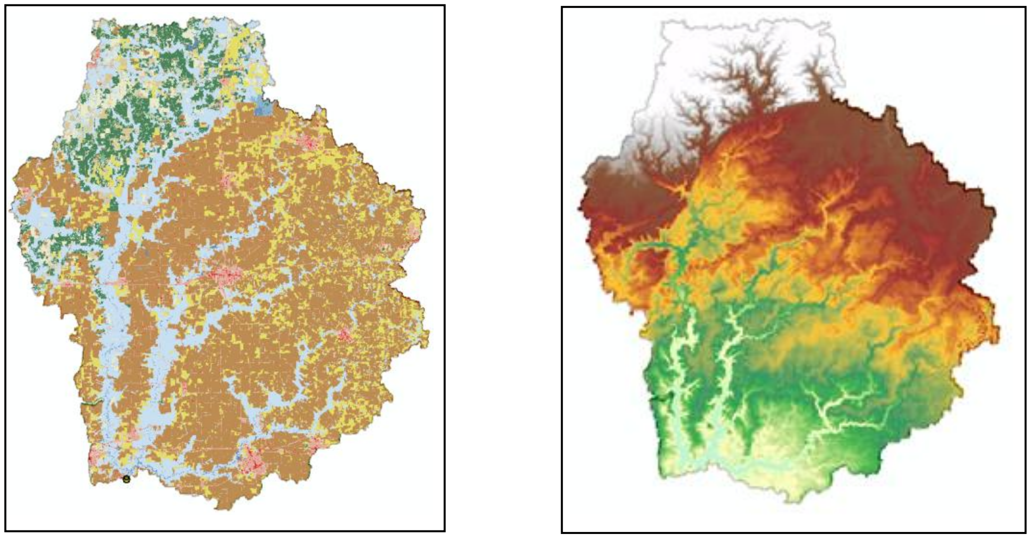


Figure 28
Geophysical data of Mermentau Bridge: land cover (left) and 10 m DEM (right)

The soil survey data is a detailed report on the soil types of a specific area, which is a map of soil boundary, descriptions, and tables of soil properties and features. The major parts of a soil survey data report include a table of contents, detailed soil map units, a use and management and interpretive table, classification of soils, an index to map sheet, and a soil map. All these kinds of information provide necessary soil properties for modeling the target area (Figure 29).

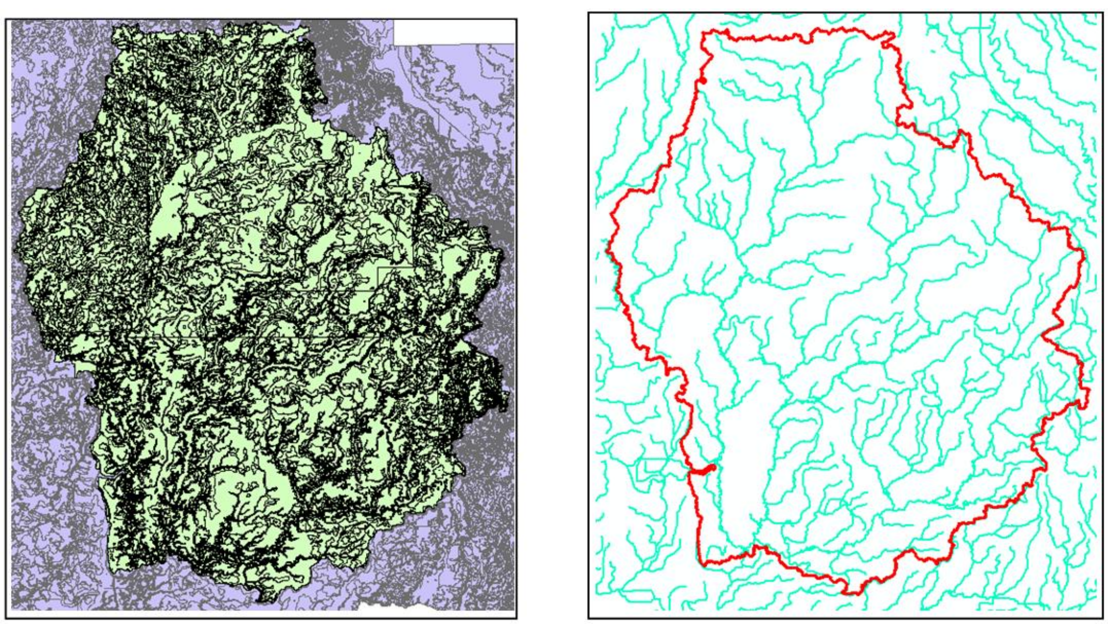


Figure 29
Soil survey data (left) and hydrography (right) from USGS

During watershed and stream network delineation, there are several intermediate data sets that are derived to facilitate further processing, including such characteristics as flow direction and accumulation, stream definition and segmentation, and watershed processing. These gridded data help to create and define the stream elements of the surface water system in the study area. Another such gridded dataset created during the extensive terrain and watershed processing utilizing HEC-GeoHMS is the SCS curve number grid, which represents the flow characteristics by many hydrologic models to extract the curve number for watersheds within the study region (Figure 30).

The output from HEC-GeoHMS produces a network schematic representative of the primary hydrologic flow with various input nodes and junctions (Figure 31). The network is formatted in a manner that provides an easy method of inputting the model into the HEC-HMS software. At this stage, it is necessary to generate the rainfall estimates that will be input into HEC-HMS during a run of model.

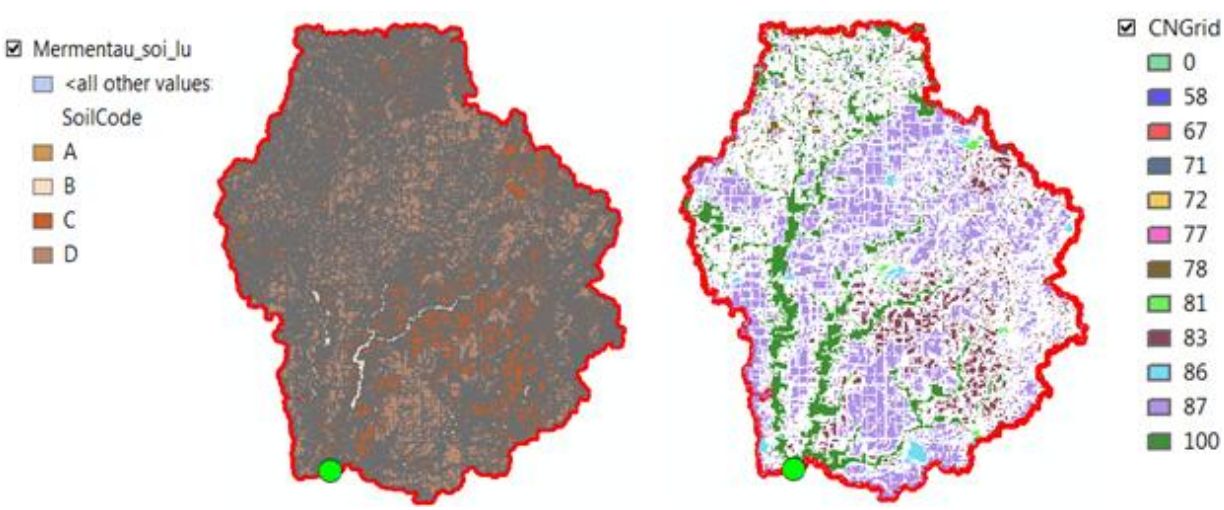


Figure 30
Merged land use soil (left) and SCS curve number grid (right)

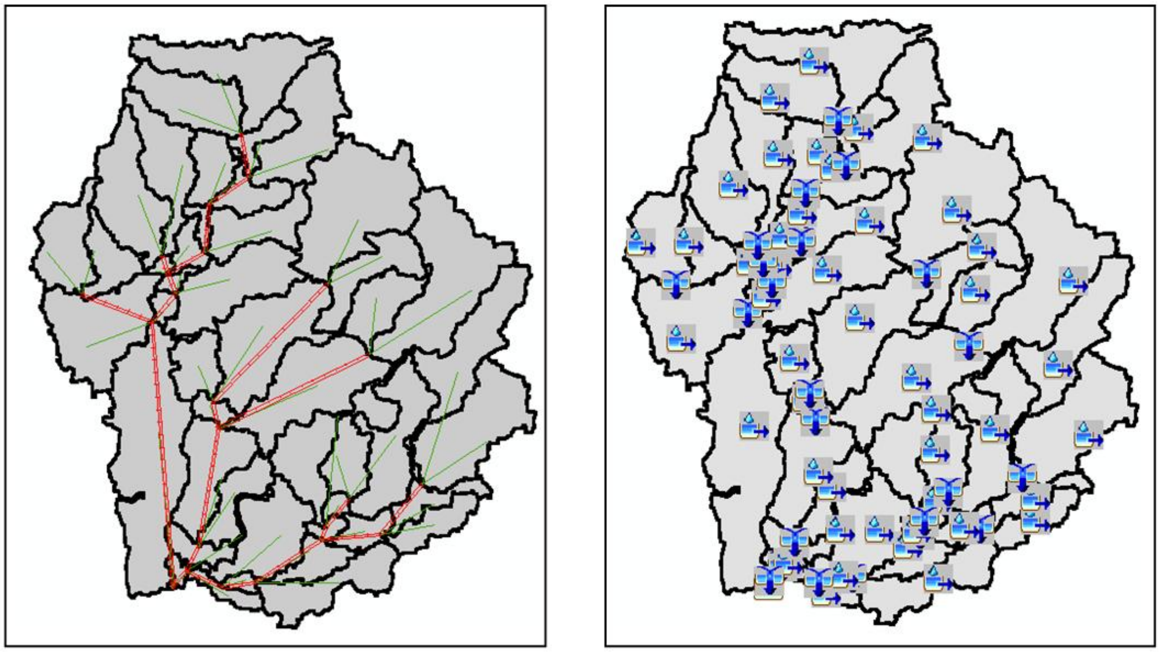


Figure 31
Geo-HMS output network (left) and HEC-HMS model schematic (right)

Preliminary Satellite Rainfall Estimates
The second major component in the hydrometeorological analysis is the derivation of the rainfall data. These preliminary estimates were generated for the basin region designated by the output of the HEC-GeoHMS software (Figure 32).

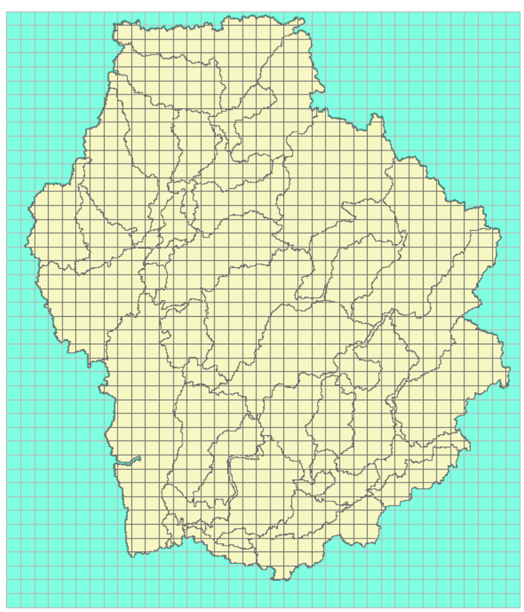


Figure 32
A 4-km grid situated over the basin region of the Mermentau Bridge

The region of interest was divided into 4-km grid cell sizes resulting in 504 cells or sample points (18 rows x 28 columns). The 4-km cell size was chosen since it is the same spatial resolution of the GOES satellite imagery used in this aspect of the study. Cloud top temperatures (CTT) obtained from channel-4 infrared GOES satellite imagery has been found to correlate with rainfall [*17*]. Utilizing a methodology similar to Vicente, actual rainfall estimates can be approximated. For this analysis of the Mermentau River Bridge, the time period covered May 11, 2004 until May 20, 2004, and images were acquired in 1-hour intervals. This time frame was chosen arbitrarily although it was based on the availability of GOES imagery from LSU Earth Scan Laboratory archives as well as archived measured rainfall available from the National Climatic Data Center, http://www.ncdc.noaa.gov. Accumulated rainfall estimates can be seen for this time frame in Figure 33. The top chart in Figure 33 shows volumetric basin-wide total precipitation (crosses) and the three-day running mean value (solid red line). Gauge height and discharge data were obtained from the National Water Information System, http://waterdata.usgs.gov/nwis. Data presented here is from USGS NWIS Station #08015500. Although estimates appear to be in relative agreement with measured daily stream flow gauge data, further calibration is required to improve rainfall estimates in all seasons. It appears as though in the summer time increased rainfall estimates do not correlate well with discharge values. This could be a result of the amount of evapotranspiration occurring during the warmer months.

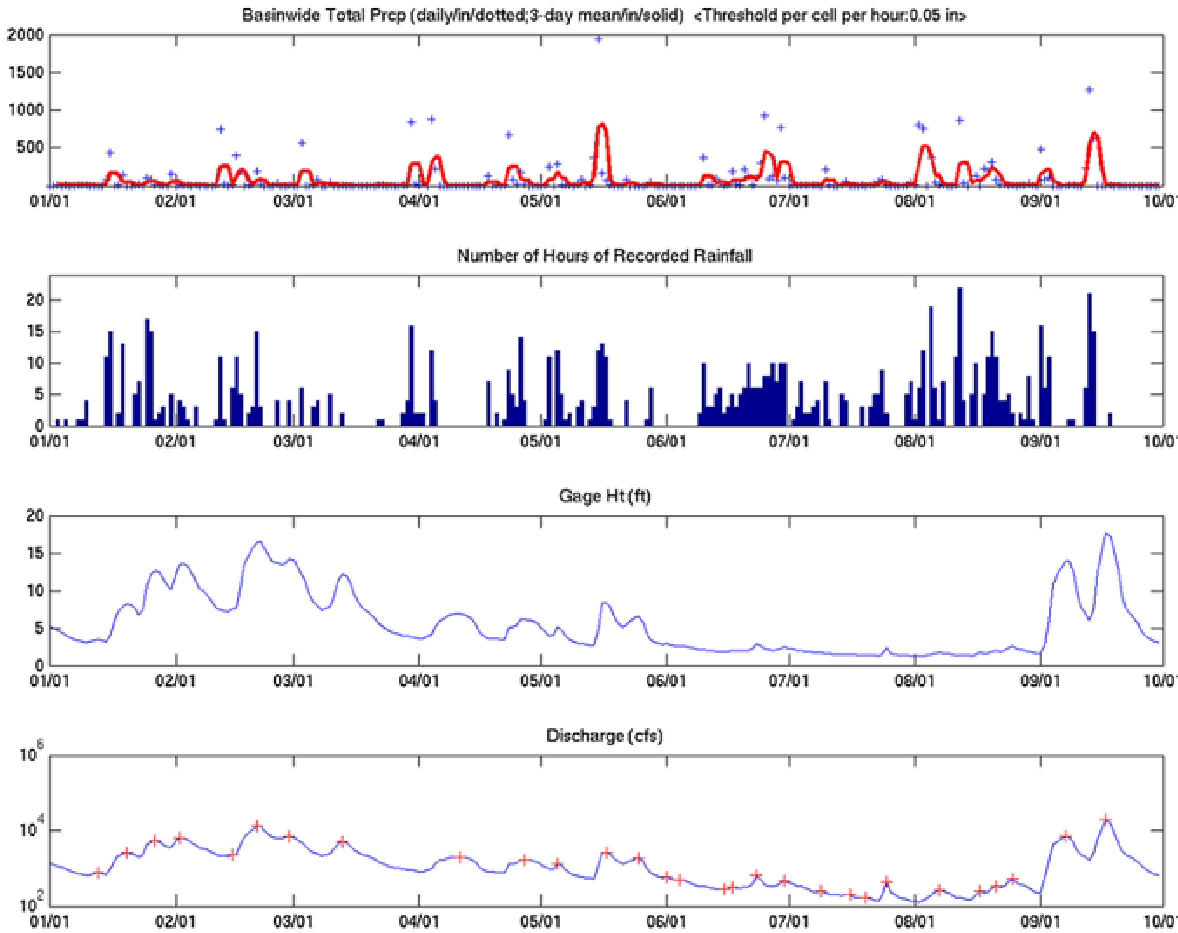


Figure 33
Estimated basin-wide total precipitation (top) along with gauge height (near-bottom) and discharge data (bottom)

Rainfall Events Defined for Research

CTT obtained from channel-4 infrared GOES satellite imagery has been found to correlate with rainfall [*17*]. Utilizing a methodology similar to Vicente et al., actual rainfall estimates can be approximated. For this project, the time period chosen for analysis is shown in Table 9, and images were acquired in 1-hour intervals. This time frame was chosen arbitrarily although it was based on the availability of GOES imagery from LSU Earth Scan Laboratory archives as well as archived measured rainfall available from the National Climatic Data Center, http://www.ncdc.noaa.gov and http://waterdata.usgs.gov.

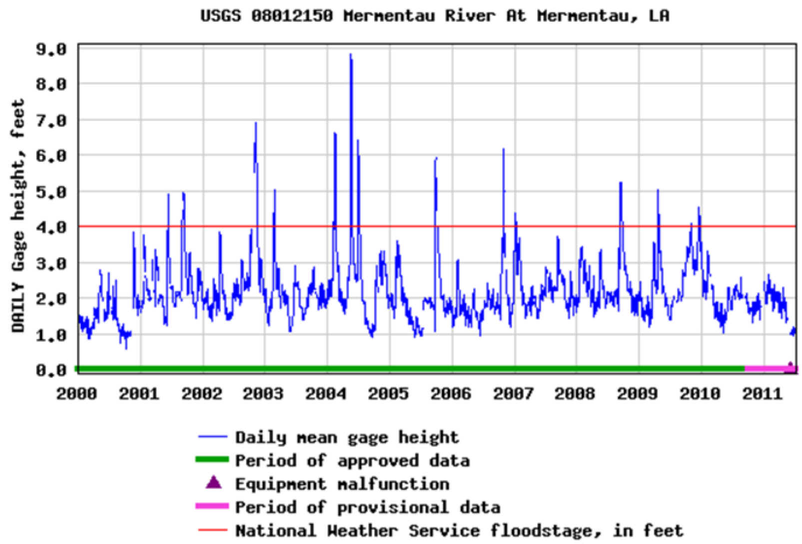
The LSU Earth Scan Lab has archived the cloud top temperature data since 1995 (i.e., with more than 15 years of data). This dataset should contain all large rainfall and storm events during this period. To isolate and identify those large rainfall events from the small ones, the USGS data were used to assist in the selection of the largest rainfall events in the period of archived data. In principle, large precipitation can substantially influence the river water surface elevation and flow velocity, and hence cause obvious riverbed elevation change (i.e., scour). USGS surface water data includes more than 850,000 station years of time-series data that describe stream levels, stream flow (discharge), reservoir and lake levels, surface-water quality, and rainfall. These values are summarized from time-series data for each day for the period of record and may represent the daily mean, median, maximum, minimum, and/or other derived value. A site name and location are used to identify the closest river gauge, which has water surface elevation and discharge records for the past 10 years.

For the Mermentau Bridge, the USGS Station# 08012150 records the daily gauge height (or water depth) and daily discharge (i.e., flow rate). The results are shown in Figure 34. Using these two charts, the time range of the largest rainfall event in this bridge's upstream watershed can be derived. For example, for this bridge site, the maximum rainfall event was identified during 05/11/2004 to 05/20/2004. Again, due to sparsity of the USGS surface water gauges, the data from this station is accurate only for that specific location, but may not be applicable to the entire basin of the bridge. To further validate whether there were large storms or rainfall events occurring on the above identified period, weather stations and forecast data were checked.

The identified time period of the largest flood or rainfall events was used to specify the specific time period used to retrieve the GOES satellite imagery data of that period for more accurate rainfall data distribution over the entire watershed, which were then used as input for the HEC-HMS hydrologic analysis.

Table 9 summarizes the identified largest rainfall events for the seven selected bridges. For some bridges, more than one largest rainfall event was chosen, because there were two or three peaks with equal values for the largest gauge height or the largest discharge in the USGS data. Therefore, multiple time periods were chosen for a detailed analysis to further identify the truly largest discharge at the bridge site.

Gage height, feet



Discharge, cubic feet per second

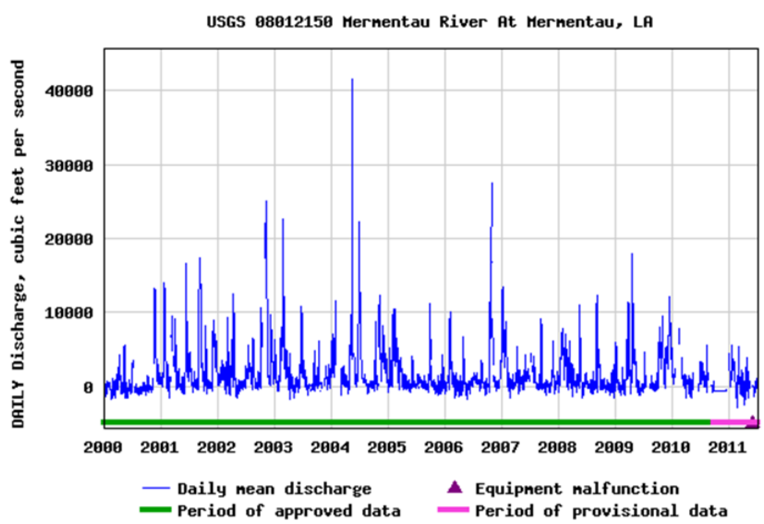


Figure 34
USGS gauge height and river discharge records at a gauge station near Mermentau River Bridge

Table 9
Summary of selected large rainfall events for the seven selected bridges

Bridge No.	Bridge name	Major soil type	Selected rainfall events
275-01-0801-1	Bogue Chitto Bridge	sand	10/25/2006-10/27/2006
			08/11/2004-08/12/2004
			04/24/2004-04/26/2004
810-12-0422-1	West Fork Calcasieu River	silty clay	09/21/2005-09/30/2005
			09/10/2008-09/20/2008
196-03-0258-1	Bayou Lacassine	silty clay	05/12/2004-05/20/2004
			02/10/2004-02/20/2004
009-05-0000-1	Saline Bayou @ St. Maurice	stiff clay	12/07/2001-12/14/2001
			11/25/2010-12/01/2010
454-02-1883-1	Tickfaw River Bridge	silty sand	02/23/2004-02/24/2004
450-04-0000-1	Bayou Nezpique at Jennings	Silty clay	11/03/2002-11/08/2002
			05/11/2004-05/18/2004
003-09-0000-1	Mermentau River @ Mermentau	gray silty clay	05/11/2004-05/20/2004

Survey Records of Scour Depth for the Studied Bridges

The analysis of the scour survey data is an extensive examination of the historical field-measured scour data in the LADOTD bridge scour database, which contains scour data for approximately 120 bridges at a monitoring frequency of one to several times per year since 1970 [*23*]. These scour data were collected on-site during scour survey, but usually at non-flooding times. The time sequence plots of the survey data versus time can also be used to roughly estimate the rate of scour (which may not be accurate, due to the discontinuity of the data series). In addition, these in-situ scour data are to be compared with the predicted scour data obtained via the HEC-18 methods.

The analysis focused on the reasons why the scour survey data do not match with the predicted scour depths by considering the soil types, bridge pier geometries, hydrological and hydraulic forcing, and other factors (e.g., special regional meteorological characteristics, flood events, riverbed meandering in addition to general scour and local scour). A particular focus of the data analysis was to examine the influence of soil type - an expected key variable for scour depth and scour rate. Several soil types have been encountered in LA bridge foundations, including sand, clayey sand, stiff clay, soft clay, and silty clay.

For the seven selected bridges, scour survey data were downloaded from the LADOTD Bridge Scour Database. The types of survey data included streambed elevations at selected points or bridge pier locations and time of the survey performed. Typically six cross-sections perpendicular to the river channel were surveyed, and these cross-sections are 18, 100, and 200 ft. upstream and downstream from the bridge deck centerline. According to the flood events selected in this study, the elevation data of the two scour surveys with their survey time spans over each selected flood event were extracted. Based on the elevation data, the change in scour depth was determined. The assumption is that those smaller flood events occurring between the two consecutive surveys will not cause a scour depth greater than the selected large flood events. This assumption is also used by the HEC-18 method.

Table 10
Scour depth from survey records on 1/6/2004 and 6/22/2004 for Mermentau Bridge

Distance from baseline (ft.)	Elevation			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	1/6/2004 (ft.)	6/22/2004 (ft.)	As-built (ft.)		
300	8	8	8	0	0
350	6	6	6	0	0
400	2.8	2.8	2.8	0	0
430	1.2	1	2	-0.2	-1
450	-1.5	0.3	1.5	1.8	-1.2
482	-3.2	-3.1	-14.5	0.1	11.4
507	-19.2	-18.7	-25.3	0.5	6.6
532	-28.2	-27.6	-33.4	0.6	5.8
557	-31.2	-30.8	-38.9	0.4	8.1
582	-32.6	-33	-40.5	-0.4	7.5
607	-35.6	-35.4	-39.2	0.2	3.8
632	-34.7	-33.9	-38	0.8	4.1
657	-35.5	-35.6	-36.4	-0.1	0.8
682	-39.8	-39.6	-34.2	0.2	-5.4
707	-35.2	-35.2	-30.8	0	-4.4
732	-27.4	-28.3	-19.6	-0.9	-8.7
757	-16	-15.8	-6.3	0.2	-9.5
782	-7.2	-7.9	-4.1	-0.7	-3.8
807	-4.4	-4.4	0.1	0	-4.5
832	-0.7	1.3	1.5	2	-0.2
847	2.7	0	2.2	**-2.7**	-2.2
860	1.2	1.2	2.8	0	-1.6
900	1.2	1.2	4.6	0	-3.4
1000	1.3	1.3	1.3	0	0

For the example analysis, the selected largest rainfall or flood event occurred on 05/11/2004 to 05/20/2004. The two consecutive surveys that cover this flood event were conducted on 1/6/2004 and 6/22/2004, respectively. As such, the elevation data from these two surveys were used to calculate the scour depth for this largest flood event. Such scour depth data were believed to be the most accurate, real scour data caused by this flood event. Table 10 shows the example calculation of the scour depth for this event. It should be noted that some scour depth data may be negative, indicating that streambed aggradation may take place at these points. Streambed aggregation is usually caused by live-bed scour, stream channel meandering, or a relatively large skew angle (the angle between channel flow direction and the bridge axis). The surveyed scour depth data will be compared with the HEC-18 data obtained using the real flood data in this study.

Hydrological Analysis

After the precipitation data were obtained, the software program HEC-HMS developed by USACE was employed for the hydrologic analysis. Proper usage of the HEC-HMS allows for an approximation of basin hydrologic flow and specific discharge characteristics for a defined point of interest (i.e., the location of selected bridge). HEC-HMS requires two primary sources of input data for the intended usage in this study. First, it is necessary to import a basin hydrologic network work, which was generated in a previous stage. Next, input about the rainfall characteristics of the region of interest must be entered. This data can come from different sources including recorded rainfall gauge data or gridded precipitation data representative of the basin characteristics. Once the rainfall data and network model have been input, fine tuning of the hydrologic model can be performed. Parameters for soil types and flow characteristics can be adjusted within the HEC-HMS as necessary.

Again, for the Mermentau Bridge used as an example, the discharge at the bridge site for the entire basin defined by this bridge using the satellite data is shown in Figure 35, while the discharge at the same watershed outlet using the USGS river gauge data is shown in Figure 36.

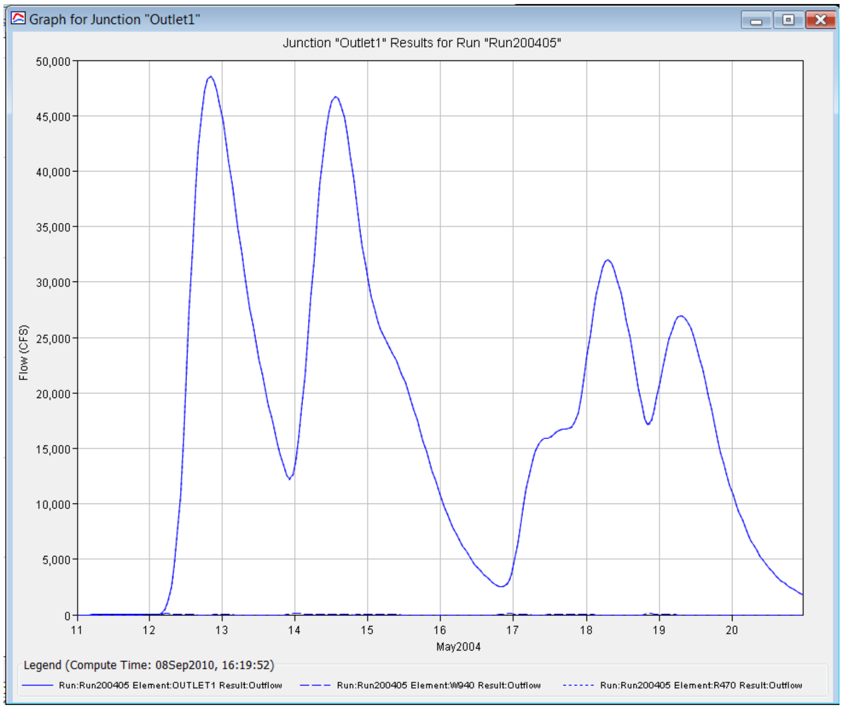


Figure 35
Discharge obtained by HEC-HMS using satellite data (Mermentau River Bridge, 05/11-20/2004)

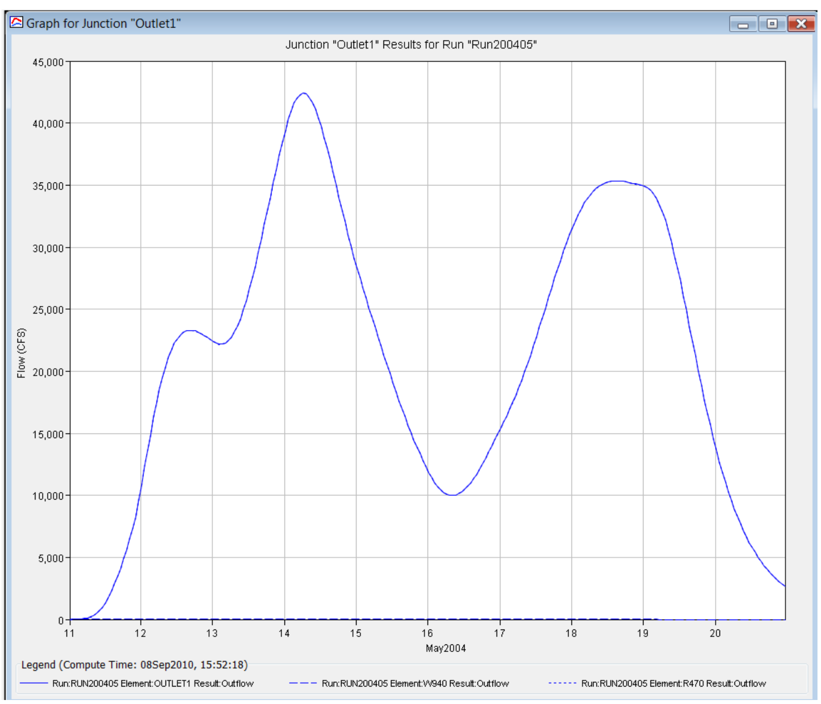


Figure 36
Discharge obtained by HEC-HMS using rainfall gauge data (Mermentau River Bridge, 05/11-20/ 2004)

It is noteworthy that discharge shown in Figure 36 was obtained from rainfall gauge data. Due to the limited number of rainfall gauges in this bridge's watershed, only the rainfall data from a nearby rainfall gauge were used. Since this rainfall data were applied as a constant value for the entire watershed, the accuracy of the discharge obtained by gauge data is questionable. Nevertheless, the maximum discharges obtained by the two different source data (i.e., gauge data vs. satellite data) are very close to 45,000 ft^3/s.

For very large precipitations, the discharges obtained from satellite cloud top temperature are usually greater than those from river gauge data. This is probably caused by the fact that the satellite data is more accurate, and the river gauge data are not very extensive for each channel or substream. However, the difference is within a reasonable range, and such a difference also can be adjusted using a series of parameters. A significant advantage is that, when there is no gauge data available in the studied watershed, the satellite data can still provide reliable data for the hydrological analysis.

Hydraulic and Scour Analyses

After the discharge data at the bridge site (flow network outlet) were obtained, the next step was to conduct the hydraulic analysis, which usually determines the flow velocity (and hence shear stress) and water surface elevation. At present, the hydraulic analysis uses the FHWA-USGS WSPRO to obtain the hydraulic variables that will be used for the subsequent analysis of scour depth development. FHWA has embedded the HEC-18 method of scour analysis into the WSPRO program. As such, the scour depth can be directly obtained from one combined step. This can also eliminate some issues involved in the data input and output interfaces between the two different analyses (i.e., hydraulic analysis and scour analysis).

For the hydraulic analysis, WSPRO requires selecting the maximum discharge (flow rate) as a key input from the studied flood event. Other input data required for this analysis include river channel morphology (such as bed profile and sloping), bridge pier locations, and other parameters. Because only one maximum discharge was used, only one maximum water surface elevation was obtained by WSPRO (Figure 37). That is, the water surface was at an elevation of 13.531 ft. at the bridge site.

The most important data from the WSPRO hydraulic analysis are the flow velocity profiles resulted from the maximum discharge. Figure 38 shows the flow velocity at the bridge site. These data were used subsequently for the HEC-18 scour analysis.

```
     *************************  W S P R O  ***************************
       Federal Highway Administration  -  U. S. Geological Survey
              Model for Water-Surface Profile Computations.
             Input Units: English  /  Output Units: English
    *----------------------------------------------------------------*
                              SCOUR RESEARCH
                             MERMENTAU RIVER
                   BRIDGE L=2031 FT. @ F.G.ELEV. 54 FT

                  << Beginning Computations for Profile  2 >>

                     WSEL     VHD       Q         AREA      SRDL      LEW
                     EGEL      HF       V           K       FLEN      REW
                     CRWS      HO     FR #         SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
 Section: EXIT       12.798   .381  48530.000  23029.190 *********      .000
 Header Type: XS     13.179 ******      2.107 3840242.00 *********  1344.472
 SRD:    1000.000   -21.052 ******       .211     ******     5.520    ******

 Section: FULV       13.119   .381  48530.000  23031.060  2000.000      .000
 Header Type: FV     13.500   .319      2.107 3840499.00  2000.000  1344.572
 SRD:    3000.000   -20.732   .000       .211      .0002     5.520      .002

        <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

 Section: APPR       13.486   .301  48530.000  23522.650  2060.000      .000
 Header Type: AS     13.787   .287      2.063 4396016.00  2060.000  1370.438
 SRD:    5060.000   -21.776   .000       .187      .0001     4.543     -.001

        <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

         <<< The Following Data Reflect The "Constricted" Profile >>>
           <<< Beginning Bridge/Culvert Hydraulic Computations >>>


                     WSEL     VHD       Q         AREA      SRDL      LEW
                     EGEL      HF       V           K       FLEN      REW
                     CRWS      HO     FR #         SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
 Section: BRDG       13.531   .172  48530.000  14571.700  2000.000   450.010
 Header Type: BR     13.704   .525      3.330 2338193.00  2000.000   950.000
 SRD:    3000.000   -24.024   .000       .142     ******     1.000      .000

 Bridge Summary Information - Coordinate Mode
-----------------------------------------------------------------------------
 Flow Class:  1 - Free-surface flow with no embankment overtopping
 Bridge Type: 3 - Sloping embankments & sloping spillthrough abutments
```

Figure 37
Water surface elevation shown in the WSPRO output results

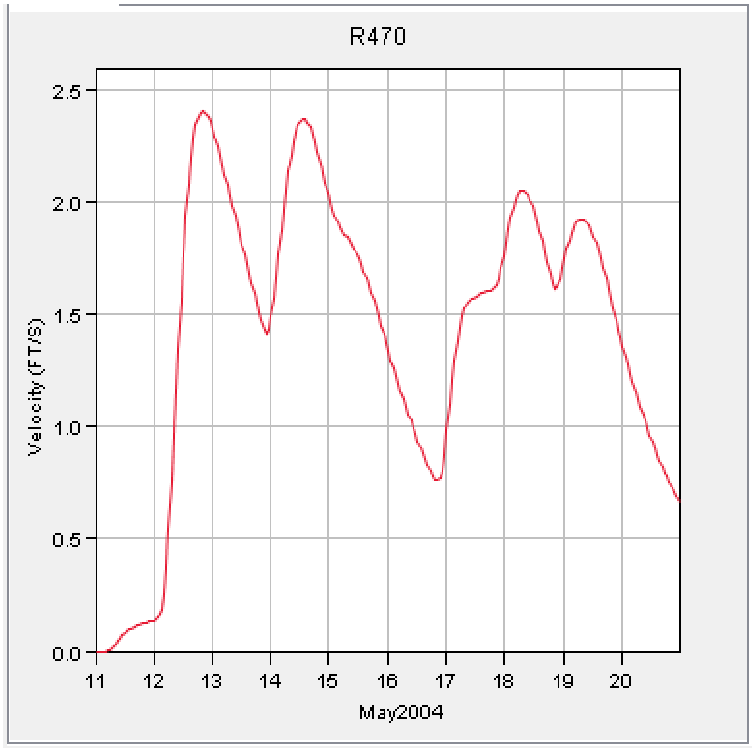


Figure 38
Flow velocities at the watershed outlet

Scour Depth Output Based on HEC-18
Since the HEC-18 method is embedded within WSPRO, a scour analysis was performed automatically within WSPRO. Figure 39 shows an example page of the scour analysis output, while Figure 40 shows the surveyed elevation change related to the selected maximum flood event.

Based on the surveyed scour data, the maximum scour depth for this flood event is 2.7 ft. (see Table 10 and Figure 40). A maximum scour depth of 9.6 ft. was obtained according to the WSPRO output, which is nearly 3.5 times greater than the surveyed scour data. The ratio of surveyed scour depth to the HEC-18 estimated scour depth is 0.28, suggesting that the HEC-18 method gives a very conservative estimate when compared with the real scour process. Again, this soil type at this bridge site is gray silty clay; it is known that the HEC-18 method tends to yield very conservative estimates of scour depths for cohesive soils. In summary, for this clay, the HEC-18 method overestimates the scour depth by 70 percent. Table 10 also summarizes the surveyed scour depth from the initial bed elevation. By carefully examining Figure 40, the more appropriate scour depth is 5.4 ft. (at distance of 682 ft.), but not 9.5 ft. at 757 ft. (Table 10) because the latter value is biased by the high sloping angle.

.LSTENTAU-CLAY.TXT - Notepad

File Edit Format View Help

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         *************************   W S P R O  ***************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
        *----------------------------------------------------------------*
                              SCOUR RESEARCH
                             MERMENTAU RIVER
                     BRIDGE L=2031 FT. @ F.G.ELEV. 54 FT

            ***  Pier Scour Calculations for Header Record BRDG   ***

                         Constants and Input Variables

                             Pier Width:   5.000
                 *-------------------------------------------*
                   Pier Shape Factor               (K1):   1.00
                   Flow Angle of Attack Factor     (K2):   1.00
                   Bed Condition Factor            (K3):   1.00
                   Bed Material Factor             (K4):   1.00
                   Velocity Multiplier             (VM):   1.00
                   Depth Multiplier                (YM):   1.00
                 *-------------------------------------------*

       Scour   ---- Localized Hydraulic Properties ----     -- X-Stations --
  #    Depth     Flow      WSE     Depth  Velocity Froude #   Left      Right
 --   ------ ---------- --------- ------ -------- -------- --------- ---------
  1    8.688  42414.600   10.707 51.707    4.393      .108   450.031   950.000
  2    9.623  48530.000   13.790 54.790    5.473      .130   450.009   950.000
 --   ------ ---------- --------- ------ -------- -------- --------- ---------

         *************************   W S P R O  ***************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
        *----------------------------------------------------------------*
                              SCOUR RESEARCH
                             MERMENTAU RIVER
                     BRIDGE L=2031 FT. @ F.G.ELEV. 54 FT

     ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                         Constants and Input Variables

                *----------------------------------------------*
                 Bed Material Transport Mode Factor (k1):   1.00
                 Total Pier Width Value             (Pw): 15.000
                *----------------------------------------------*

       Scour     -- Flow --         -- Width --        --- X-Limits ---
  #    Depth  Contract Approach  Contract Approach  Side   Contract Approach
 --   ------ --------- --------- -------- --------  ------ -------- --------
  1    2.518 42414.600 40216.230  484.968  499.968  Left:   450.032  450.032
       ----------------------------------------     Right:  950.000  950.000
       Hydraulic Depths +++++++ Approach:   28.516  ++++++++ Bridge:  28.242
  2    4.506 48530.000 45505.750  484.990  499.990  Left:   450.010  450.010
       ----------------------------------------     Right:  950.000  950.000
       Hydraulic Depths +++++++ Approach:   31.729  ++++++++ Bridge:  30.045
 --   ------ --------- --------- -------- --------  ------ -------- --------
         *************************   W S P R O  ***************************
```

Figure 39
An example output sheet of WSPRO for Mermentau River Bridge

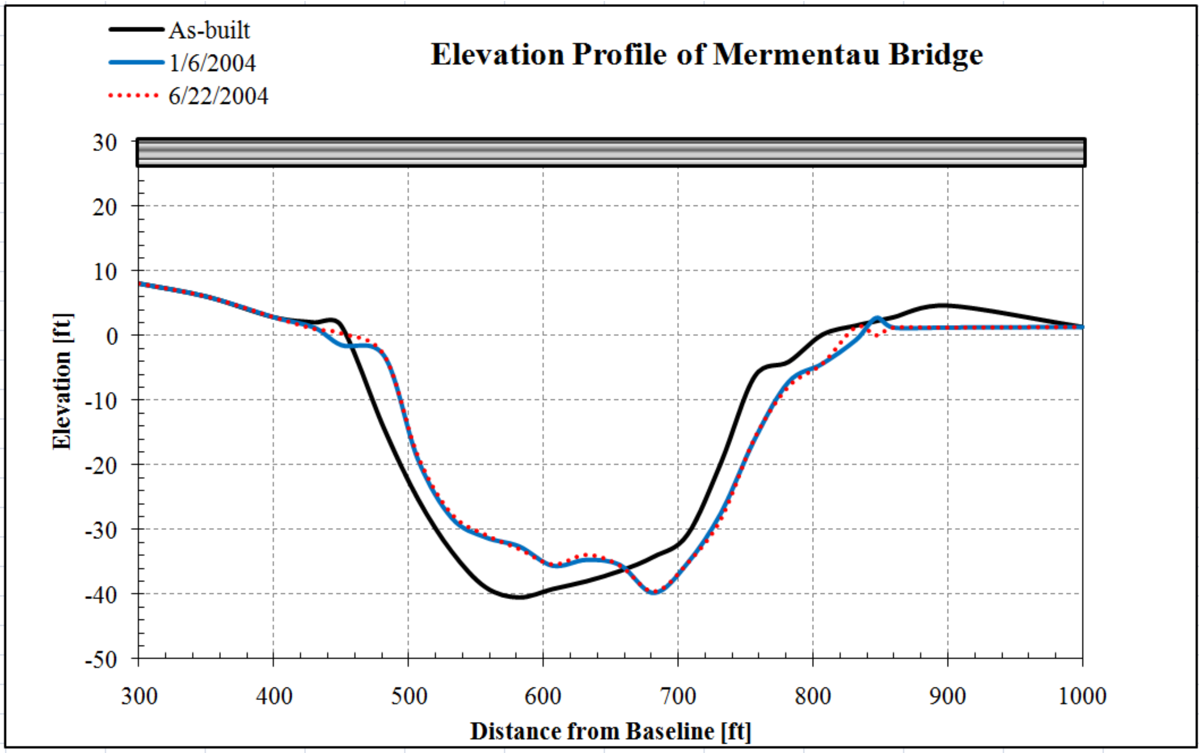

Figure 40
Surveyed elevation change related to the selected flood event (Mermentau River Bridge)

Input Data for WSPRO Analysis

For the WSPRO analysis of the rainfall event between 05/11-20/2004 at Mermentau River Bridge, the input data were summarized in an input data file shown in Figure 41. The input data can be divided into several categories:

- Basic bridge data, such as bridge length, and pier locations
- The selected maximum flood discharge calculated from HEC-HMS
- Stream or river bed elevations after construction
- Stream bed sloping angles
- Hydraulic parameters and constants used in the scour equations

Mermentau-clay.txt - Notepad

File Edit Format View Help

```
T1        Scour Research
T2        Mermentau River
T3        Bridge L=2031 ft. @ F.G.Elev. 54 ft
*         Q50     Q052004
Q         42414.6   48530
SK       0.00016   0.00016
XT   TEMP  3030  0.00016
GR         0,-0.5     100,0      200,-1     300,-1.9   400,0
GR         455,-8     465,-10    475,-20    500,-24    515,-30
GR         552,-38.5  555,-38    587,-40    595,-39    635,-37.9
GR         675,-34    700,-25.3  715,-22.5  755,-12.2  790,-5
GR         798,-2     800,-1.0   900,5.0    959,6.5    975,9.8
GR         1000,7.9   1049,8.2   1070,6.1   1100,7.0   1127,10.3
GR         1128,9     1200,11.6  1300,12.5  1400,13.9  1500,14.6
GR         1600,13.7
*
XS   EXIT  1000
GT
SA               450     500     600    650
N           0.15  0.10     0.04    0.10     0.15
*
XS   FULV  3000
*         Bridge L=2031 ft
BR   BRDG 3000
GR         450,15    450,1.0
GR         455,1.6   465,-0.4    475,-11.4   500,-22.3   515,-28.7
GR         552,-39   555,-38.7   587,-41     595,-39.8   635,-37.9
GR         675,-35   700,-32.2   715,-29.3   755,-6.4    790,-3.3
GR         798,-0.5  800,0.1     900,4.6     950,10      450,15
CD         3, 28, 3.0 205
N              0.06
*
XR   ROAD 3030 49
GR         0, 54  1000, 54
*
XS   APPR 5060
GR         0,-0.5     100,0      200,-1     300,-1.9   400,0
GR         455,-8     465,-10    475,-20    500,-24    515,-30
GR         552,-38.5  555,-38    587,-40    595,-39    635,-37.9
GR         675,-34    700,-25.3  715,-22.5  755,-12.2  790,-5
GR         798,-2     800,-1.0   900,5.0    959,6.5    975,9.8
GR         1000,7.9   1049,8.2   1070,6.1   1100,7.0   1127,10.3
GR         1128,9     1200,11.6  1300,12.5  1400,13.9  1500,14.6
GR         1600,13.7
SA               450     500     600    650
N           0.15  0.06    0.04  0.06     0.15
*
HP  2 APPR 196.4 1 39.5 89725
*    SECID  BXL   BXR    PW    YB    QB    K1    K2    K3    K4    V1M    D1M
DP   BRDG   *     *      5
*  0 SECID  BXL   BXR    AXL    AXR    K1    PW    YB    YA
DC 0 BRDG   *     *      *      *      1.0   15
*  1 SECID  BXL   BXR    AXL    AXR   D50          PW    YB    YA
DC 1 BRDG   *     *      *      *   0.00000456   15
*
EX
```

Figure 41
Input data for WSPRO analysis for Mermentau Bridge

Summary Results of Other Studied Bridges

Bogue Chitto River Bridge (10/25/2006-10/27/2006)

Input data for WSPRO hydraulic and scour analysis are shown in Figure 42. Figure 43 shows an example page of the WSPRO output data. Table 11 summarizes the scour depth estimated from survey records for this flood event.

Bogur Chitto-0610-sand.txt - Notepad

File Edit Format View Help

```
T1        Scour Research Test0610
T2        Bogue Chitto River
T3        Proposed Bridge L=700 ft. @ F.G.Elev. 205 ft
*         Q0610
Q         74111
WS        183
* XT   TEMP  950
*
XS   EXIT  1000
GR         -2450,200  -2000,195  -1450,195    -1006,190   -700,190
GR         0,190  150,190    300,190    370,172.3    393,171.9    417,171.7
GR         440,171.3   463,169.8   510,170.9   533,172.5
GR         557,172.6  580,173.8   603,171.5  627,172.2
GR         633,172.6  650,180    700,190  840,195  1200,200
GT
SA                 370       500
N              0.09     0.06      0.09
*
XS   FULV 1688
*
*         Bridge L=700 ft
BR   BRDG 1688
GR         0.1,200      30,180    70,182.51    140,174.21     210,175.81
GR         280,177.31  370,172.5   393,170.75   417,170.35
GR         440,171.7   463,170.35  487,170.4    510,171.3    533,169.65
GR         557,171.2   580,178.8   603,170.95   627,171.3    675,173
GR         700, 205     0.1, 200
CD         3  24   2.5  42
N          0.04
*
XR   ROAD 1700  205
GR         0, 205  1000, 205
*
XS   APPR 2400
GR         -2450,200  -2000,200     -1450,190    -800,185
GR         -200,180   -50,180    0,180  350,180     360,173
GR         370,172.6   417,169  440,169.3  463,169.8
GR         487,170.7   510,171  533,172.1
GR         770,180  820,190  1000,195    1200,200
*
*  HP  2  APPR  37.5  1  39.5  71391

*    SECID  BXL    BXR    PW    YB    QB    K1    K2    K3    K4    V1M    D1M
DP   BRDG   *      *      2
*  0 SECID  BXL    BXR    AXL     AXR     K1    PW    YB    YA
DC 0 BRDG   *      *      *       *       1.1   18
*
*  1 SECID  BXL    BXR    AXL     AXR    D50    PW    YB    YA
DC 1 BRDG   *      *      *       *    0.0083 18
*
EX
```

Figure 42
Input data of WSPRO for Bogue Chitto River Bridge (10/25/2006-10/27/2006)

.LSTR CHITTO-0610-SAND.TXT - Notepad

File Edit Format View Help

```
         ************************  W S P R O  **************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
      *----------------------------------------------------------------*

                              SCOUR RESEARCH TEST0610
                                 BOGUE CHITTO RIVER
                 PROPOSED BRIDGE L=700 FT. @ F.G.ELEV. 205 FT

          ***  Pier Scour Calculations for Header Record BRDG   ***

                          Constants and Input Variables

                              Pier Width:   2.000
               *-------------------------------------------*
                 Pier Shape Factor             (K1):   1.00
                 Flow Angle of Attack Factor   (K2):   1.00
                 Bed Condition Factor          (K3):   1.00
                 Bed Material Factor           (K4):   1.00
                 Velocity Multiplier           (VM):   1.00
                 Depth Multiplier              (YM):   1.00
               *-------------------------------------------*

     Scour    ---- Localized Hydraulic Properties ----     -- X-Stations --
  #  Depth     Flow      WSE     Depth  Velocity Froude #  Left      Right
 -- ------ ---------- -------- ------ -------- -------- --------- ---------
  1  4.951  74111.000 196.591 26.941   5.824     .198      5.196   693.431
 -- ------ ---------- -------- ------ -------- -------- --------- ---------

         ************************  W S P R O  **************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
      *----------------------------------------------------------------*

                              SCOUR RESEARCH TEST0610
                                 BOGUE CHITTO RIVER
                 PROPOSED BRIDGE L=700 FT. @ F.G.ELEV. 205 FT

   ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                          Constants and Input Variables

              *-----------------------------------------------*
                Bed Material Transport Mode Factor (k1):   1.10
                Total Pier Width Value             (Pw): 18.000
              *-----------------------------------------------*

     Scour      -- Flow --          -- Width --         --- X-Limits ---
  #  Depth   Contract Approach   Contract Approach  Side    Contract Approach
 -- ------ --------- ---------  -------- --------  ------ -------- --------
  1 14.943 74110.990 40651.950   670.217   688.217  Left:     5.207    5.207
      ------------------------------------------    Right:  693.425  693.425
     Hydraulic Depths +++++++ Approach:   21.552  ++++++++ Bridge:   22.049
 -- ------ --------- ---------  -------- --------  ------ -------- --------
```

Figure 43
Output sheet of WSPRO for Bogue Chitto River Bridge (10/25/2006-10/27/2006)

Table 11
Scour depth estimated based on survey records

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	7/19/2006	2/14/2007	As-built		
0	205	205	205	0	0
30	203	203	203	0	0
70	182.51	182	184	-0.51	-2
140	174.21	173.5	176	-0.71	-2.5
210	175.81	176.2	177	0.39	-0.8
280	177.31	176.89	178.5	-0.42	-1.61
360	172.99	172.61	174	-0.38	-1.39
370	172.6	171.9	172.5	-0.7	-0.6
393	170.9	170.4	170.75	-0.5	-0.35
417	170.1	169.6	170.35	-0.5	-0.75
440	172.2	171.6	171.7	-0.6	-0.1
463	170.3	169.4	170.35	-0.9	-0.95
487	169.9	169.5	170.4	-0.4	-0.9
510	172.5	171.6	171.3	-0.9	0.3
533	169.4	168.6	169.95	-0.8	-1.35
557	171.3	169.2	171.2	**-2.1**	-2
580	179	177.9	178.8	-1.1	-0.9
603	171.3	169.5	170.95	-1.8	-1.45
627	171.2	169.9	171.3	-1.3	-1.4
635	172.6	171.9	180	-0.7	-8.1
675	203	203	203	0	0
700	205	205	205	0	0

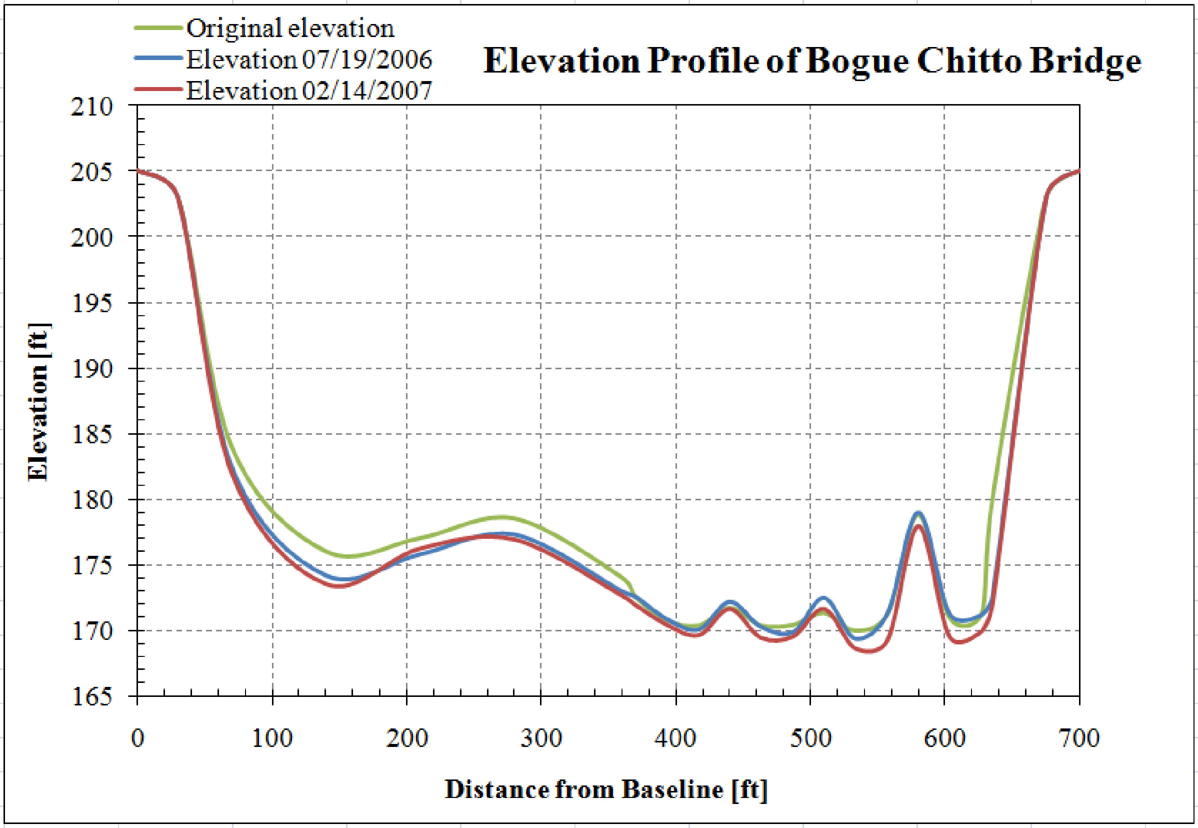

Figure 44
Bed elevation profiles for the studied event at Bogue Chitto River Bridge

As shown in Figure 44 and Table 11, the surveyed scour depth for this rainfall event is 2.1 ft. The WSPRO and HEC-18 calculation yields a maximum scour depth of 4.95 ft., which is more than two times greater than the surveyed scour depth. The ratio of the surveyed scour depth to the WSPRO calculated scour depth is 0.43. By carefully examining Figure 44, the more appropriate scour depth calculated from the initial bed elevation is 2.5 ft. (at a distance of 140 ft.), but not 8.1 ft. at 635 ft. (Table 11) because the latter one is biased by the high sloping angle along the river channel.

Bogue Chitto River Bridge (08/11/2004-08/12/2004)

Bogur Chitto - 0408.txt - Notepad

File Edit Format View Help

```
T1        Scour Research Test0408
T2        Bogue Chitto River
T3        Proposed Bridge L=700 ft. @ F.G.Elev. 205 ft
*         Q0408
Q         11938
SK        0.0003
*
XT   TEMP  1700
GR         50,   200       60, 170       370,171.2      393,169
GR         417, 170.85     440, 170.95   463, 170.25    487, 170.6
GR         510, 170.3      533, 171.7    557, 172.95    580, 172.95
GR         603, 172.4      627, 173      840, 170       850, 200
 *
XS   EXIT  1000
GT
SA                 370       500
N              0.09     0.06      0.09
*
XS   FULV 1688
*
*         Bridge L=700 ft
BR   BRDG 1688
GR         0.1,205       30,173       370,172.5     393,170.75
GR         417,170.35    440,171.7    463,170.35    487,170.4
GR         510,171.3     533,169.65   557,171.2     580,178.8
GR         603,170.95    627,171.3    675,173       700, 205
GR         0.1, 205
CD         3  24    2.5   42
N          0.04
*
XR   ROAD 1700  205
GR         0, 205   1000, 205
*
XS   APPR 2400
*
*  HP 2 APPR 37.5 1 39.5 71391

*    SECID  BXL    BXR    PW   YB   QB   K1   K2   K3   K4   V1M   D1M
DP   BRDG   *      *      2
*  0 SECID  BXL    BXR    AXL     AXR    K1   PW   YB   YA
DC 0 BRDG   *      *      *       *      1.1  18
*
*  1 SECID  BXL    BXR    AXL     AXR   D50   PW   YB   YA
DC 1 BRDG   *      *      *       *   0.0083 18
*
EX
```

Figure 45
Input data of WSPRO for Bogue Chitto River Bridge (08/11/2004-08/12/2004)

.LSTR CHITTO - 0408.TXT - Notepad

File Edit Format View Help

```
         *************************  W S P R O  ***************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
        *---------------------------------------------------------------*
                           SCOUR RESEARCH TEST0408
                              BOGUE CHITTO RIVER
                 PROPOSED BRIDGE L=700 FT. @ F.G.ELEV. 205 FT

            ***  Pier Scour Calculations for Header Record BRDG   ***

                         Constants and Input Variables

                           Pier Width:   2.000
                 *--------------------------------------------*
                   Pier Shape Factor              (K1):   1.00
                   Flow Angle of Attack Factor    (K2):   1.00
                   Bed Condition Factor           (K3):   1.00
                   Bed Material Factor            (K4):   1.00
                   Velocity Multiplier            (VM):   1.00
                   Depth Multiplier               (YM):   1.00
                 *--------------------------------------------*

        Scour   ---- Localized Hydraulic Properties ----     -- X-Stations --
  #     Depth     Flow      WSE     Depth  Velocity Froude #  Left      Right
 --    ------ ---------- -------- ------ -------- -------- --------- ---------
  1     2.919  11938.000  181.642 11.992   2.198     .112     21.925   681.752
 --    ------ ---------- -------- ------ -------- -------- --------- ---------

         *************************  W S P R O  ***************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
        *---------------------------------------------------------------*
                           SCOUR RESEARCH TEST0408
                              BOGUE CHITTO RIVER
                 PROPOSED BRIDGE L=700 FT. @ F.G.ELEV. 205 FT

     ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                         Constants and Input Variables

                *------------------------------------------------*
                  Bed Material Transport Mode Factor (k1):   1.10
                  Total Pier Width Value             (Pw): 18.000
                *------------------------------------------------*

        Scour     -- Flow --          -- Width --         --- X-Limits ---
  #     Depth  Contract Approach   Contract Approach   Side    Contract Approach
 --    ------ ---------- --------- -------- --------  ------ --------- --------
  1     2.963 11938.000  9778.414  641.821  659.821   Left:     21.928   21.928
        -------------------------------------------   Right:   681.749  681.749
        Hydraulic Depths +++++++ Approach:   10.255   ++++++++ Bridge:    9.565
 --    ------ ---------- --------- -------- --------  ------ --------- --------
         *************************  W S P R O  ***************************
```

Figure 46
An example page of the WSPRO output data for Bogue Chitto River Bridge (08/11/2004-08/12/2004)

Table 12
Scour depth estimated based on survey records for Bogue Chitto River Bridge

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	4/21/2004	9/27/2004	As-built		
0	205	205	205	0	0
30	203	203	203	0	0
70	182.51	182	184	-0.51	-2
140	174.21	173.5	176	-0.71	-2.5
210	175.81	176.2	177	0.39	-0.8
280	177.31	176.89	178.5	-0.42	-1.61
360	172.99	172.61	174	-0.38	-1.39
370	173	172.8	172.5	-0.2	0.3
393	171	171.3	170.75	0.3	0.55
417	170.4	170.6	170.35	0.2	0.25
440	172.7	172.3	171.7	-0.4	0.6
463	170.9	170.3	170.35	-0.6	-0.05
487	170.5	170.4	170.4	-0.1	0
510	172.8	172.1	171.3	-0.7	0.8
533	170.2	170.4	169.95	0.2	0.45
557	171.2	170.3	171.2	-0.9	-0.9
580	179.7	180.1	178.8	0.4	1.3
603	171	171.4	170.95	0.4	0.45
627	171.5	171.3	171.3	-0.2	0
635	173	172.8	180	-0.2	-7.2
675	203	203	203	0	0
700	205	205	205	0	0

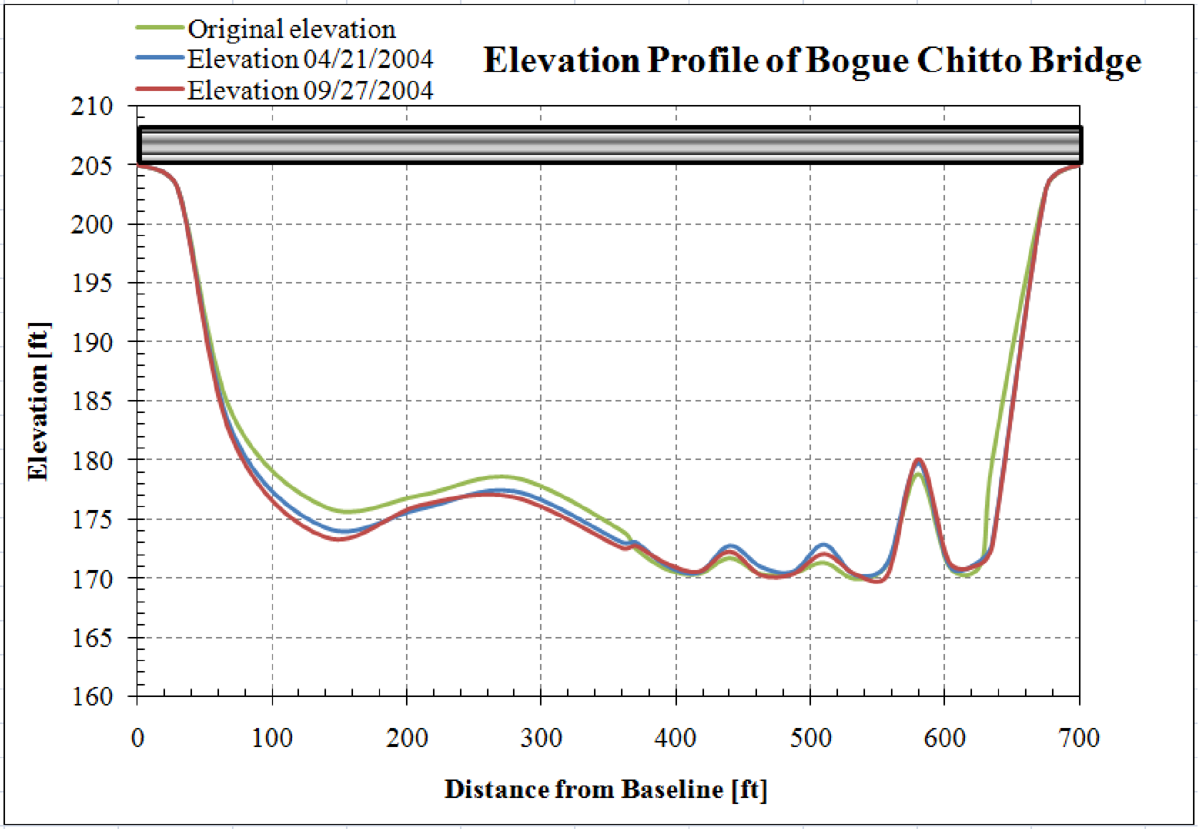

Figure 47
Elevation profiles of the river bed from the survey records for this rainfall event at Bogue Chitto River Bridge

In this case, the scour depth from the survey records is 0.9 ft., and the WSPRO and HEC-18 calculation yields a value of 2.9 ft., which has a ratio of 0.31. By carefully examining Figure 47, the more appropriate scour depth calculated from the initial bed elevation is 2.5 ft. (at distance of 140 ft.), but not 8.1 ft. at 635 ft. (Table 12), because the latter one is biased by the high sloping angle along the river channel.

Tickfaw River Bridge

tickfaw.txt - Notepad

File Edit Format View Help

```
T1         Scour Research
T2         Tickfaw River
T3         Bridge L=562 ft. @ F.G.Elev. 39.6 ft
*          Qtest
Q          2526.2
SK         0.0002
XT    TEMP  1562
GR          -245,33.61    -215,24     -185,24     -157,25    -145,23.7
GR          -125,22       -78,22      -65,24      -5,25
GR          19,25         55,10       135,10      161,23
GR          195,20        227,20      255,23      298,28     315,33.6
*
XS    EXIT  1000
GT          -0.11
SA                55     135
N            0.10   0.06      0.10
*
XS    FULLV  1562
*
*          Bridge L=562 ft
BR    BRDG 1562
GR          -245,33.61    -215,24     -185,24     -157,25   -145,23.7
GR          -125,22       -78,22      -65,24      -5,25
GR          19,25         55,10       135,10      161,23
GR          195,20        227,20      255,23      298,28     315,33.6
GR          -245,33.61
CD          3, 33.5, 3.0 205
N                0.06
*
XR    ROAD 1562 42
GR          0, 33.6   315, 33.6
*
AS    APPR 2152
GT         0.12
SA                55     135
N            0.10   0.06      0.10
*
HP  2 APPR   10 1 39.6 2526.2
*     SECID  BXL    BXR    PW    YB    QB    K1    K2    K3    K4    V1M    D1M
DP    BRDG   *      *      2
*   0 SECID  BXL    BXR    AXL     AXR    K1    PW    YB    YA
DC  0 BRDG   *      *      *       *      1.0   10
*
*   1 SECID  BXL    BXR    AXL     AXR    D50         PW    YB    YA
DC  1 BRDG   *      *      *       *     0.00005      10
*
EX
```

Figure 48
Input data for WSPRO for Tickfaw River Bridge

TICKFAW.LST - Notepad

File Edit Format View Help

```
          *************************   W S P R O   ***************************
            Federal Highway Administration  -  U. S. Geological Survey
                   Model for Water-Surface Profile Computations.
                  Input Units: English  /  Output Units: English
         *----------------------------------------------------------------*
                                  SCOUR RESEARCH
                                  TICKFAW RIVER
                      BRIDGE L=562 FT. @ F.G.ELEV. 39.6 FT

             ***  Pier Scour Calculations for Header Record BRDG   ***

                           Constants and Input Variables

                               Pier Width:   2.000
                  *--------------------------------------------*
                    Pier Shape Factor            (K1):   1.00
                    Flow Angle of Attack Factor  (K2):   1.00
                    Bed Condition Factor         (K3):   1.00
                    Bed Material Factor          (K4):   1.00
                    Velocity Multiplier          (VM):   1.00
                    Depth Multiplier             (YM):   1.00
                  *--------------------------------------------*

      Scour    ---- Localized Hydraulic Properties ----     -- X-Stations --
  #   Depth     Flow      WSE     Depth  Velocity Froude #   Left       Right
 --  ------ ---------- -------- ------ -------- -------- --------- ---------
  1   2.754   2526.200   23.849 13.849   1.834     .087   -146.374   262.300
 --  ------ ---------- -------- ------ -------- -------- --------- ---------

          *************************   W S P R O   ***************************
            Federal Highway Administration  -  U. S. Geological Survey
                   Model for Water-Surface Profile Computations.
                  Input Units: English  /  Output Units: English
         *----------------------------------------------------------------*
                                  SCOUR RESEARCH
                                  TICKFAW RIVER
                      BRIDGE L=562 FT. @ F.G.ELEV. 39.6 FT

      ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                           Constants and Input Variables

                 *------------------------------------------------*
                  Bed Material Transport Mode Factor (k1):   1.00
                  Total Pier Width Value             (Pw): 10.000
                 *------------------------------------------------*

      Scour     -- Flow --           -- Width --          --- X-Limits ---
  #   Depth   Contract Approach  Contract Approach  Side   Contract Approach
 --  ------ --------- --------- -------- --------  ------ -------- --------
  1    .123  2526.200  2526.200  395.673  405.673  Left:  -144.799 -144.799
            ---------------------------------------  Right:  260.873  260.873
      Hydraulic Depths +++++++ Approach:     4.720  ++++++++ Bridge:   4.717
 --  ------ --------- --------- -------- --------  ------ -------- --------
```

Figure 49
An example WSPRO output page for Tickfaw River Bridge

Table 13
Scour depth estimated based on survey records for Tickfaw River Bridge

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	As-built	1/20/2004	7/19/2004		
-245	33.61	33.61	33.61	0	0
-215	24	24	24	0	0
-185	24	24	24	0	0
-157	25	25	25	0	0
-125	22	22	22	0	0
-78	22	22	22	0	0
-65	24	24	24	0	0
-5	25	25	25	0	0
19	25	25	25	0	0
52	12	15.8	16.2	0.4	4.2
55	10	15.2	14.3	-0.9	4.3
82	10	13.5	13.8	0.3	3.8
108	10	13.6	14.4	0.8	4.4
135	10	15.4	15	-0.4	5
140	12.5	15.8	16.2	0.4	3.7
161	23	23	23	0	0
195	20	20	20	0	0
227	20	20	20	0	0
255	23	23	23	0	0
298	28	28	28	0	0
315	33.6	33.6	33.6	0	0

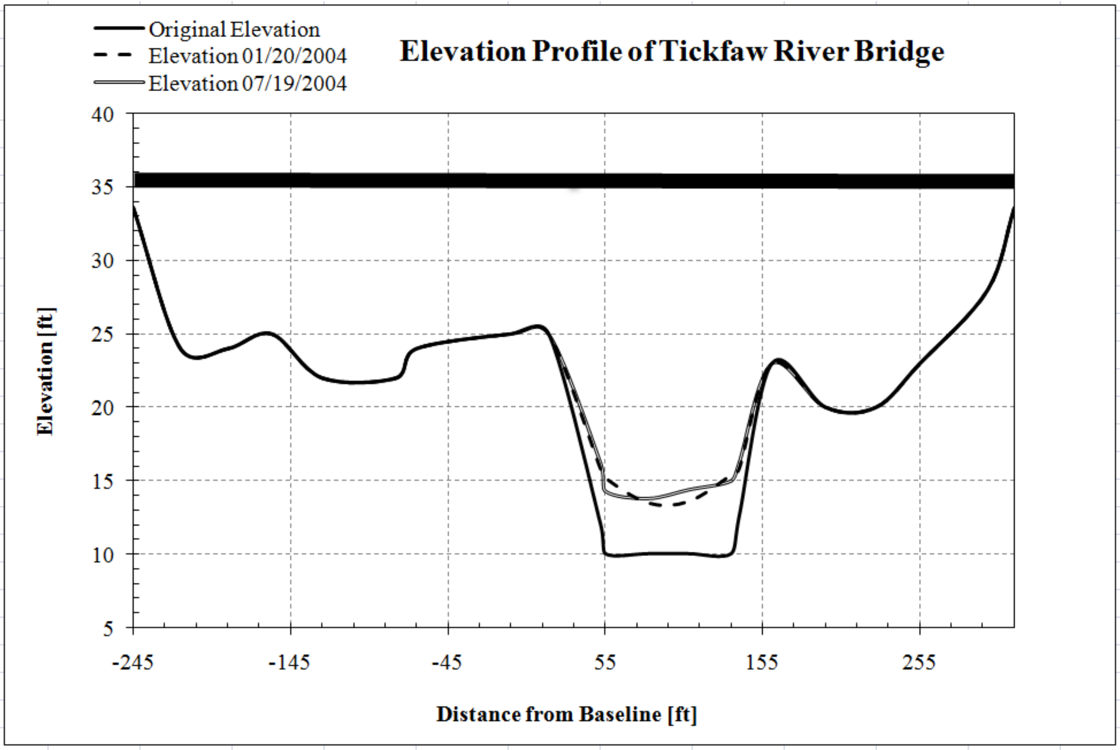

Figure 50
Elevation profiles of the river bed from the survey records for this rainfall event at Tickfaw River Bridge

In this case, the scour depth given by survey records is 0.9 ft., and the calculation of WSPRO gives a value of 2.75 ft., which has a ratio of 0.33. By carefully examining Figure 50, there was no scour if it is calculated from the initial bed elevation. In other words, only aggredation occurred if the initial bed elevation is used as a reference datum for scour analysis.

West Fork Calcasieu River Bridge

westfork - Copy.txt - Notepad

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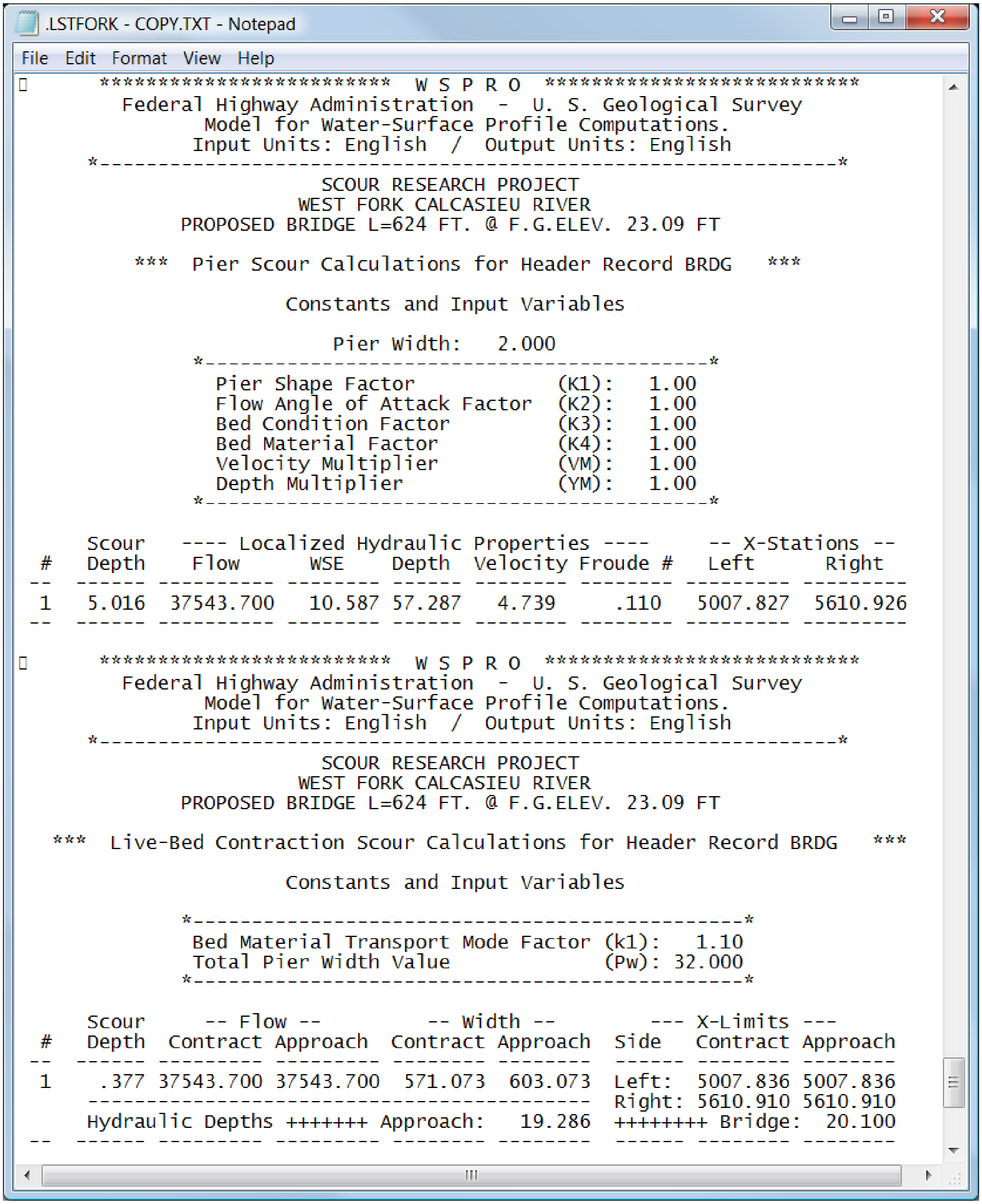
```
T1          Scour Research Project
T2          West Fork Calcasieu River
T3          Proposed Bridge L=624 ft. @ F.G.Elev. 23.09 ft
*           Q
Q           37725
SK          0.0001
*
XT    TEMP  0.0
GR          0,40.0      2000,20.0     2300,15.0     4600,10.0     5025,5.0
GR          5033,4.5    5066,5.1      5098,4.7      5131,4.9      5163,5.4
GR          5196,-0.7   5228,-11.7    5261,-46.7    5312,-43.7    5364,-29.7
GR          5396,-23.7  5429,-16.7    5461,0.7      5494,4.6      5526,5.1
GR          5559,6.1    5591,6.6      5599,8.4      6023,10.0     6123,15.0
GR          7098,20.0   10000,40.0
*
XS    EXIT  -623
GT          -0.06
SA          5260   5370
N           0.18   0.031   0.18
*
XS    FULV  0.0
SA          5190   5370
N           0.18   0.031   0.18
*     Bridge L=624 ft
BR    BRDG  0.0
GR          5000,13.7    5000,13.1    5025,5.0     5033,4.5     5066,5.1
GR          5098,4.7     5131,4.9     5163,5.4     5196,-0.7    5228,-11.7
GR          5254,-21.7   5268,-46.7   5312,-43.7   5357,-29.7   5364,-31.7
GR          5371,-30.7   5396,-23.7   5429,-16.7   5461,0.7     5494,4.6
GR          5526,5.1     5559,6.1     5591,6.6     5599,8.4     5623,12.8
GR          5623,13.7    5591,14.7    5559,15.7    5526,16.1    5494,16.5
GR          5461,16.7    5429,16.9    5396,17.6    5365,18.25   5364,19.0
GR          5131,16.5    5098,16.1    5066,15.7    5033,14.7    5000,13.7
CD          3  31.0   3  8.4
PW 1        -46.7,7.5  -29.7,7.5,-29.7,15.0  -16.7,15.0,-16.7,17.0
PW 1        -0.7,17.0,-0.7,19.0  4.6,19.0,4.6,21.0  4.9,21.0,4.9,25.0
PW 1        6.1,25.0,6.1,27.0
SA          5190   5461
N           0.06   0.031   0.06
HP 1 BRDG   10.51,1,10.51
HP 1 BRDG   10.51,1,10.51,37725
XR    ROAD  0.0
GR          0,30.0       2050,20.0    2350,15.0    3150,10.0    5000,18.3
GR          5261,22.83   5364,22.83   5623,18.3    6625,10.0    6850,15.0
GR          7450,20.0    10000,30.0
*
XS    APPR  654
GT          0.07
SA          5260   5370
N           0.18   0.031   0.18
HP 1 APPR   10.12,1,10.12
HP 2 APPR   10.12,1,10.12,37725
*
*     SECID  BXL   BXR    PW   YB   QB   K1   K2   K3   K4   V1M   D1M
DP    BRDG   *     *      2
*   0 SECID  BXL   BXR    AXL    AXR    K1   PW   YB   YA
DC  0 BRDG   *     *      *      *      1.1  32
*
*   1 SECID  BXL   BXR    AXL    AXR   D50       PW   YB   YA
DC  1 BRDG   *     *      *      *     0.000066  32
*
EX
ER
```

Figure 51
WSPRO input data for West Fork Calcasieu Bridge



```
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         *************************  W S P R O  ***************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
      *----------------------------------------------------------------*

                            SCOUR RESEARCH PROJECT
                          WEST FORK CALCASIEU RIVER
                PROPOSED BRIDGE L=624 FT. @ F.G.ELEV. 23.09 FT

          ***  Pier Scour Calculations for Header Record BRDG   ***

                          Constants and Input Variables

                              Pier Width:   2.000
               *--------------------------------------------*
                 Pier Shape Factor              (K1):   1.00
                 Flow Angle of Attack Factor    (K2):   1.00
                 Bed Condition Factor           (K3):   1.00
                 Bed Material Factor            (K4):   1.00
                 Velocity Multiplier            (VM):   1.00
                 Depth Multiplier               (YM):   1.00
               *--------------------------------------------*

        Scour   ---- Localized Hydraulic Properties ----     -- X-Stations --
   #    Depth     Flow       WSE     Depth  Velocity Froude #   Left      Right
  --   ------ ---------- -------- ------ -------- -------- --------- ---------
   1    5.016  37543.700   10.587 57.287    4.739     .110  5007.827  5610.926
  --   ------ ---------- -------- ------ -------- -------- --------- ---------

         *************************  W S P R O  ***************************
           Federal Highway Administration  -  U. S. Geological Survey
                  Model for Water-Surface Profile Computations.
                 Input Units: English  /  Output Units: English
      *----------------------------------------------------------------*

                            SCOUR RESEARCH PROJECT
                          WEST FORK CALCASIEU RIVER
                PROPOSED BRIDGE L=624 FT. @ F.G.ELEV. 23.09 FT

   ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                          Constants and Input Variables

              *------------------------------------------------*
                Bed Material Transport Mode Factor (k1):   1.10
                Total Pier Width Value             (Pw): 32.000
              *------------------------------------------------*

        Scour     -- Flow --          -- Width --        --- X-Limits ---
   #    Depth  Contract Approach  Contract Approach  Side   Contract Approach
  --   ------ --------- --------- -------- --------  ------ --------- --------
   1     .377 37543.700 37543.700  571.073  603.073  Left:  5007.836 5007.836
        ----------------------------------------     Right: 5610.910 5610.910
        Hydraulic Depths +++++++ Approach:   19.286  ++++++++ Bridge:   20.100
  --   ------ --------- --------- -------- --------  ------ --------- --------
```

Figure 52
An example WSPRO output page for West Fork Calcasieu River Bridge

Table 14
Scour depth estimated based on survey records for West Fork Calcasieu River Bridge

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	As-built	4/13/2005	11/14/2005		
62	4.4	4.4	4.4	0	0
98	4.4	1	-1.1	-2.1	-5.5
127	-6.25	-17.5	-20.3	-2.8	-14.05
149	-11.25	-30.1	-30.6	-0.5	-19.35
192	-28.75	-30.2	-30.4	-0.2	-1.65
219	-30	-43.2	-44.1	-0.9	-14.1
234	-34.5	-45.2	-46.3	-1.1	-11.8
251	-35.63	-44.4	-44.5	-0.1	-8.87
268	-30.13	-34.6	-37.5	**-2.9**	-7.37
294	-28.13	-22.7	-23.4	-0.7	4.73
326	-16.12	-16.1	-14.2	1.9	1.92
359	3.13	-1	-0.1	0.9	-3.23
380	7.63	1	1.9	0.9	-5.73
424	5	5	5	0	0
489	2.5	2.5	2.5	0	0
525	1.8	1.8	1.8	0	0

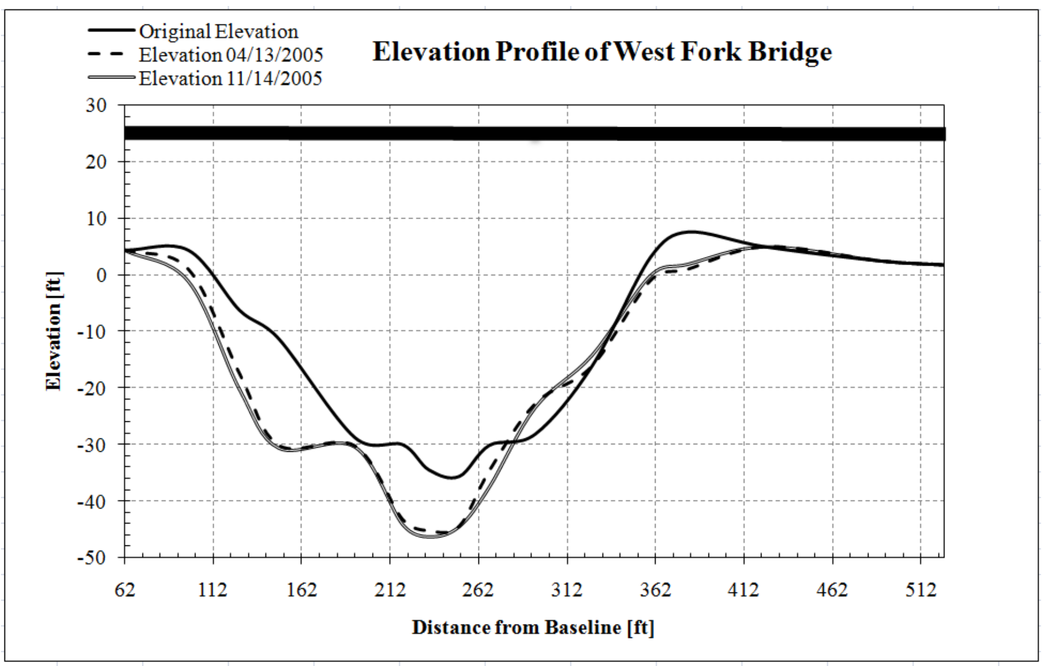

Figure 53
Riverbed elevation profiles from the survey records for this rainfall event at West Fork Calcasieu River Bridge

In this case, the scour depth derived from survey records is 2.9 ft. and the scour depth given by WSPRO is 5.0 ft., which gives a ratio of 0.58. The surveyed scour depth calculated from the initial bed elevation is 19.35 ft., which is much greater than the above two scour depths. It is possible that a major flood event greater than the one used for this calculation may have happened in history, hence a much greater scour depth occurred.

Bayou Lacassine Bridge (rainfall event: 05/12/2004-05/20/2004)

Bayou Lacassine -WITH PW.txt - Notepad

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```
T1          Scour Research Project
T2          Bayou Lacassine
T3          Proposed Bridge L=811 ft. @ F.G.Elev. 12 ft
*           Q
Q           11486
SK          0.0001
*
XT    TEMP  0.0
GR          1550,7      2550,5      8040,5.1    8060,4.1    8080,2.7
GR          8100,0.4    8120,0.0    8140,-1.1   8160,-1.0   8180,-1.4
GR          8200,-3.0   8220,-4.5   8240,-6.7   8260,-8.6   8280,-10.9
GR          8300,-11.0  8320,-12.2  8340,-12.7  8363,-11.6  8384,-11.8
GR          8414,-11.8  8444,-9.9   8465,-6.4   8516,-5.3   8570,-5.1
GR          8590,-4.1   8610,-4.1   8630,-3.3   8650,-3.1   8670,-2.6
GR          8690,-2.8   8710,-2.6   8730,-1.6   8750,-0.9   8770,1.6
GR          15560,4.0   18860,5.0   22000,7.0
*
XS    EXIT  -810
GT          -0.08
SA          8200  8570
N           0.20  0.030  0.20
*
XS    FULV  0.0
GT
SA          8075  8775
N           0.15  0.030  0.20
*
*     Bridge L=811 ft
BR    BRDG  0.0
GR          8000,10.10   8000,9.8    8020,5.5     8040,5.1     8060,4.1
GR          8080,2.7     8100,0.4    8120,0.0     8140,-1.1    8160,-1.0
GR          8180,-1.4    8200,-3.0   8220,-4.5    8240,-6.7    8260,-8.6
GR          8280,-10.9   8300,-11.0  8320,-12.2   8340,-12.7   8363,-11.6
GR          8384,-11.8   8414,-11.8  8444,-9.9    8465,-6.4    8516,-5.3
GR          8570,-5.1    8590,-4.1   8610,-4.1    8630,-3.3    8650,-3.1
GR          8670,-2.6    8690,-2.8   8710,-2.6    8730,-1.6    8750,-0.9
GR          8770,1.6     8790,5.2    8810,9.6     8810,10.53   8770,11.31
GR          8730,12.01   8690,12.55  8650,12.94   8610,13.17   8570,13.25
GR          8340,13.25   8320,13.20  8280,13.06   8240,12.81   8200,12.48
GR          8160,12.04   8120,11.56  8080,11.07   8040,10.59   8000,10.10
CD          3  27.0   3  9.6
PW 1        -12.2,1.5  -11.8,1.5,-11.8,4.67  -10.9,4.67,-10.9,6.17
PW 1        -9.9,6.17,-9.9,7.84  -6.7,7.84,-6.7,9.17  -6.4,9.17,-6.4,35.17
PW 1        -5.1,35.17,-5.1,36.67  -4.1,36.67,-4.1,38.00
PW 1        -3.1,38.00,-3.1,41.99  -1.6,41.99,-1.6,44.49  0.0,44.49,0.0,45.66
PW 1        1.6,45.66,1.6,48.16  5.1,48.16,5.1,49.33
SA          8.75  8775
N           0.06  0.030  0.06
HP 1 BRDG   3.14,1.3,3.14
HP 2 BRDG   3.14,1.3,3.14,11486
XR    ROAD  18.5,37.0
GR          4200,7.0    5900,5.0    7900,10.0    8000,12.85
GR          8340,16.0   8810,13.28  8985,10.0    16310,5.0
XS    APPR  837
GT          0.08
SA          8200  8570
N           0.20  0.030  0.20
HP 1 APPR   3.19,1,3.19
HP 2 APPR   3.19,1,3.19,11486
*
*     SECID  BXL    BXR    PW    YB    QB    K1    K2    K3    K4    V1M    D1M
DP    BRDG   *      *      1.25
*   0 SECID  BXL    BXR    AXL    AXR    K1    PW    YB    YA
DC  0 BRDG   *      *      *      *      1.1   30
*
*   1 SECID  BXL    BXR    AXL    AXR    D50       PW    YB    YA
DC  1 BRDG   *      *      *      *      0.000066  30
*
EX
ER
```

Figure 54
WSPRO input data for Bayou Lacassine Bridge

.LSTU LACASSINE.TXT - Notepad

File Edit Format View Help

```
        ************************  W S P R O  **************************
          Federal Highway Administration  -  U. S. Geological Survey
                 Model for Water-Surface Profile Computations.
                Input Units: English  /  Output Units: English
       *----------------------------------------------------------------*
                            SCOUR RESEARCH PROJECT
                               BAYOU LACASSINE
                PROPOSED BRIDGE L=811 FT. @ F.G.ELEV. 12 FT

           ***  Pier Scour Calculations for Header Record BRDG   ***

                        Constants and Input Variables

                            Pier Width:   1.250
                *--------------------------------------------*
                  Pier Shape Factor             (K1):   1.00
                  Flow Angle of Attack Factor   (K2):   1.00
                  Bed Condition Factor          (K3):   1.00
                  Bed Material Factor           (K4):   1.00
                  Velocity Multiplier           (VM):   1.00
                  Depth Multiplier              (YM):   1.00
                *--------------------------------------------*

      Scour    ---- Localized Hydraulic Properties ----     -- X-Stations --
  #   Depth     Flow       WSE     Depth  Velocity Froude #   Left       Right
 --  ------ ---------- -------- ------ -------- -------- --------- ---------
  1   2.356  11486.000   3.154 15.854   2.491     .110   8073.510  8778.635
 --  ------ ---------- -------- ------ -------- -------- --------- ---------

        ************************  W S P R O  **************************
          Federal Highway Administration  -  U. S. Geological Survey
                 Model for Water-Surface Profile Computations.
                Input Units: English  /  Output Units: English
       *----------------------------------------------------------------*
                            SCOUR RESEARCH PROJECT
                               BAYOU LACASSINE
                PROPOSED BRIDGE L=811 FT. @ F.G.ELEV. 12 FT

    ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                        Constants and Input Variables

               *------------------------------------------------*
                Bed Material Transport Mode Factor (k1):   1.10
                Total Pier Width Value             (Pw): 30.000
               *------------------------------------------------*

      Scour      -- Flow --          -- Width --       --- X-Limits ---
  #   Depth   Contract Approach  Contract Approach  Side    Contract Approach
 --  ------ --------- --------- -------- --------  ------  -------- --------
  1    .055 11486.000 11434.910  675.044  705.044  Left:   8073.568 8073.568
      ------------------------------------------   Right:  8778.612 8778.612
      Hydraulic Depths +++++++ Approach:    8.456  ++++++++ Bridge:    8.849
 --  ------ --------- --------- -------- --------  ------  -------- --------
```

Figure 55
An example WSPRO output page for Bayou Lacassine Bridge

Table 15
Scour depth estimated based on survey records for Bayou Lacassine Bridge

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	As-built	1/7/2004	2/15/2006		
42	1.4	2.5	2	-0.5	0.6
47	1.4	-0.5	0	0.5	-1.4
67	1.4	-0.8	-0.8	0	-2.2
89	1.4	-0.5	-1.3	-0.8	-2.7
107	1.4	-1	-2	-1	-3.4
127	1.4	-1.4	-2.1	-0.7	-3.5
147	1.4	-1.7	-2.5	-0.8	-3.9
167	-0.6	-2	-2.8	-0.8	-2.2
187	-2.65	-2.6	-3.3	-0.7	-0.65
207	-4.7	-3.1	-4	-0.9	0.7
227	-4.7	-3.4	-4.3	-0.9	0.4
248	-4.7	-4.6	-5.7	**-1.1**	-1
275	-6.6	-4.4	-5.3	-0.9	1.3
301	-6.7	-4.8	-5.6	-0.8	1.1
326	-6.7	-5.5	-6.1	-0.6	0.6
352	-7.76	-6.1	-6.9	-0.8	0.86
378	-9.7	-8.3	-9.3	-1	0.4
404	-11.6	-11.3	-12.2	-0.9	-0.6
429	-13.4	-12.6	-13.7	**-1.1**	-0.3
456	-14.33	-11.5	-12.3	-0.8	2.03
476	-13.83	-12.1	-12.6	-0.5	1.23
496	-13.3	-12	-13	-1	0.3
516	-12	-11.1	-12.1	-1	-0.1
536	-10.7	-10.2	-11.1	-0.9	-0.4
556	-7.8	-8.4	-9.3	-0.9	-1.5
576	-5	-6.3	-7.1	-0.8	-2.1
596	-3.8	-3.4	-4.3	-0.9	-0.5
616	-1.3	-1.9	-2.9	-1	-1.6
636	1.8	-0.7	-1.7	-1	-3.5
656	1.8	-0.2	-1	-0.8	-2.8
676	1.8	0	-1	-1	-2.8
696	1.8	0.5	-0.5	-1	-2.3
716	1.8	0.5	0	-0.5	-1.8
736	1.8	1	2	1	0.2

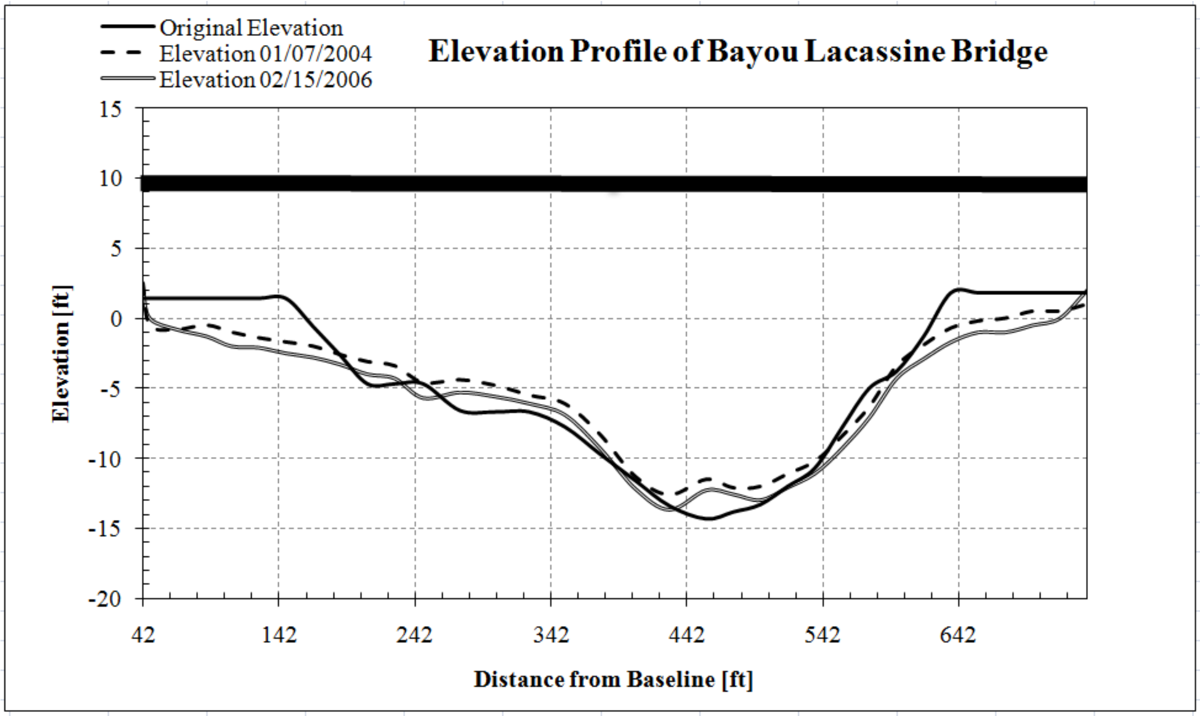

Figure 56
Riverbed elevation profiles from the survey records for this rainfall event at Bayou Lacassine Bridge

In this case, the survey records give a scour depth of 1.1 ft., and the calculation of WSPRO gives a value of 2.4 ft., which has a ratio of 0.46. Also from Table 15, the surveyed scour depth calculated from the initial bed elevation is 3.9 ft., which is greater than the scour depths calculated for this flood event. Again, a possible reason is that a flood event greater than the one used in this calculation may have taken place in history.

Bayou Nezpique at Jennings (rainfall event between 11/03/2002-11/08/2002)

Bayou Nezpique-T.txt - Notepad

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```
T1        Scour Research
T2        Bayou Nezpique  STR.NO.450-04-00001/2
T3        Bridge L=1486.9  ft. @ F.G.Elev. 37 ft
*         Q
Q         26575
SK       0.0002
XT   TEMP  0.0
GR         -2350,25.0  -200,20.0  3800,15.0  5050,7.6   5075,6.7   5100,6.2
GR         5125,5.4    5150,4.9   5175,4.6   5200,4.3   5225,4.8   5250,5.1
GR         5275,5.4    5300,6.0   5325,5.8   5350,5.8   5375,6.0   5400,6.1
GR         5425,6.4    5450,6.6   5475,6.2   5500,5.7   5525,5.2   5550,5.3
GR         5575,5.2    5600,4.0   5625,3.7   5650,3.2   5675,3.2   5700,2.9
GR         5725,3.4    5750,3.8   5790,-2.8  5830,-15.9 5893,-29.9 5955,-7.4
GR         5995,6.0    6035,4.9   6060,4.2   6085,3.7   6110,3.3   6135,3.3
GR         6160,3.1    6185,4.2   6210,4.3   6235,4.3   6260,4.5   6285,5.7
GR         6310,5.6    6335,5.8   6360,4.5   6385,4.9   6410,4.6   6435,5.0
GR         6460,6.8    6485,6.8   6510,7.9   6535,10.5  8585,15.0  11085,20.0
GR         14985,25.0
*
XS   EXIT  -1585
GT         -0.32
SA         5750    5985
N          0.15  0.030  0.15
*
XS   FULV  0.0
*    Bridge L=2031 ft
BR   BRDG  0.0
CD         3,119.0,3.0,18.1
AB         3.0
GR         5000,18.1   5025,7.9    5050,7.6    5075,6.7    5100,6.2    5125,5.4
GR         5150,4.9    5175,4.6    5200,4.3    5225,4.8    5250,5.1    5275,5.4
GR         5300,6.0    5325,5.8    5375,6.0    5400,6.1    5460,6.6    5475,6.2
GR         5500,5.7    5525,5.2    5600,4.0    5625,3.7    5675,3.2    5700,2.9
GR         5725,3.4    5750,3.8    5790,-2.8   5830,-15.9  5893,-29.9  5955,-7.4
GR         5995,6.0    6035,4.9    6060,4.2    6085,3.7    6110,3.3    6135,3.3
GR         6160,3.1    6210,4.3    6235,4.3    6260,4.5    6285,5.7    6310,5.6
GR         6360,4.5    6385,4.9    6410,4.6    6435,5.0    6460,6.8    6510,7.9
GR         6535,10.5   6585,23.0   6585,23.8   6560,24.7   6535,25.6   6510,26.4
GR         6485,27.3   6460,28.7   6435,29.4   6410,30.2   6385,30.9   6360,31.7
GR         6335,32.4   6310,32.5   6235,32.7   6210,32.8   6185,32.9   6135,33.0
GR         6110,33.1   6085,33.2   6060,33.3   5995,33.5   5955,30.7   5830,30.7
GR         5790,33.1   5750,33.0   5725,32.9   5700,32.9   5675,32.8   5650,32.7
GR         5625,32.6   5575,32.5   5550,32.4   5525,32.3   5475,32.2   5450,32.1
GR         5425,31.3   5400,30.6   5375,29.8   5325,28.3   5300,27.6   5250,26.1
GR         5225,25.3   5175,23.8   5150,23.1   5100,21.6   5075,20.8   5050,20.1
GR         5025,19.3   5000,18.6   5000,18.1
PW 1       -19.6,4.0   -15.9,4.0   -15.9,8.0   -7.4,8.0    -7.4,12.0   -0.8,12.0
PW 1       -0.8,16.0   2.9,16.0    2.9,17.67   3.2,17.67   3.2,32.02   4.0,32.02
PW 1       4.0,50.02   5.0,50.02   5.0,65.02   6.0,65.02   6.0,75.52   7.6,75.02
PW 1       7.6,77.02   10.5,77.02  10.5,78.52
SA         5750   5985
N          0.10   0.030   0.10
HP 1 BRDG  8.31,1,8.31
HP 2 BRDG  8.34,1,8.34,26575
*
XR   ROAD  60,131
GR         -2800,30.0  -1800,25.0  5000,22.13  5750,37.0  6035,37.0
GR         6585,27.38  14000,30.0
AS   APPR  1704
GT         0.34
SA         5750   5985
N          0.15   0.030   0.15
HP 1 APPR  8.39,1,8.39
HP 2 APPR  8.39,1,8.39,26575
*
*    SECID  BXL    BXR    PW    YB    QB    K1    K2    K3    K4    V1M    D1M
DP   BRDG   *      *      2
*  0 SECID  BXL    BXR    AXL    AXR    K1    PW    YB    YA
DC 0 BRDG   *      *      *      *      1.0   10
*
*  1 SECID  BXL    BXR    AXL    AXR    D50         PW    YB    YA
DC 1 BRDG   *      *      *      *     0.000066     10
*
EX
```

Figure 57
WSPRO input data for Bayou Nezpique Bridge

.LSTU NEZPIQUE.TXT - Notepad

File Edit Format View Help

```
      **************************  W S P R O  ****************************
         Federal Highway Administration  -  U. S. Geological Survey
                Model for Water-Surface Profile Computations.
               Input Units: English  /  Output Units: English
      *-----------------------------------------------------------------*

                              SCOUR RESEARCH
                  BAYOU NEZPIQUE  STR.NO.450-04-00001/2
                  BRIDGE L=1486.9  FT. @ F.G.ELEV. 37 FT

          ***  Pier Scour Calculations for Header Record BRDG   ***

                        Constants and Input Variables

                            Pier Width:   2.000
               *--------------------------------------------*
                 Pier Shape Factor             (K1):   1.00
                 Flow Angle of Attack Factor   (K2):   1.00
                 Bed Condition Factor          (K3):   1.00
                 Bed Material Factor           (K4):   1.00
                 Velocity Multiplier           (VM):   1.00
                 Depth Multiplier              (YM):   1.00
               *--------------------------------------------*

      Scour    ---- Localized Hydraulic Properties ----     -- X-Stations --
  #   Depth     Flow       WSE    Depth  Velocity Froude #   Left      Right
 --  ------ ---------- -------- ------ -------- -------- --------- ---------
  1   5.403  26575.000    8.411 38.311   6.391     .182   5023.747  6514.916
 --  ------ ---------- -------- ------ -------- -------- --------- ---------

      **************************  W S P R O  ****************************
         Federal Highway Administration  -  U. S. Geological Survey
                Model for Water-Surface Profile Computations.
               Input Units: English  /  Output Units: English
      *-----------------------------------------------------------------*

                              SCOUR RESEARCH
                  BAYOU NEZPIQUE  STR.NO.450-04-00001/2
                  BRIDGE L=1486.9  FT. @ F.G.ELEV. 37 FT

   ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                        Constants and Input Variables

              *------------------------------------------------*
               Bed Material Transport Mode Factor (k1):   1.00
               Total Pier Width Value             (Pw): 10.000
              *------------------------------------------------*

      Scour      -- Flow --          -- Width --         --- X-Limits ---
  #   Depth   Contract Approach  Contract Approach  Side   Contract Approach
 --  ------ --------- --------- -------- --------  ------ -------- --------
  1   0.249 26575.000 26575.000 1480.730 1490.730  Left:   5023.836 5023.836
      ---------------------------------------------  Right: 6514.566 6514.566
      Hydraulic Depths +++++++ Approach:    5.911  ++++++++ Bridge:    6.200
 *  Negative Scour Depth Encountered - Check If Variables Are Reasonable  *
 --  ------ --------- --------- -------- --------  ------ -------- --------
```

Figure 58
An example WSPRO output page for Bayou Nezpique Bridge

Table 16
Scour depth estimated based on survey records for Bayou Nezpique Bridge

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	As-built	9/5/2002	5/8/2003		
-353	6	6	6	0	0
47	0	0	0	0	0
97	1.3	1.3	1.3	0	0
147	2.7	2.7	2.7	0	0
197	4	4	4	0	0
239.5	4	4	4	0	0
254	-3.6	2	1.9	-0.1	5.5
257	-3.8	0	-0.1	-0.1	3.7
277	-16	-6.4	-6.8	-0.4	9.2
302	-29	-20.7	-20.4	0.3	8.6
327	-30	-27.6	-27.7	-0.1	2.3
352	-30	-29.9	-29.5	0.4	0.5
377	-30	-28.4	-28.6	-0.2	1.4
402	-13	-16.6	-16	0.6	-3
422	0	-7.4	-7.4	0	-7.4
442	0	-4.7	-4.4	0.3	-4.4
462	0	-0.6	0.9	1.5	0.9
469	0	2	1.9	-0.1	1.9
487	0	0	0	0	0
490	1	1	1	0	0
532	5	5	5	0	0
582	3.7	3.7	3.7	0	0
632	2.5	2.5	2.5	0	0
682	1.3	1.3	1.3	0	0
732	0	0	0	0	0
782	0	0	0	0	0
832	0	0	0	0	0

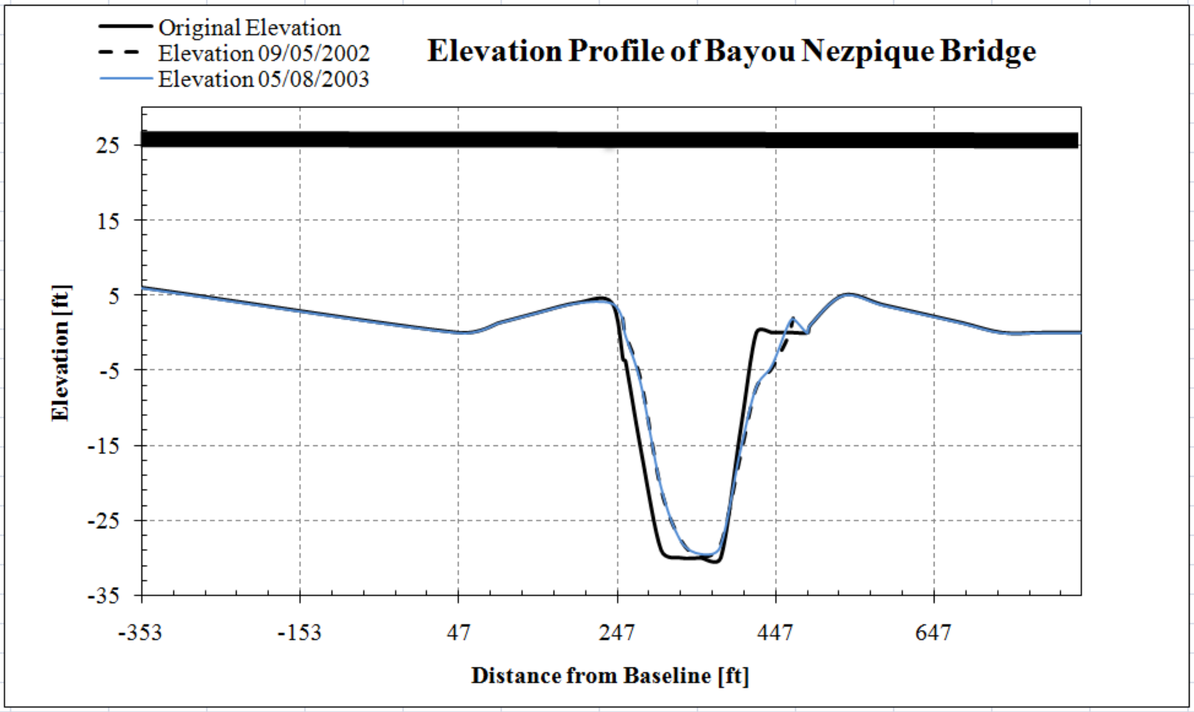

Figure 59
Riverbed elevation profiles from the survey records for this rainfall event at Bayou Nezpique Bridge

In this case, the survey record gives a scour depth of 0.4 ft., and the calculation of WSPRO gives a value of 5.4 ft., which has a ratio of 0.07. Also from Table 16, the surveyed scour depth calculated from the initial bed elevation is 7.4 ft., which is greater than the scour depths calculated for this flood event. Again, a possible reason is that a flood event greater than the one used in this calculation may have taken place in history.

Saline Bayou Bridge (rainfall event between 12/07/2001-12/14/2001)

Saline Bayou US71-detour.txt - Notepad

File Edit Format View Help

```
T1        scour research
T2        US 71 Bridge over Saline Bayou
T3        Bridge L=280 ft  (Bridge Width = 28 ft)
*         Q
Q         7885
SK        0.0004
*
XT   TEMP  720
GR         195,116    234,103.5   256.5,100  266,97    292,97
GR         324.5,97   420,61      459,68     482,75    520,93
GR         591,110    600,108
*
XS   EXIT  440
GT
SA                       310      545
N                 0.10      0.05       0.10
*
XS   FULV  706
*
BR   BRDG  706    109.4
GR         275,109.4  323,95
GR         336,92    386,73    412,68    420,61    436,62
GR         443,66    507,93    519,95    555,108   275,109.4
CD         3  28  3.0   109.4
AB         3.0
N          0.04
*
XR   ROAD 720  28
GR         185, 113.3  800, 113.3
*
XS   APPR 1000
*
HP 2 BRDG * 110 * 15700
*    SECID  BXL    BXR    PW    YB    QB    K1    K2    K3    K4    V1M    D1M
DP   BRDG   *      *      2.5
*  0 SECID  BXL    BXR    AXL    AXR    K1    PW    YB    YA
DC 0 BRDG   *      *      *      *      1.1   10
*
*  1 SECID  BXL    BXR    AXL    AXR   D50    PW    YB    YA
DC 1 BRDG   *      *      *      *    0.0007  10
*
EX
ER
```

Figure 60

WSPRO input data for Saline Bayou Bridge

```
.LSTNE BAYOU US71-DETOUR.TXT - Notepad
File  Edit  Format  View  Help

        *************************  W S P R O  ***************************
          Federal Highway Administration  -  U. S. Geological Survey
                 Model for Water-Surface Profile Computations.
                Input Units: English  /  Output Units: English
       *----------------------------------------------------------------*
                              SCOUR RESEARCH
                      US 71 BRIDGE OVER SALINE BAYOU
                 BRIDGE L=280 FT  (BRIDGE WIDTH = 28 FT)

            ***  Pier Scour Calculations for Header Record BRDG   ***

                        Constants and Input Variables

                            Pier Width:   2.500
                *--------------------------------------------*
                  Pier Shape Factor                (K1):   1.00
                  Flow Angle of Attack Factor      (K2):   1.00
                  Bed Condition Factor             (K3):   1.00
                  Bed Material Factor              (K4):   1.00
                  Velocity Multiplier              (VM):   1.00
                  Depth Multiplier                 (YM):   1.00
                *--------------------------------------------*

      Scour    ---- Localized Hydraulic Properties ----     -- X-Stations --
  #   Depth     Flow       WSE     Depth  Velocity Froude #   Left      Right
 --  ------ ---------- -------- ------ -------- -------- --------- ---------
  1   5.484   7885.000   87.187 26.187   5.320     .183    348.666   493.221
 --  ------ ---------- -------- ------ -------- -------- --------- ---------

        *************************  W S P R O  ***************************
          Federal Highway Administration  -  U. S. Geological Survey
                 Model for Water-Surface Profile Computations.
                Input Units: English  /  Output Units: English
       *----------------------------------------------------------------*
                              SCOUR RESEARCH
                      US 71 BRIDGE OVER SALINE BAYOU
                 BRIDGE L=280 FT  (BRIDGE WIDTH = 28 FT)

    ***  Live-Bed Contraction Scour Calculations for Header Record BRDG   ***

                        Constants and Input Variables

               *-----------------------------------------------*
                Bed Material Transport Mode Factor (k1):   1.10
                Total Pier Width Value             (Pw): 10.000
               *-----------------------------------------------*

      Scour     -- Flow --          -- Width --        --- X-Limits ---
  #   Depth  Contract Approach  Contract Approach  Side    Contract Approach
 --  ------ --------- --------- -------- --------  ------  -------- --------
  1   2.400  7885.000  7885.000  134.372  144.372  Left:    348.762  348.762
      ---------------------------------------------  Right:   493.134  493.134
      Hydraulic Depths +++++++ Approach:   15.836  ++++++++ Bridge:   14.737
 --  ------ --------- --------- -------- --------  ------  -------- --------
```

Figure 61

An example WSPRO output page for Saline Bayou Bridge

Table 17
Scour depth estimated based on survey records for Saline Bayou Bridge

Distance from baseline (ft.)	Elevation (ft.)			Scour depth for this event (ft.)	Scour depth from initial elevation (ft.)
	As-built	9/13/2001	4/4/2002		
0	109				
11	108.33	95.2	95.2	0	-13.13
25	99.33	93.2	91.9	-1.3	-7.43
42	94.33	85.6	82.3	-3.3	-12.03
59	88.33	77.6	77	-0.6	-11.33
75	82	70.9	68.6	-2.3	-13.4
92	72.67	62.5	61.3	-1.2	-11.37
109	65.6	61.3	61.6	0.3	-4
125	68	64.2	70.4	6.2	2.4
142	68.7	73.8	74.6	0.8	5.9
159	71	76.8	76.5	-0.3	5.5
175	76	82.8	83	0.2	7
192	81.67	91.9	92.3	0.4	10.63
207	88.33	95.2	95.2	0	6.87
254	103.33				

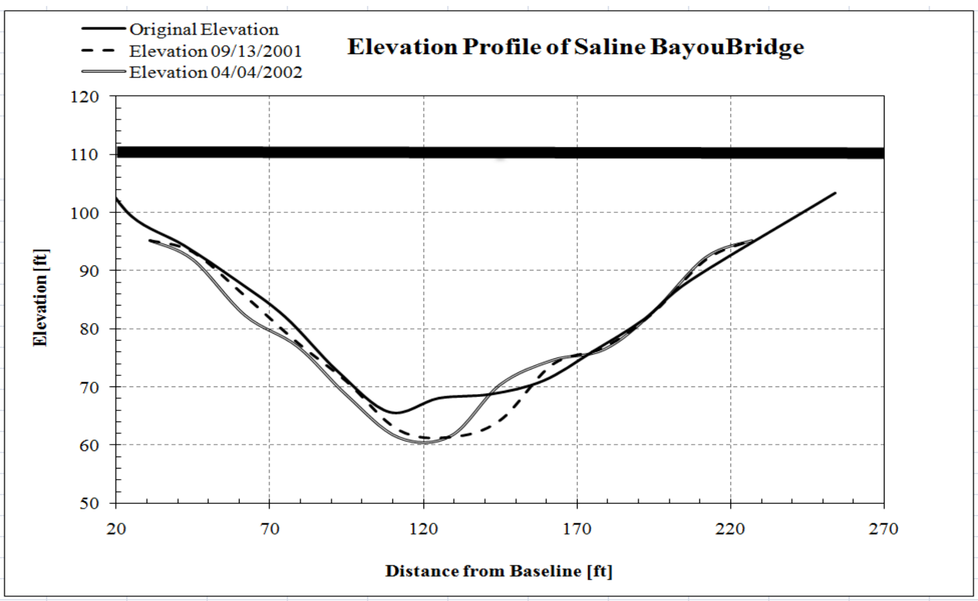

Figure 62
Riverbed elevation profiles from the survey records for this rainfall event at Saline Bayou Bridge

In this case, the survey record gives a scour depth of 3.3 ft., and the calculation of WSPRO gives a value of 5.5 ft., which has a ratio of 0.6. Also from Table 17, the surveyed scour depth calculated from the initial bed elevation is 11.7 ft., which is greater than the scour depths calculated for this flood event. Again, a possible reason is that a flood event greater than the one used in this calculation may have taken place in history.

Summary of All Case Studies

The results of above case studies are summarized in Table 18. For all seven bridges, the ratio of surveyed scour depth to the calculated scour depth ranges from 0.07 to 0.60. Of the seven studied bridges, four types of soils were encountered: sand, silty sand, silty clay, and stiff clay. The difference between the surveyed scour depth and the calculated depth was not correlated well with the soil type. The maximum ratio of the two scour depths occurred in a stiff clay, but not a sand, and the minimum ratio occurred in a silty clay. The reason is that the HEC-18 method does not consider the difference of soil types in the calculation. Moreover, only a few limited soil properties (e.g., mean particle size) are required by the HEC-18 method. Therefore, for sandy soil and cohesive soil, the HEC-18 method cannot detect the difference.

The above findings also demonstrate the need for a better, improved scour prediction method that can take into account of the different soil properties and can differentiate the scour development in sandy soils and cohesive soils.

Table 18
Comparison of the seven case studied bridges

Bridge name	Soil type	Selected rainfall event	Surveyed scour depth (ft.)	Calculated scour depth (ft.)	Ratio
Bogue Chitto Bridge	Sand	10/25/2006-10/27/2006	2.1	4.9	0.43
		08/11/2004-08/12/2004	0.9	2.9	0.31
Tickfaw River Bridge	Silty sand	02/23/2004-02/24/2004	0.9	2.7	0.33
West Fork Calcasieu River	Silty clay	09/21/2005-09/30/2005	2.9	5.0	0.58
Bayou Lacassine Bridge	Silty clay	05/12/2004-05/20/2004	1.1	2.4	0.46
Bayou Nezpique Bridge	Silty clay	11/03/2002-11/08/2002	0.4	5.4	0.07
Mermentau River Bridge	Silty clay	05/11/2004-05/20/2004	2.7	9.6	0.28
Saline Bayou Bridge	Stiff clay	12/07/2001-12/14/2001	3.3	5.5	0.60

CONCLUSIONS

Literature Review on Existing Methods

- Scour predictions of the HEC-18 method tends to give conservative results, leading to costly design and unnecessarily deep or large bridge foundations.
- The HEC-18 method will provide inaccurate scour prediction for cohesive soils.
- The HEC-18 has no consideration of flood or flow duration and hence cannot predict the rate of scour.
- Most existing methods, including the HEC-18, SRICOS-EFA, Simplified SRICOS, and most state DOTs methods, utilize assumed flood events statistically derived from past flood data.
- The SRICOS-EFA method can predict the rate of scour considering the soil's erodibility and the past flood discharge hydrographs.
- Erosional properties of riverbed soils or sediments play an important role in scour depth and rate development, thus the geotechnical properties need to be considered.
- None of the existing methods (except that one study used field monitored hydraulic data) utilize long-term, real-time rainfall data for scour evaluation.
- None of the existing methods makes comparison between long-term field scour survey data sets and predicted or designed scour.

Hydrometeorological Analysis

- The study of the chosen bridge sites demonstrated that precipitation can be obtained from satellite remotely sensed data.
- Basin hydrologic models can be established using GIS software.
- Hydrologic analysis may need to consider the influence of evapotranspiration, especially for the dry and hot seasons, which can be adjusted for relative parameters during the use of HEC-HMS.

The Analytical Method for Hydrologic and Hydraulic Analyses

- A novel method that uses satellite remote sensing data to derive hydraulic properties of flood events for scour analysis was developed and validated in this study.
- This method can yield accurate hydrologic data for scour analysis and hence eliminates the need for using assumed flood events as used by other methods, including the HEC-18 method.
- The developed method also provides a technical alternative for water surface elevation that can be used for bridge design.

Scour Depth Prediction

- Significant discrepancy exists between the surveyed scour depth and the calculated scour depth based on the HEC-18 method. For all the studied cases, the former is always smaller than the latter, and the ratio ranges from 0.07 to 0.60.

- The HEC-18 method usually yields a conservative design, according to the case studies.
- The HEC-18 method does not differentiate the scour development in different soil types. As such, the calculated scour depth based on the HEC-18 method does not reflect the influence of soil types.
- The scour survey records provide useful data for the validation of existing scour design methods and for the development of new, reliable empirical scour design methods.

RECOMMENDATIONS

Bridge scour is a very complex process that involves flow, soil, and obstacle properties. A thorough understanding of the scour development and the development of more reliable design method require synergistic efforts from researchers and engineers from hydraulic engineering, geotechnical engineering, and even experienced field experts. Based on this study, the following recommendations are provided:

- Because this study has derived the scour depth based on real, accurate flood data and the bridge scour survey database can provide the real scour depth, future efforts should be made to modify the existing scour equations by taking into account the influence of different soil types or incorporating more soil properties into the scour equations.

- Because the existing bridge scour database can only provide limited geotechnical data for the riverbed soils, future studies should include a more extensive geotechnical site investigation and testing program to obtain the necessary soil properties for the scour analysis.

- This study has analyzed seven bridges with different rainfall events as case studies. Future work can extend this work by including more case studies.

- The bridges studied in this project are all away from the influence of coastal waves, tides, and even coastal climatic conditions. However, Louisiana has a very long coastal line and there are many bridges along Louisiana coast; there is a need to conduct a study to consider the influence of these coastal conditions on bridge scour.

- It is also recommended that a second phase of research should be conducted to evaluate the errors associated with soil geotechnical properties and to modify the HEC-18 using some case studies with sufficient geotechnical data. Such a study would also need a more detailed geotechnical site investigation and laboratory testing program.

ACRONYMS, ABBREVIATIONS & SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ABSCOUR	Abutment & Contraction Scour
CTT	Cloud Top Temperature
DEM	Digital Elevation Model
DOT	Department of Transportation
EFA	Erosion Function Apparatus
ESRI	Environmental Systems Research Institute
FHWA	Federal Highway Administration
FLDOT	Florida Department of Transportation
GA	Georgia
GADOT	Georgia Department of Transportation
GIS	Geographic Information System
GMRSA	GOES Multispectral Rainfall Algorithm
GOES	Geostationary Operational Environmental Satellite
HEC-18	Hydraulic Engineering Circular documents
HEC-RAS	Hydrologic Engineering Center River Analysis System
HEC-GeoHMS	Geospatial Hydrologic Modeling System
HEC-HMS	Hydrologic Modeling System
IR	Infra-Red
LA	Louisiana
LADOTD	Louisiana Department of Transportation and Development
LRFD	Load Resistance Factor Design
LTRC	Louisiana Transportation Research Center
MDSHA	Maryland State Highway Administration
NCHRP	National Cooperative Highway Research Program
NCEP	National Centers for Environmental Prediction
PW	Precipitable Water
RAS	River Analysis System
RIT	RAS Interactive Tool
NHD	National Hydrography Dataset
SCaMPER	Self-Calibrating Multivariate Precipitation Retrieval Algorithm
SRICOS-EFA	Scour Rate In Cohesive Soil-Erosion Function Apparatus
USGS	United States Geological Survey
USACE	United Stated Army Corps of Engineers
TxDOT	Texas Department of Transportation

WSPRO	Water Surface Profile
a	Pier width
B	the pier width
b_{col}	column width
b_{pc}	pile cap width
D	pier diameter
D^*	effective diameter of structure
D_m	Diameter of the smallest non-transportable particle in the bed material ($1.25D_{50}$) in the contracted section
D_{50}	Median diameter of bed material
D^*_{col}	effective diameter of the column
D^*_{pc}	effective diameter of the pile cap
D^*_{pg}	effective diameter of the pile group
Fr_1	Froude Number directly upstream of the pier = $V1/(gy1)^{1/2}$
g	Acceleration of gravity (32.2 ft/s^2)
H	the water depth
H_{col}	distance between the bed and the bottom of the column
H_{pc}	distance between the bed and the bottom of the pile cap
K_u	0.025 SI units (0.0077 English units)
K_1	Correction factor for pier nose shape
K_2	Correction factor for angle of attack of flow
K_3	Correction factor for bed condition
K_4	Correction factor for armoring by bed material size
k_w	the correction factor for the effect of water depth
k_{sp}	the correction factor for the effect of pier spacing
k_{sh}	the correction factor for the effect of pier shape
k_a	the correction factor for the effect of attack angle
K_s	shape factor
K_α	flow skew angle coefficient
K_f	pile cap extension coefficient
K_{sp}	pile spacing coefficient
K_h	coefficient that accounts for the height of the pile group above the adjusted bed
K_m	number of piles in the direction of the unskewed flow
L	Length of pier
Q	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W, ft^3/s

Q_1	Flow in the upstream channel transporting sediment, ft^3/s
Q_2	Flow in the contracted channel, ft^3/s
R_e	the Reynolds number equal to VB/ν
S_1	Slope of energy grade line of main channel, m/m
τ_c	critical shear stress
T	pile cap thickness
V^*	shear velocity in the upstream section, m/s
V_1	Mean velocity of flow directly upstream of the pier, ft/s
V	mean flow velocity
V	the upstream velocity
W	Bottom width of the contracted section less pier widths, ft
W_p	projected width of the piles in the pile group
W_1	Bottom width of the upstream main channel that is transporting bed material, ft
W_2	Bottom width of the main channel in the contracted section less pier widths, ft
y_o	Average existing depth in the contracted section, ft
y_1	Average depth in the upstream main channel, ft
y_2	Average depth in the contracted section, ft
$y_{0(max)}$	limiting value for the effective diameter calculation
$\dot{z}$	erosion rate
Z_{max}	the maximum depth of pier scour
Ω	Fall velocity of bed material based on the D_{50}, m/s
τ_0	Shear stress on the bed, Pa
τ_{max}	maximum shear stress
ρ	Density of water
Θ	parameter quantifying the concentration of fine sediments in suspension

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