FLOW AND BED TOPOGRAPHY IN THE MISSISSIPPI RIVER

Final Technical Report

By

Colin R. Thorne and Lisa J. Hubbard

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NOTATION USED IN TABLES

A	Bend arc angle (degrees)
Av. Dst Elev	Average bed elevation at downstream crossing (ft MSL)
Av. Upst Elev	Average bed elevation at upstream crossing (ft MSL)
Dmax	Maximum scour depth in bend.
dm1....4	Lowest bed elevation above datum. Number indicates 1st, 2nd, 3rd or 4th quarter of bend (ft MSL)
Dst X Loc	Location of downstream crossing (RM)
Loc.	Location of measurement in river miles (RM)
p	Sinuosity (Channel length/valley length)
Q	Discharge (thousands of cfs)
R	Bend radius (ft)
S	Water surface slope (ft/ft)
Upst X loc.	Location of upstream crossing (RM)
Vtoe	Maximum depth averaged velocity at the toe of the outer bank
w	Crossing width (ft)
WS	Water surface elevation at bend apex (ft MSL)
λ	Meander wave length (ft)
% error	((Predicted value - Observed value) / Observed value) x 100
Subscripts	Obs = observed value, Pred = predicted value

ABSTRACT

A data base for bend geometry, flow pattern and bed topography of selected bends on the Lower Mississippi River was compiled. Preliminary analysis was undertaken to establish the applicability of analytical and empirical models to predict scour depth and outer bank velocity at bends.

The results indicate that the Bridge (1982) model of bend flow may be used to predict scour depth associated with formative flows in the the channel, usually with an accuracy of about +/- 10 to 20 %. Scour predictions for flows other than those around the formative discharge are prone to greater uncertainty and tend to underestimate the observed scour depth. Application of the model is not recommended for such flows.

Velocity may also be predicted for formative flows provided that the ratio of bend radius to width is greater than about 4. The WES design line for outer bank velocity prediction is very conservative in that it always over predicts the observed outer bank velocity. It did not do quite as well as the Bridge model, overall. In many cases observed near bank velocities were similar to or less than the mean velocity at the crossing upstream. This runs contrary to established theory and observation and casts some doubt on the validity of the data. The validity of the field data deserves further investigation.

KEYWORDS

Bend modeling Bend scour River Meander bends Bank Stabilization
Mississippi River Outer bank velocity Scour prediction Velocity prediction

TECHNICAL REPORT

1. Methodology

Recent studies of bend flow have illustrated a loose relationship between geometry, velocity distribution and bed topography over a wide range of channel sizes. However, there has been a severe shortage of reliable data against which to test existing equations and models describing these relationships, especially for large rivers. The purpose of this study was, therefore, to use archive data from the Lower Mississippi River to develop a data base on bend geometry, velocity distribution and bed topography and to test some empirical and analytical models for river bend analysis against the data to investigate their applicability to such a large river.

Data were collected for a series of bends selected by mutual agreement between the sponsors and the researchers from the potamology surveys of the Lower Mississippi. In view of the limited scope of this project. only a few "representative locations" could be specified. Within this scope of study, data for 47 different flows at 10 different reaches of river were collected.

The data were reduced and manipulated by the second author, who was employed on the project to produce a data base containing the basic parameters of bend geometry, flow velocity and bed topography. The principal investigator then used that data base to apply predictive techniques and compare observed and predicted values of maximum near bank scour depth and maximum, near bank, depth-averaged velocity for each of the flow/bend combinations.

The results were put into graphical form and errors analysed to set limits to the applicability of the methods.

2. Results

The data base produced by the research assistant is presented in Appendix A, Table 1. These data were used first to calculate the mean depth at the crossings and the mean velocity of the river at the crossings. These parameters help to define the characteristic depth and flow speed of the river excluding the influence of any bend curvature. Next the data were used to apply the Bridge analytical model of bend flow and bed topography (Bridge, 1982). In a previous project for the US Army WES this model had been found to give potentially useful predictions of outer bank velocity (Thorne and Abt, 1990). The data were then used to apply the empirical prediction method for velocity over the toe of the outer bank used at WES in riprap design for bendways. The design curve is shown in Fig. 1.

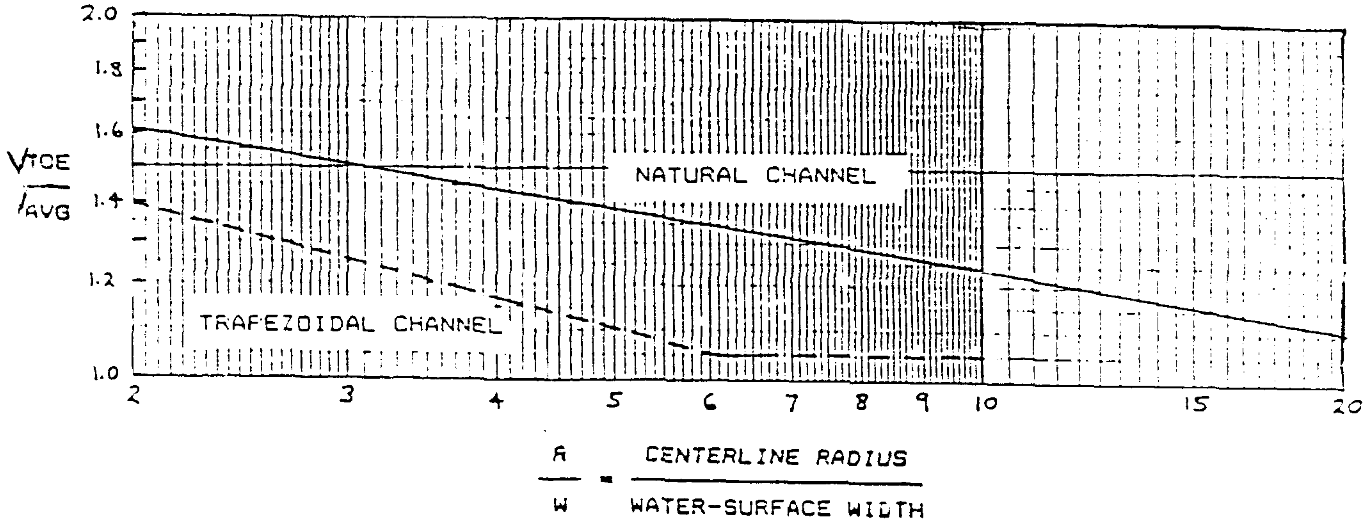

Figure 1. WES design diagram for prediction of outer bank velocity at a bend

The line for natural channels can be defined by the equation:

$$\frac{V_{toe}}{V_{avg}} = 1.75 - 0.5 \log \left(\frac{R}{W}\right)$$

The results of these applications are listed in Appendix A, Table 2 and are shown graphically in Figs. 2 - 10.

3. Discussion of Results

3.1 Scour Depth Prediction (Bridge Model)

Figure 2 shows that the predicted values of maximum scour depth close to the outer bank scatter around the line of perfect agreement. There appears to be a general tendency to under-estimate the observed scour depth, but there is no systematic trend in the scatter as a function of absolute scour depth. Nearly two thirds of the predicted values fall within +/- 50% of the observed value and about a third falls within +/- 20%. Given the inherent difficulties of predicting bend scour, the Principal Investigator believes that this is a reasonable and somewhat encouraging result.

Examination of the distribution of errors in prediction as functions of discharge (Fig. 3) and R/w (Fig. 4), suggest reasons for the errors and limitations to the applicability of the Bridge model. If a band of +/- 20% is taken to be acceptable for design purposes, then Fig. 3 shows that the model tends to under predict observed scour depths at low flows and, possibly, to over predict at high flows. This pattern of errors can be at least partially explained on a rational basis.

At low discharges the river inherits the bed topography left by the previous high flow. Hence, the deep hole scoured by that high flow remains, perhaps to be slowly filled in by the lower flow depending on the pattern of sediment transport and deposition. However, Bridge's model starts with a flat bed and a trapezoidal cross-section and then allows the flow being modelled to excavate a scour hole appropriate to its particular flow geometry and erosive power. It is, therefore, prone to under-predicting the observed scour depth where that depth is a product of a previous high flow rather than being adjusted to the actual discharge at the time. It is not possible to model bend scour dynamically throughout the hydrographic year using the Bridge model since the bed scour is not adjusted to the prevailing flow and this explains the under-prediction of scour depth at low flows less than about 500,000 cfs. However, if the model is required only to predict **maximum** scour during the year, then this may not be critical since maximum scour is unlikely to be associated with flows well below the formative discharge.

For flows greater than 500,000 cfs the model does much better with over half the predictions in the +/- 20 band. Such flows approach the formative flow for the channel when it is expected that bed topography would be adjusted to the imposed flow. There are still 6 cases where there is a 30%+ under-prediction and 3 with over-estimates greater than 30% and these require further investigation to find the causes of the problems.

If the very high discharges cause overbank flow then strictly the model should not be applied to such situations. The results show that scour depth may be over-estimated. This is because the model assumes that the flow remains in the thalweg channel and continues to scour ever more deeply, when in fact the flow overtops point and middle bars, occupies sloughs, and may spill out on to the flood plain. Under these circumstances the effective discharge in the thalweg channel running between the point bar and the concave bank is unknown, but is considerably less than the total flow. Further investigation into the specific nature of overbank flow at the particular bends would be needed to determine if this was the cause of the over-estimated depths.

Two of the under-estimates of greater than 30% come from Marshall Brown's Point Revetment. The R/w for this bend is less than 0.5 (Appendix A, Table 2 and Fig. 4). Previous research has shown that the Bridge model is inapplicable to extremely tight bends where R/w is less than 1 and so these two points should be ignored. Of the other 4 points with serious underestimates of scour depth, three come from a rising limb and one from a falling limb. The falling limb point may be distorted by the persistence of a deep scour hole from the preceding peak flow. There is no obvious explanation for the error in the rising limb flows without further detailed examination of the bends in question, which is beyond the scope of the present study.

3.2 Outer Bank Velocity Prediction (Bridge Model)

Figure 5 shows the observed and predicted maximum outer bank velocities. Generally, the Bridge model over predicts the observed values to a considerable degree. There are very few under-predictions (and no significant ones) and to this extent the model would be conservative if used in a design approach.

The results must, however, cast some doubt on the applicability of the observed data in as much as many of the observed near bank velocities are actually *slower* than the mean velocity at the crossings (calculated from observed discharge, width and mean depth using the continuity equation). Conventional thought on bend flow is that skewing of the velocity field at a bend results in the velocity maximum being located close to the outer bank at the bend exit. The Bridge model will always predict an elevated near bank velocity downstream of the bend apex. Since the observed data do no show this, it suggests that further examination of the way in which they were collected and selected needs to be undertaken to confirm that they are appropriate for use in this analysis.

A plot of error in prediction versus discharge (Fig. 6) shows no systematic trend in the over-prediction with errors of 0 to 60 percent possible at any flow. However, a plot against R/w (Fig. 7) does suggest that the upper bound to the errors tends to increase as R/w decreases. For R/w greater than about 4, only three points shows an error greater than 50%, and these appear as outliers from the main trend, but the top of the cluster of points for R/w less than 4 is greater than 50%.

Further examination of the observed data is required to verify that they are true representative values for the maximum velocity adjacent to the bank anywhere in the bend. Particularly, this further investigation would center on the way in which the measurements were made in the field, the way they were plotted and the way in which these plots were used to derive depth-averaged velocities over the bank toe.

3.3 Outer Bank Velocity Prediction (WES Empirical Line)

Outer bank velocity predictions based on the WES line also tend to over-predict the observed values (Fig. 8). This is inevitable because the WES method is an upper bound approach and because it always predicts that the maximum outer bank velocity at a bend is higher than the mean velocity in the approach channel. Since the observed data do not show this, there is further support for a re-examination of those data.

The error plots for the WES method in Figs 9 and 10 show no systematic variation with discharge, but again indicate that (ignoring outliers) the general degree of over-prediction increases as R/w decreases. In absolute terms the errors associated with the WES design approach are similar to those of the Bridge model. Bridge has 13 points within the +/- 20% band, and 25 within +/- 50%: the figures for the WES method are 8 and 24, respectively.

CONCLUSIONS AND RECOMMENDATIONS

Based on an initial analysis of the data base for selected bends of the Lower Mississippi River, the following conclusions may be drawn:

1. The analytically derived bend flow and bed topography model developed by Bridge can be used to make predictions of maximum scour depth associated with formative discharges between about 500,000 and 900,000 cfs. It is likely that the predicted values may be too low by 10 to 20%, but in some cases they may be as great as 30% too low and in one case it is 50% too low. For flows greater than 900,000 cfs over-prediction was likely, with some errors greater than +20%. While some of the under-predictions may be discounted because they came from extremely tight bends where the Bridge model is known to be inapplicable, some further investigation is required to determine the cause of the larger errors for other specific situations.
2. The bend flow model under-estimates the scour depth associated with low flows. This is the case because at such low flows the scour depth is not adjusted to the prevailing flow, but persists from the previous, formative flow. Consequently, the

bend flow model cannot be used to model annual scour depth dynamics due to changing discharge.

3. It is questionable whether the model should be applied to discharges which produce over-bank flow although it would be likely to produce conservative results for design scour depth.

4. The limited data obtained in this study suggest that the Bridge model may have the potential to be used to predict maximum outer bank velocity for bends with R/w values greater than about 4. The predicted values may over-estimate observed values by up to about 50%.

5. The observed data seem to indicate that, contrary to conventional thinking, outer bank velocities at bends of the Mississippi are actually lower than the mean velocity at the crossings, especially in bends with R/w ratios less than 4. Further investigation is needed to verify this significant finding, which could have important implications, or could be a function of the way in which the data have been collected or analysed.

6. The WES design line for outer bank velocity is very conservative and in practically all cases over predicted the observed velocity.

7. Compared to the Bridge model's predictions (with 60% of predictions lying within 50% of the observed value), the WES approach only produced 40% of its predictions within 50% of the observed value.

8. The data base established in this study should be a valuable tool in further testing and evaluation of analytical and empirical design approaches.

ACKNOWLEDGEMENTS

The data base was developed by Lisa Hubbard. Her diligence and skill are much appreciated. The active support and encouragement of all the staff at the River Engineering Branch, Mississippi River Commission, US Army Corps of Engineers, Vicksburg Division is gratefully acknowledged. Time to undertake the preliminary analysis was donated by the University of Nottingham through cost sharing.

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APPENDIX A

APPENDIX TABLE 1. DATA BASE FOR SELECTED BENDS ON THE LOWER MISSISSIPPI

Table 1 Mississippi River Data * dm is not depth (sub from WS)

Date	Bend Radius (ft)	Width (ft)	Arc Angle	Slope	Loc. dm1 (RM)	dm1 (ft)	Loc dm2 (RM)	dm2 (ft)	Loc. dm3 (RM)	dm3 (ft)	Loc. dm4 (RM)	dm4 (ft)	Discharge (000 cfs)	WS at Apex (ft MSL)	Sinuosity	Wavelength (ft)	Upstream Upst X Loc (Rm)	Upstream Av. Upst Eleve (ft-MSL)	Downstream Dst X Loc (Rm)	Downstream Av. Dst Elev (ft-MSL)
Arkansas City Q																				
Bend Name	Smith Point Revetment				Bend Location			599.1 RM			ALWP	115								
18-21 Nov 68	6500	3200		6.7E-05	600.4	63	599.4	52	599.0	19	598.0	34	322.50	122.01	1.34	33100	601.2	99.36	597.0	91.58
11-18 Feb 69	7667	4225		8.5E-05	600.6	59	599.0	17	598.2	23	597.4	53	1392.38	149.63	1.30	37300	601.2	105.03	596.6	105.42
5-7 Mar 69	7667	3550		5.3E-05	600.4	61	599.0	17	598.4	21	597.4	46	660.00	134.02	1.32	36700	601.2	96.78	596.6	94.71
17-25 Jul 69	6667	3800		7.3E-05	600.4	58	599.0	27	598.2	20	597.4	53	354.67	140.82	1.33	36500	601.2	101.63	596.6	103.67
15-18 Sep 69	6167	3425		4.6E-05	600.4	62	599.0	22	598.2	18	597.4	46	264.00	121.00	1.32	36700	601.2	100.17	596.6	98.29
Bend Name	Prentiss Revetment				Bend Location			583.8 RM			ALWP	104								
11-14 Mar 68	11000	2850	135	9.5E-05	585.2	75	583.8	61	583.0	35	581.8	37	279.00	114.06	1.32	40000	586.2	91.75	581.2	74.07
25Apr-1May 68	11500	4375	120	5.8E-05	585.4	72	583.8	67	583.0	33	582.0	36	737.00	128.08	1.32	39900	586.2	99.46	581.2	92.27
5-11 Jun 68	11500	4450	120	5.0E-05	585.2	73	583.8	67	583.0	35	581.4	33	1093.29	139.54	1.33	39800	586.2	101.26	581.2	86.94
28Aug-3Sep 68	11000	2450	135	1.0E-04	585.4	67	583.8	60	582.8	42	581.2	47	286.71	116.64	1.30	40600	586.2	91.16	581.2	69.07
Bend Name	Prentiss Revetment				Bend Location			583.7 RM			ALWP	104								
16-22 Oct 68	11000	2500	135	1.3E-04	585.4	64	583.8	66	583.2	53	581.2	44	229.14	112.21	1.30	40650	586.2	92.75	581.2	70.44
18-25 Feb 69	12000	4500	115	6.4E-05	585.2	67	584.8	62	583.0	54	582.0	44	1239.63	142.54	1.33	39700	586.2	97.17	581.2	98.76
29Jul-6Aug 69	11500	4325	120	7.0E-05	585.0	70	583.8	61	583.2	65	581.2	48	636.78	130.52	1.32	40000	586.2	103.00	581.2	95.13
18-29 Sep 69	11000	2950	130	9.8E-05	585.4	69	583.8	54	583.4	60	581.2	60	264.25	114.65	1.32	40100	586.2	91.56	581.2	83.82
Bend Name	Catfish Point Revetment				Bend Location			573.8 RM			ALWP	102								
23-29 Oct 68	14000	2400	75	2.8E-05	574.8	45	573.8	28	573.2	38	572.8	35	289.14	109.46	1.07	34500	575.5	74.18	572.0	69.06
10-12 Mar 69	14000	2425	75	4.0E-05	574.8	28	573.6	18	573.6	20	572.8	23	612.83	122.31	1.07	34500	575.5	69.65	572.0	68.38
24-30 Apr 69	16000	2750	65	8.4E-05	574.8	43	574.0	26	573.6	22	572.6	38	1131.71	136.30	1.06	36700	575.5	75.26	571.8	77.90
30Sep-2Oct 69	14000	2300	75	2.6E-05	574.8	37	574.0	29	573.6	34	572.8	35	252.67	108.90	1.07	34500	575.5	74.88	572.0	72.[illegible]7

Date	Bend Radius (ft)	Width (ft)	Arc Angle	Slope	Loc. dm1 (RM)	dm1 (ft)	Loc. dm2 (RM)	dm2 (ft)	Loc. dm3 (RM)	dm3 (ft)	Loc. dm4 (RM)	dm4 (ft)	Discharge (000 cfs)	WS at Apex (ft-MSL)	Sinuosity	Wavelength (ft)	Upstream Upst X Loc (Rm)	Upstream Av. Upst Eleve (ft-MSL)	Downstream Dst X Loc (Rm)	Downstream Av. Dst Elev (ft-MSL)
Bend Name	Catfish Point Revetment				Bend Location			573.6	RM		ALWP	102								
24Jun-6Jul 71	14000	2550	80	2.9E-05	574.8	44	574.0	32	573.6	34	572.6	43	406.08	115.76	1.07	36600	575.5	75.85	571.8	80.28
15-22 Mar 72	15000	2700	75	6.6E-05	575.2	37	574.0	26	573.6	29	572.6	41	911.13	130.84	1.07	36600	575.5	75.29	571.8	78.70
27Jul-2Aug 72	14000	2600	75	2.3E-05	574.8	43	574.0	29	572.8	31	572.6	37	377.43	116.09	1.09	35800	575.5	79.40	571.8	74.17
Bend Name	Cypress Bend Revetement				Bend Location			569.1	RM		ALWP	101								
4-16 Sept 68	8000	2300	200	7.0E-05	571.2	44	569.4	34	567.8	32	567.6	32	189.46	104.55	1.56	36500	571.8	70.58	566.4	65.18
10-12 Mar 69	8500	2525	170	1.2E-04	571.4	40	569.4	36	567.8	28	566.8	24	612.83	120.575	1.58	36200	571.8	75.40	566.4	68.54
24-30 Apr 69	9000	3175	160	1.3E-04	571.6	50	569.4	36	568.0	37	567.0	36	1131.71	133.865	1.59	35800	571.8	78.43	566.4	86.04
30Sep-2Oct 69	8000	2400	200	6.2E-05	571.6	52	569.4	40	567.8	38	566.8	39	252.67	107.775	1.58	36200	571.8	73.29	566.4	68.86
Bend Name	Cypress Bend Revetement				Bend Location			568.8	RM		ALWP	101								
24Jun-6Jul 71	8500	2825		7.4E-05	571.4	55	569.4	38	567.6	38	567.0	36	406.08	114.328	1.55	40100	571.8	80.28	565.9	81.18
15-22 Mar 72	9083	3175		8.2E-05	571.2	40	569.4	34	567.8	31	566.8	27	911.13	128.783	1.56	40000	571.8	78.70	565.9	78.95
27Jul-2Aug 72	8500	2900		7.1E-05	571.2	40	569.4	36	567.6	31	567.0	37	377.43	114 563	1.55	40300	571.8	74.17	565.9	83.55
Bend Name	Marshall Browns Point Revetment				Bend Location			448.0	RM		ALWP	48								
21-31 Oct 68	1400	3075	135	8.8E-05	450.6	11	449.0	20	446.4	-19	446.2	-19	320.00	57.66	1.25	54200	451.2	39.50	444.8	20.47
2-8 Apr 69	1450	3075	115	7.5E-05	450.4	10	448.8	14	446.4	-40	445.0	-25	811.71	77.77	1.22	48400	450.4	38.48	444.8	18.65
2-14 Jul 69	1450	3150	115	7.5E-05	450.4	14	448.8	16	446.2	-31	445.8	-20	710.77	77.41	1.22	48400	450.4	42.00	444.8	33.38
15-18 Dec 69	1400	3050	135	8.2E-05	450.2	11	448.6	9	446.6	-34	446.4	-34	362.50	60.45	1.25	54200	451.2	38.46	444.8	17.33
Bend Name	False Point Revetment				Bend Location			443.2	RM		ALWP	46								
21-31 Oct 68	7750	2125	120	3.3E-05	444	-60	443.4	-71	443.0	-55	442.0	-42	320.00	56.18	1.26	26800	444.8	20.47	441.6	12.83
2-8 Apr 69	8000	2375	110	7.6E-05	444	-65	443.4	-77	443.0	-58	441.8	-49	811.71	76.24	1.27	26600	444.8	18.65	441.6	18.13
2-14 Jul 69	8000	2325	110	6.6E-05	444	-68	443.4	-66	442.8	-50	441.8	-37	710.77	73.05	1.26	26900	444.8	33.38	441.6	20.88
15-18 Dec 69	7750	2050	120	3.6E-05	444	-75	443.2	-66	443.0	-58	441.8	-48	362.50	59.06	1.27	26700	444.8	17.33	441.6	13.71
Bend Name	Delta Point Revetment				Bend Location			437.7	RM		ALWP	45								
21Oct-6Nov 68	8250	3075		5.9E-05	439.8	8	438.2	-8	436.2	-57	436.0	-43	290.91	55.44	1.58	41400	440.8	32.14	434.6	17.06
2Apr-18Apr 69	8750	3275		6.7E-05	440.8	5	437.8	-9	436.2	-43	436.0	-62	811.71	75.84	1.59	41300	440.8	32.96	434.5	24.27
16Dec-8Jan 70	8250	3125		3.2E-05	439.2	5	438.0	-7	436.2	-31	436.0	-53	445.65	56.93	1.58	41500	440.8	30.32	434.6	13.00

Date	Bend Radius (ft)	Width (ft)	Arc Angle	Slope	Loc. dm1 (RM)	dm1 (ft)	Loc. dm2 (RM)	dm2 (ft)	Loc. dm3 (RM)	dm3 (ft)	Loc. dm4 (RM)	dm4 (ft)	Discharge (000 cfs)	WS at Apex (ft-MSL)	Sinuosity	Wavelength (ft)	Upstream: Upst X Loc (Rm)	Upstream: Av. Upst Eleve (ft-MSL)	Downstream: Dst X Loc (Rm)	Downstream: Av. Dst Elev (ft-MSL)
Non-Revetted Bends																				
Natchez Q																				
Bend Name	St. Catherine Townhead				**Bend Location**			350.5	RM		**ALWP**	16								
29 Apr-5May 71	18500	3975		5.5E-05	352.8	-10	350.6	-32	349.6	-51	348.6	-33	459.57	34.29	1.06	49900	353.0	7.19	348.0	11.00
18-27 Jan 72	19500	4075		4.6E-05	353.0	-14	350.6	-34	349.6	-50	348.6	-44	793.70	44.31	1.06	49800	353.0	6.13	348.0	7.54
15-21 Jun 72	18000	2950		5.5E-05	353.0	-10	350.6	-33	349.6	-48	348.6	-50	345.29	29.06	1.05	50100	353.0	4.61	348.0	
Bend Name	Esperance Point				**Bend Location**			346.3	RM		**ALWP**	14								
29 Apr-5May 71	9750	3100	100	4.0E-05	347.2	-39	346.4	-60	345.8	-75	344.8	-98	459.57	33.22	1.20	29900	348.0	11.00	344.6	-17.69
18-27 Jan 72	10250	3450	95	5.7E-05	347.4	-32	346.4	-74	345.8	-76	344.8	-94	793.70	43.93	1.19	30100	348.0	7.54	344.6	-4.71
15-21 Jun 72	9500	2100	95	8.5E-05	347.8	-27	346.4	-73	346.2	-75	344.8	-81	345.29	28.02	1.26	28500	348.0	-2.39	344.6	-14.80
Bend Name	Downstream Esperance point				**Bend Location**			343.3	RM		**ALWP**	14								
29 Apr-5May 71	20000	2125	40	3.6E-05	344.0	-65	343.4	-87	343.2	-75	342.4	-47	459.57	32.60	1.02	27000	344.6	-17.69	342.0	-14.33
18-27 Jan 72	20500	2450	40	4.5E-05	344.2	-73	343.4	-101	343.2	-87	342.4	-54	793.70	43.18	1.02	27000	344.6	-4.71	342.0	-14.07
15-21 Jun 72	20000	1975	40	2.9E-05	344.2	-68	343.4	-93	343.2	-83	342.4	-54	345.29	27.31	1.02	26800	344.6	-14.80	342.0	-17.50

APPENDIX TABLE 2. RESULTS OF APPLICATION OF PREDICTIVE METHODS

Mississippi data — Tue, Sep 24, 1991

	Discharge (cfs)	Bend Radius	Width (ft)	R/W	Obs Vtoe (fps)	Pred Vtoe (fps)	% error	Obs Dmax (ft)	Pred Dmax (ft)	% error	WES Pred Vtoe	% error
1	322500.0	6500.000	3200.000	2.031	4.450	6.790	52.584	103.000	56.000	-45.631	7.103	59.612
2	1392380.0	7667.000	4225.000	1.815	7.390	11.020	49.120	133.000	136.000	2.256	11.976	62.060
3	660000.0	7667.000	3550.000	2.160	4.990	7.640	53.106	117.000	104.000	-11.111	7.898	58.280
4	354670.0	6667.000	3800.000	1.754	4.900	4.260	-13.061	121.000	116.000	-4.132	3.874	-20.929
5	264000.0	6167.000	3425.000	1.801	3.700	5.900	59.459	103.000	57.000	-44.660	6.002	62.229
6	279000.0	11000.000	2850.000	3.860	4.390	6.600	50.342	79.000	51.000	-35.443	6.395	45.673
7	737000.0	11500.000	4375.000	2.629	6.750	9.150	35.556	95.000	87.000	-8.421	9.071	34.391
8	1093290.0	11500.000	4450.000	2.584	6.900	9.180	33.043	106.000	118.000	11.321	9.911	43.643
9	286710.0	11000.000	2450.000	4.490	4.590	15.640	240.741	75.000	52.000	-30.667	6.536	42.389
10	229140.0	11000.000	2500.000	4.400	4.710	6.790	44.161	68.000	40.000	-41.176	6.727	42.827
11	1239630.0	12000.000	4500.000	2.667	6.250	9.610	53.760	99.000	142.000	43.434	9.330	49.275
12	636780.0	11500.000	4325.000	2.659	5.350	8.850	65.421	83.000	84.000	1.205	8.226	53.764
13	284250.0	11000.000	2950.000	3.729	4.000	5.900	47.500	61.000	54.000	-11.475	5.681	42.029
14	289140.0	14000.000	2400.000	5.833	3.410	4.100	20.235	81.000	57.000	-29.630	4.6[illegible]	36.704
15	612830.0	14000.000	2425.000	5.773	5.500	5.570	1.273	104.000	86.000	-17.308	6.5[illegible]	19.502
16	1131710.0	16000.000	2750.000	5.818	7.750	7.970	2.839	114.000	99.000	-13.158	9.218	18.938
17	252670.0	14000.000	2300.000	6.087	3.230	3.840	18.885	80.000	54.000	-32.500	4.386	35.780
18	406080.0	14000.000	2550.000	5.490	4.250	4.690	10.353	84.000	64.000	-23.810	5.507	29.577
19	911130.0	15000.000	2700.000	5.556	7.250	7.150	-1.379	105.000	92.000	-12.381	8.362	15.341
20	377430.0	14000.000	2600.000	5.385	4.700	4.630	-1.489	87.000	64.000	-26.437	5.482	16.645
21	189460.0	8000.000	2300.000	3.478	2.750	3.740	36.000	73.000	82.000	12.329	3.580	30.180
22	612830.0	8500.000	2525.000	3.366	5.370	8.460	57.542	97.000	117.000	20.619	7.982	48.642
23	1131710.0	9000.000	3175.000	2.835	9.500	10.750	13.100	98.000	168.000	71.429	9.798	3.134
24	252670.0	8000.000	2400.000	3.333	3.050	4.820	58.033	70.000	86.000	22.857	4.540	48.856
25	406080.0	8500.000	2825.000	3.009	4.220	6.660	57.820	78.000	88.000	12.821	6.376	51.080
26	911130.0	9083.000	3175.000	2.861	5.730	9.050	57.941	102.000	139.000	36.275	8.720	52.176
27	377430.0	8500.000	2900.000	2.931	3.220	5.250	63.043	84.000	105.000	25.000	4.883	51.649
28	320000.0	1400.000	3075.000	0.455	5.730	7.510	31.065	77.000	34.000	-55.844	11.007	92.086
29	811710.0	1450.000	3075.000	0.472	6.720	8.690	29.315	118.000	78.000	-33.898	12.857	91.324
30	710770.0	1450.000	3150.000	0.460	6.370	8.400	31.868	108.000	71.000	-34.259	12.221	91.847
31	362500.0	1400.000	3050.000	0.459	5.400	7.210	33.519	94.000	42.000	-55.319	10.363	91.909
32	320000.0	7750.000	2125.000	3.647	4.220	5.440	28.910	127.000	83.000	-34.646	6.199	46.903
33	811710.0	8000.000	2375.000	3.368	7.500	8.100	8.000	153.000	146.000	-4.575	8.814	17.516
34	710770.0	8000.000	2325.000	3.441	7.710	9.150	18.677	141.000	98.000	-30.496	11.424	48.16[illegible]
35	362500.0	7750.000	2050.000	3.780	5.400	5.480	1.481	134.000	96.000	-28.358	6.196	14.735
36	290910.0	8250.000	3075.000	2.683	4.060	6.590	62.315	112.000	63.000	-43.750	6.235	53.570
37	611710.0	8750.000	3275.000	2.672	5.780	8.950	54.844	138.000	121.000	-12.319	8.882	53.66[illegible]
38	445650.0	8250.000	3125.000	2.640	5.360	7.080	32.090	110.000	72.000	-34.545	8.250	53.920
39	459570.0	18500.000	3975.000	4.654	4.400	5.380	22.273	85.000	45.000	-47.059	6.047	37.424
40	793700.0	19500.000	4075.000	4.785	5.100	6.300	23.529	94.000	64.000	-31.915	7.191	41.005

Mississippi data

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	Discharge (cfs)	Bend Radius	Width (ft)	R/W	Obs Vtoe (fps)	Pred Vtoe (fps)	% error	Obs Dmax (ft)	Pred Dmax (ft)	% error	WES Pred Vtoe	% error
41	345290.0	18000.000	2950.000	6.102	4.250	5.590	31.500	79.000	35.100	-55.570	6.501	52.973
42	459570.0	9750.000	2950.000	3.305	6.670	7.800	16.942	131.000	57.000	-56.489	9.941	49.041
43	793700.0	10250.000	3450.000	2.971	6.500	8.360	28.615	138.000	99.000	-28.261	9.566	47.163
44	345290.0	9500.000	2100.000	4.524	3.250	7.420	128.000	109.000	68.000	-37.615	7.694	136.750
45	459570.0	20000.000	2125.000	9.412	4.300	7.110	65.349	120.000	195.000	62.500	5.432	26.316
46	793700.0	20500.000	2450.000	8.367	7.500	7.110	-5.200	144.000	69.000	-52.083	8.712	16.155
47	345290.0	20000.000	1975.000	10.127	4.150	4.490	8.193	120.000	57.000	-52.500	5.176	24.727

Figure 2. Observed versus predicted Maximum Outer Bank Scour Depth

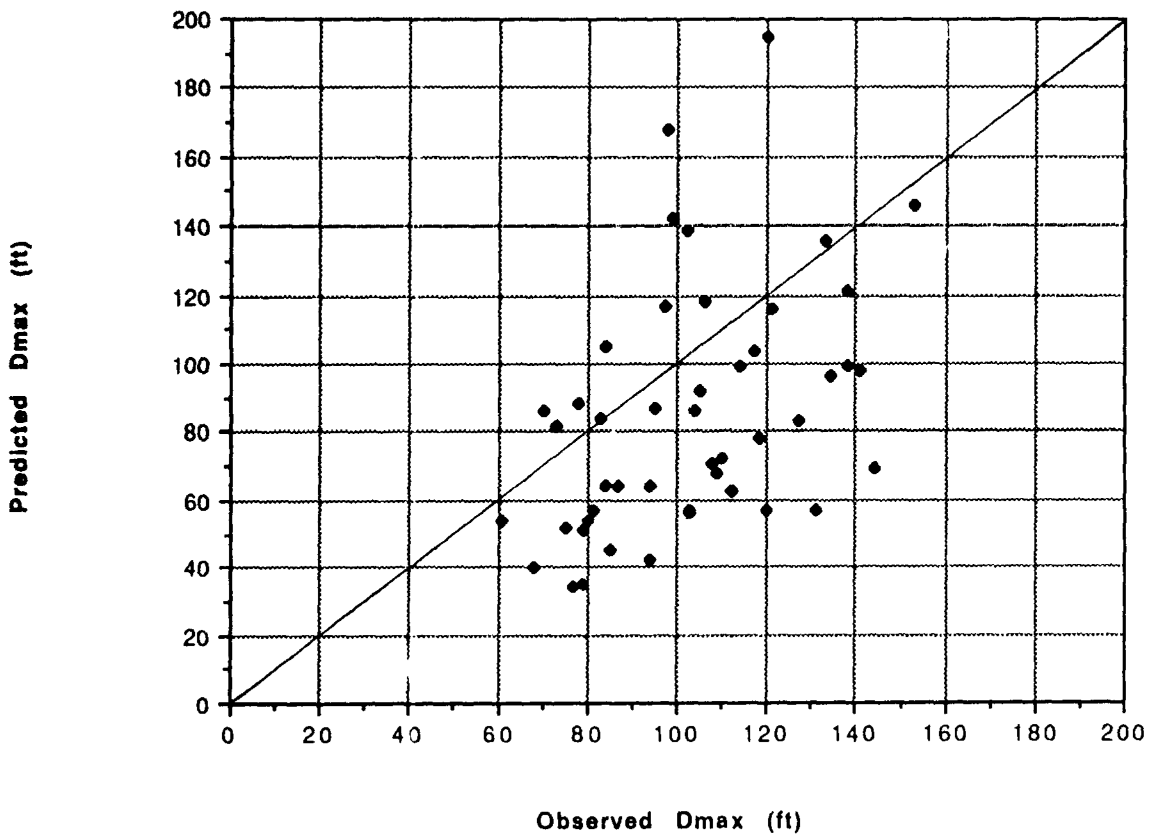

Figure 3. Percentage error in predicted maximum scour depth versus discharge

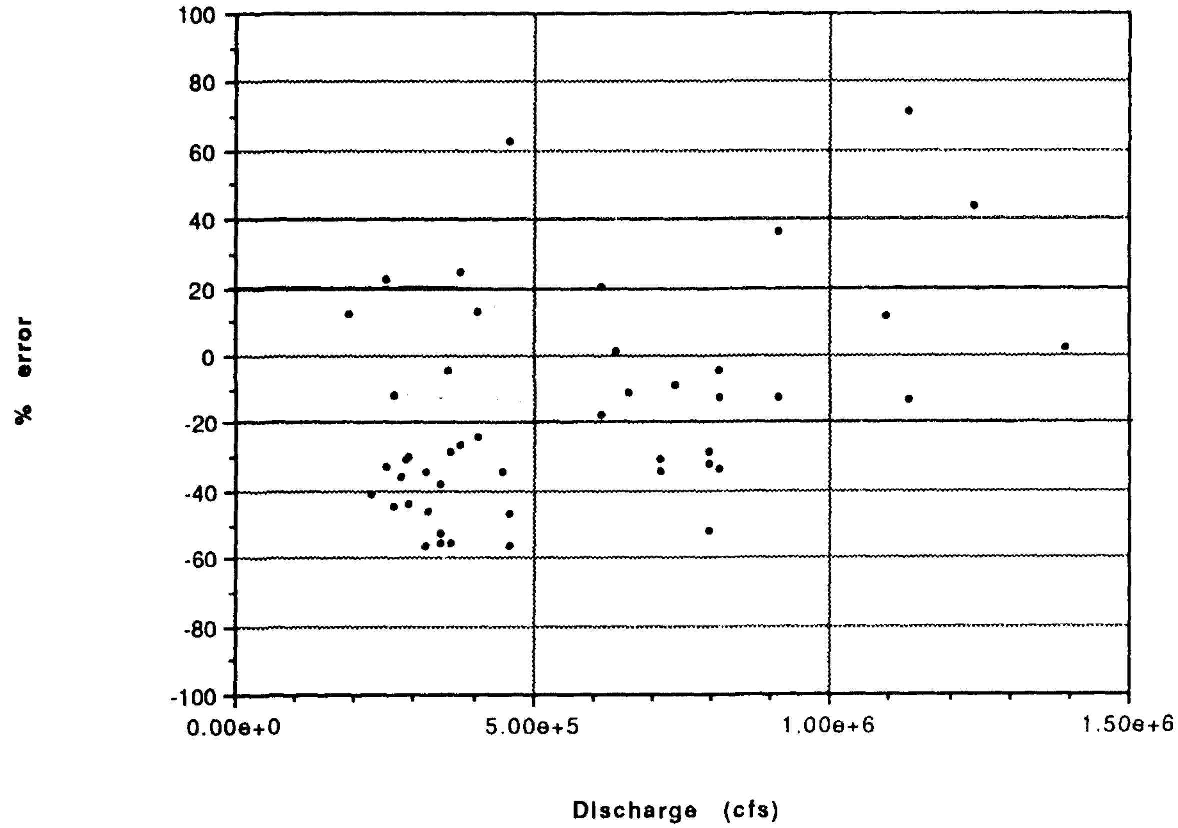

Figure 4. Percentage error in predicted maximum scour depth versus R/w

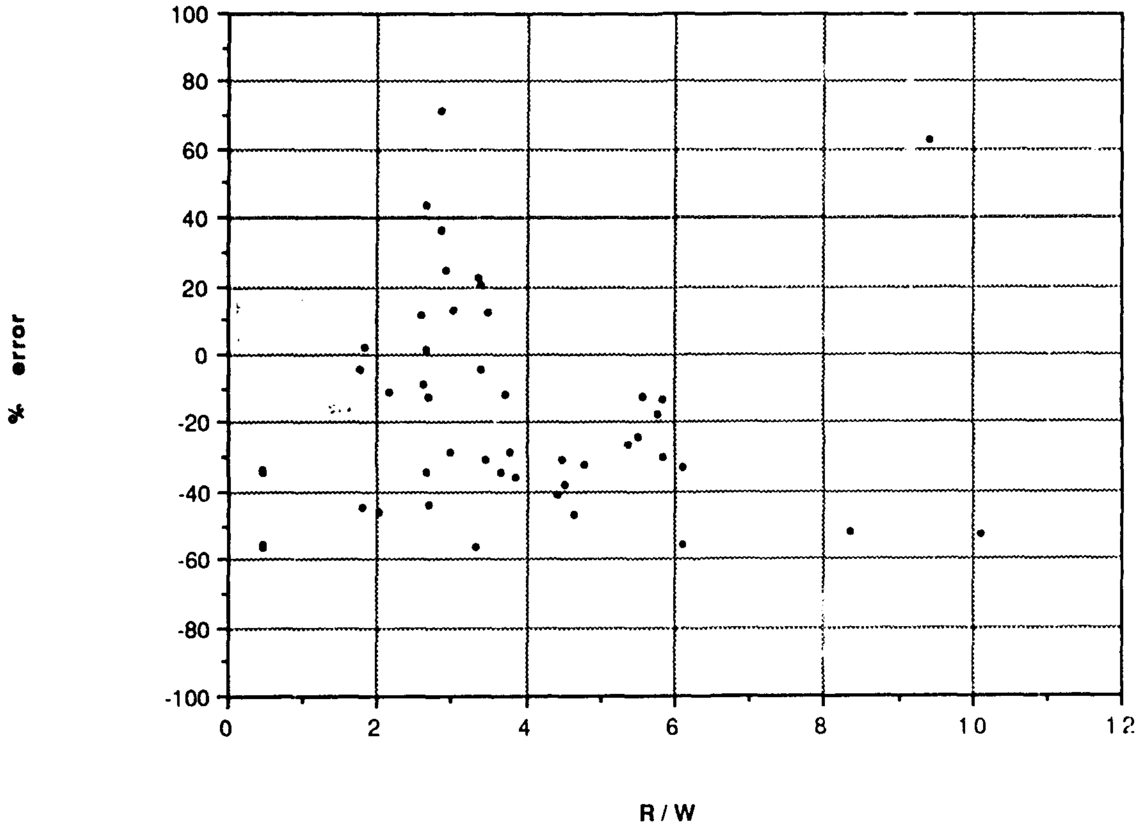

Figure 5. Observed versus predicted maximum toe velocities from the Bridge (1982) model

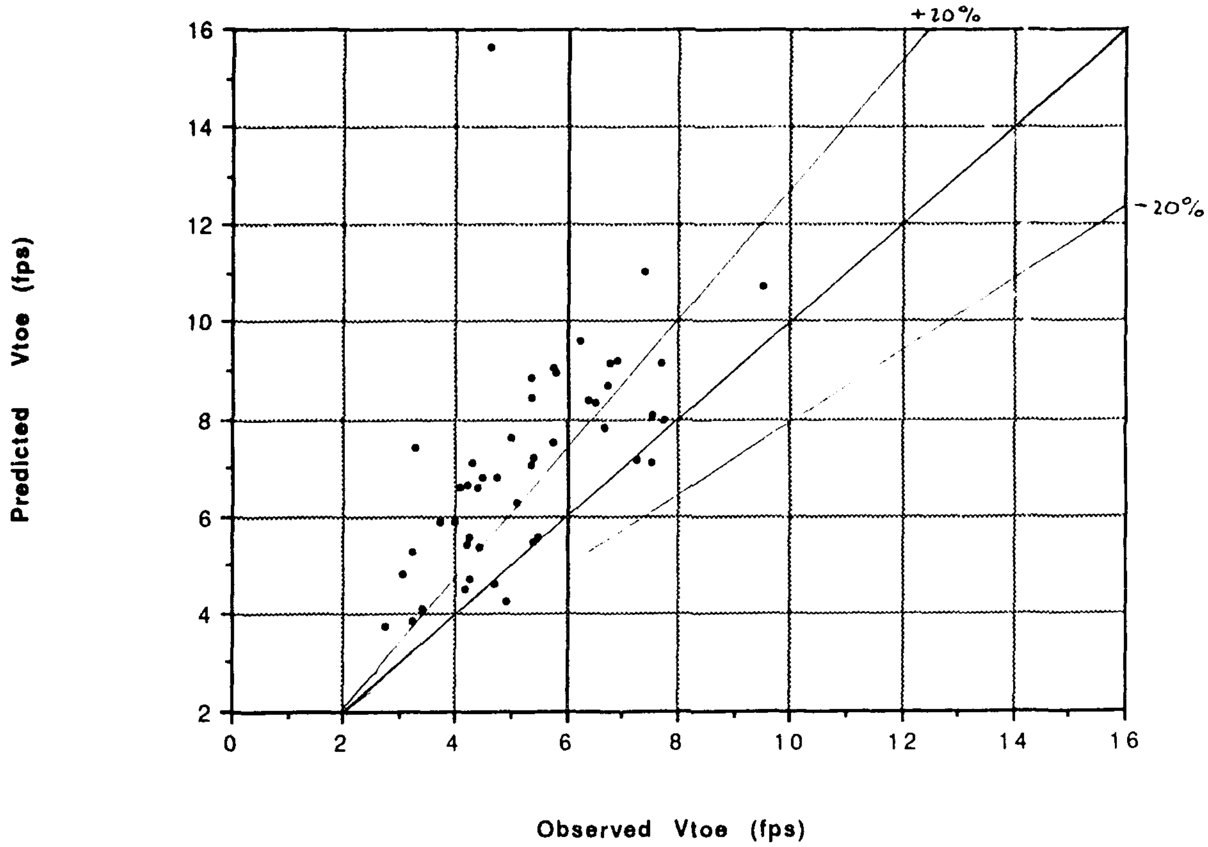

Figure 6. Percentage error in predicted maximum outerbank velocity (Bridge model) versus discharge

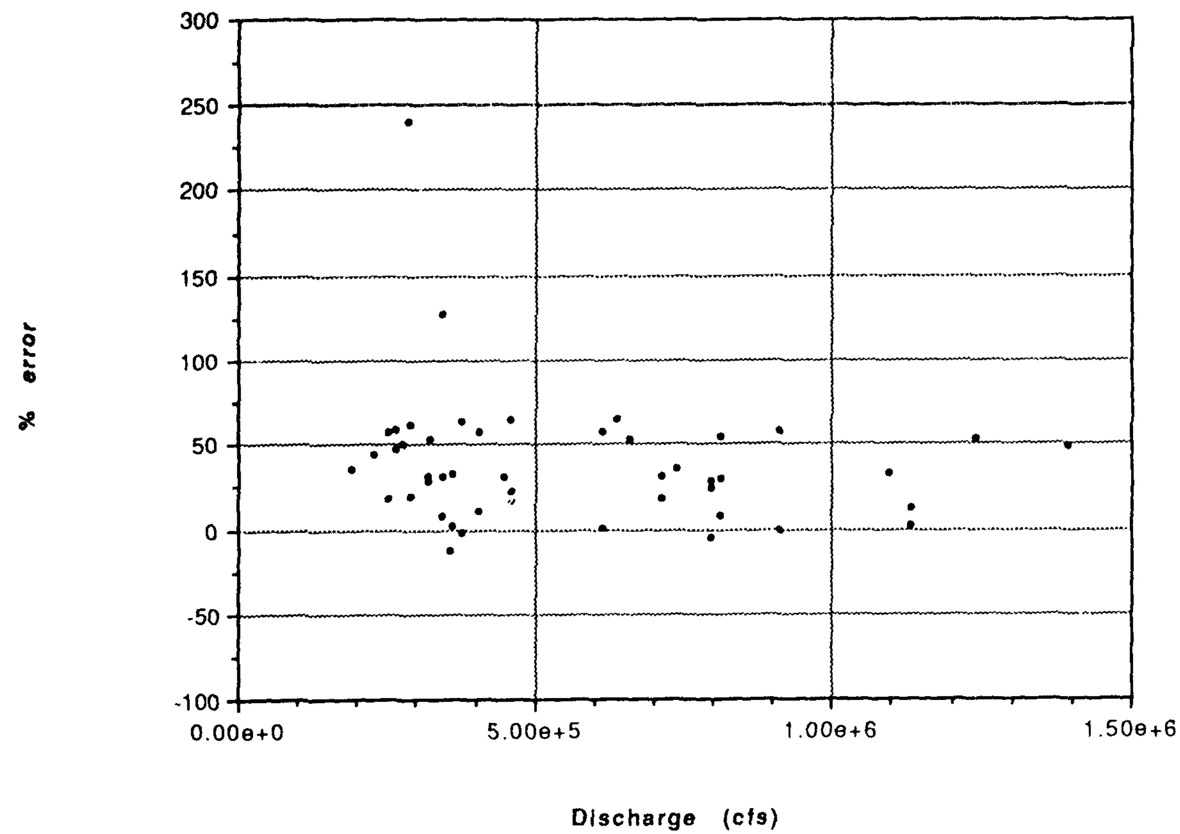

Figure 7. Percentage error in predicted maximum outerbank velocity (Bridge model) versus R/w

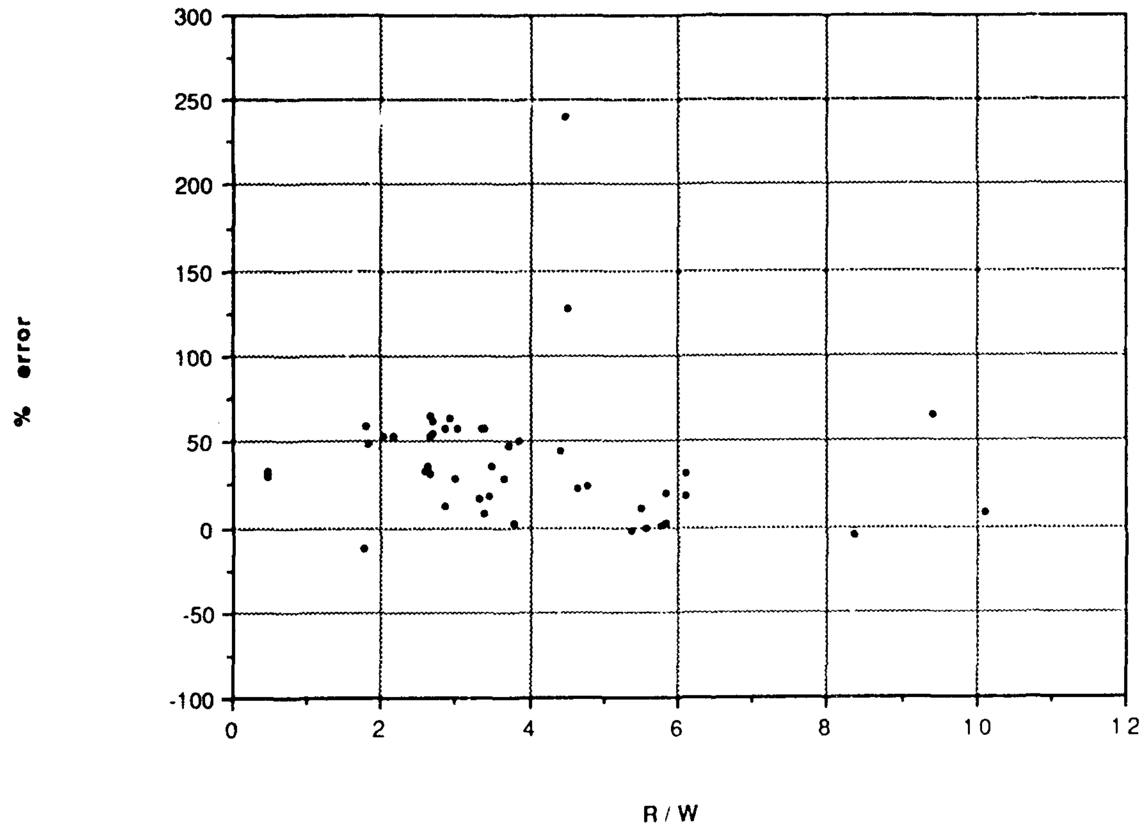

Figure 8. Observed versus predicted maximum outerbank velocity from the WES empirical curve

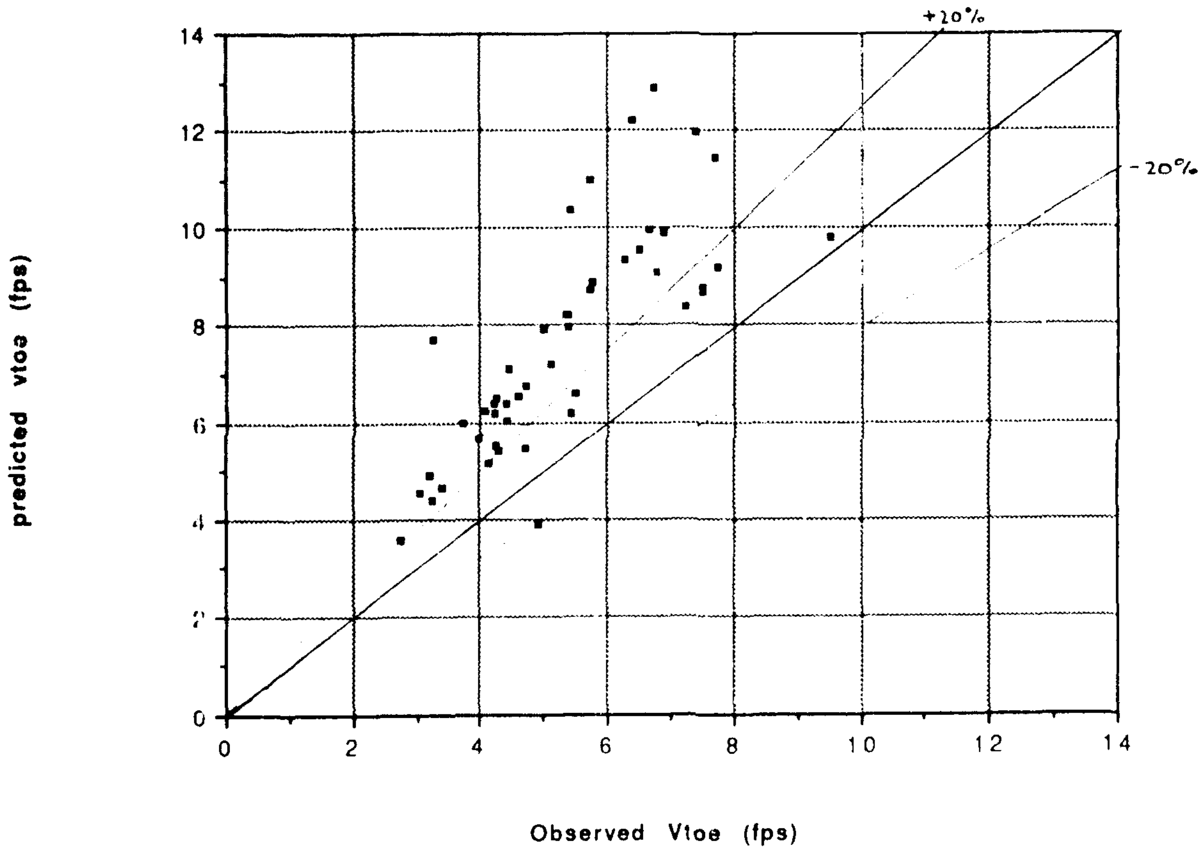

Figure 9. Percentage error in predicted maximum outerbank velocity (WES curve) versus discharge

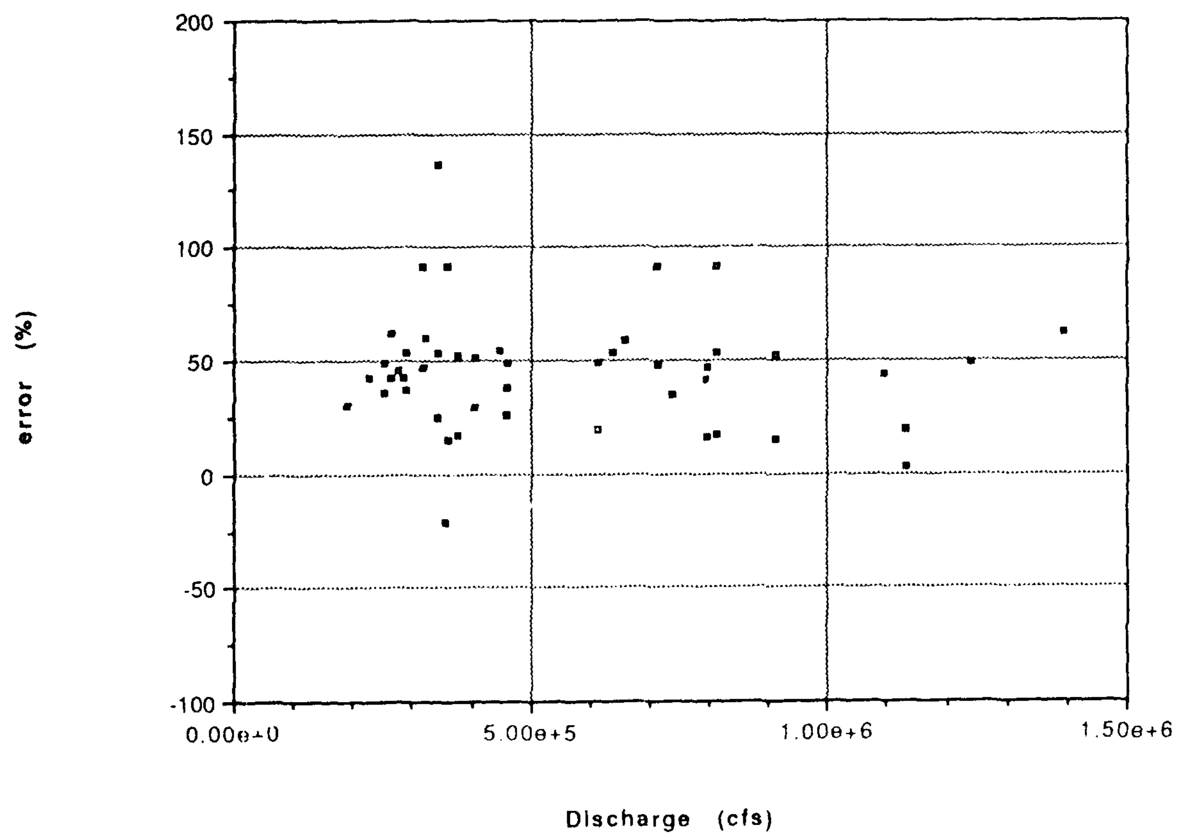

Figure 10. Percentage error in predicted maximum outerbank velocity (WES curve) versus R/w