AN ASSESSMENT STUDY OF FIVE SEDIMENT TRANSPORT MODELS

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Abstract

When modeling alluvial streams, it is usually assumed that the channel bed is fixed. However, more often than not, natural river systems are unsteady and, therefore, changing constantly. These unsteady conditions (changes in velocity, cross sections, water temperature, bed movement, etc.) may vary quite drastically between river systems; therefore, it is improbable that a model capable of handling all unsteady conditions in a river system will ever be developed. Although some models have been developed to handle many unsteady river systems, most of them do not consider the effects of changes in bed movement. The changes in bed movement are caused by sediment transport.

There are many factors that affect the sediment transport process including channel geometry, sediment characteristics, flow velocity, flow depth, and water temperature. Consequently, there are many sediment transport models available for estimating the sediment discharge in rivers. It is up to the engineer to decide which factors are most important and to select a model which will consider them. When choosing the factors needed in determining the sediment discharge, the availability and quality of the input data for use in any sediment model must also be considered. In many cases, the necessary data is difficult to obtain or may be of poor quality. In these situations a model that requires very little input may be preferred. On the other hand, if the data is available and of good quality, a model that can utilize all the available data would be favorable. Therefore, when deciding on a model, it is imperative to know which models are available along with their capabilities and limitations. To help the engineer decide which model is most suitable for his particular application, this assessment study of several commonly used sediment models is conducted. The goal is to develop a set of useful model selection guidelines.

Introduction

There are many factors that affect the sediment transport process including channel geometry, sediment characteristics, flow velocity, flow depth, and water temperature. Consequently, there are many sediment models available for estimating the sediment discharge in rivers. It is up to the engineer, when choosing a model, to decide which factors are most important and to select a model which will consider them. The engineer must also consider the availablility and quality of the input data that is to be used in the sediment transport model. To help the engineer decide which model is most suitable for his particular application, five (5) sediment models will be studied and assessed to determine their applicability on different rivers and their ability to predict the sediment discharge. In this study, the sediment discharge is considered to be the bed material load discharge (BML), i.e., the sediment discharge for all sediment sizes in the bed for which the finest size is > 10% of the bed material.

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General Information

The five sediment transport models chosen for this study include Ackers and White's Method (1973), Meyer-Peter and Muller's Equation (1948), the Modified Einstein Procedure (Colby and Hembree, 1955), Toffaleti's Method (1968), and Yang's Method (1973). Ackers and White's model and Yang's model are total load models, i.e., the total sediment discharge is computed from one equation based on dimensional analysis. The Modified Einstein Procedure and the Toffaleti's method, however, compute the sediment discharge for certain grain sizes ranges and the summation of sediment discharge in these ranges produces the total discharge. The Meyer-Peter and Muller Equation is designed to compute BML when there is no suspended load in the channel and when the sediment sizes in the stream are larger than 0.5 mm.

A total of 330 data sets are selected for this study from the following six (6) rivers: Atchafalaya River at Simmesport, Louisiana (Toffaleti, 1968); Mississippi River at Tarbert Landing, Mississippi (Toffaleti, 1968); Mississippi River at St. Louis, Missouri (Jordan, 1965); Red River at Alexandria, Louisiana (Toffaleti, 1968); the Rio Grande near Benalillo, New Mexico (Nordin, 1964); Middle Loup River at Dunning, Nebraska (Hubbell and Matjeka, 1959); and Niobrara River near Cody, Nebraska (Colby and Hembree, 1955). All of these rivers are sand bed channels with mild slopes. They are also all in the subcritical flow regime. The Atchafalaya, Mississippi, and Red rivers are considered large rivers with minimum depths of 10 feet; whereas the Rio Grande, Middle Loup, and Niobrara rivers are small rivers with maximum depths of 5 feet. The wash load for all rivers except the Atchafalaya and Red rivers is fine sand (0.125 mm). These two rivers have very fine sand as wash load. Since the measured sediment discharge on all of the rivers except the Middle Loup and Niobrara rivers does not represent the entire depth of flow, the sediment discharge in these rivers has been modified to account for the sediment discharge in the unmeasured zone by Toffaleti's Method (1968).

Procedure

Each model will be tested using a computer program, MODELS (Lewis, 1985), to determine its applicability when actual sediment data is used (Applicability Study). Average sediment parameters are then used in each model to determine its ability to predict the sediment discharge (Prediction Study). Five (5) tests will be conducted to determine the model sensitivity to changes in temperature, slope, sediment size, flow depth, and water discharge (velocity) due to measurement errors. Each of these parameters will be perturbed to determine its affect on the computed sediment discharge (Sensitivity Study). Finally, a set of model selection guidelines will be determined for engineer use based on the results of the above analyses. These guidelines will consider data requirements, data availability, ease of model usage, model limitations, and model accuracy.

The accuracy of each model will be determined by a discrepancy ratio (D_R) which is the ratio of the computed BML to the actual (or observed) BML. When $D_R < 1$, the model is undercomputing the BML; when $D_R > 1$, the model is overcomputing the BML; and when $D_R = 1$, the model is computing the same BML that is measured in the channel. The mean discrepancy ratio ($\bar{D}_R$) is the average of all D_R values in a given channel section. In this study, a model is considered to be reliable if 65% or more of the data sets fall into the range of $0.5 \leq D_R \leq 2.0$, i.e., the model does not undercompute the BML by more than 50%, and it does not overcompute the BML by more than 100%.

Applicability Study

The results of the applicability study are depicted in Table 1 which represents the analyses of D_R for each method on BML.

Ackers and White Method This method is designed to compute the total sediment discharge for all sediment sizes larger than 0.04 mm. When computing BML, the Ackers and White method does not perform well except in the very shallow streams with large sediment sizes and very little wash load (i.e. Rio Grande at section F and Middle Loup River). Using D_{35}, the method overcomputes the BML excessively on all rivers except the Atchafalaya River. The method is expected to overcompute the BML since BML is always smaller than the total sediment discharge. However, if D_{50} is used as the effective grain

diameter instead of D_{35}, the method computes less sediment and the results are very good on all rivers except on the Atchafalaya River with more than 65% of the data sets falling in the acceptable range. The Atchafalaya River has a substantial amount of silt in the channel bed. If the data sets with more than 10% silt in the bed are omitted, $\bar{D}_R$ improves from 2.03 TO 0.95 with 77% of the data sets falling within the acceptable D_R range as opposed to 44% previously. The model cannot compute BML for this type of river.

Meyer-Peter and Muller Method This method is designed to compute the total sediment discharge for large sediment sizes (> 0.5 mm) and when there is no suspended sediment in the channel, i.e., bed load only. Since the BML used in this study includes smaller sediment sizes and suspended load, the data sets used do not meet this criterion. Consequently, the results in Table 1(c) indicates that there is no real correlation between the actual and computed sediment discharge. When computing BML on the Middle Loup River, 70% of the data falls in the acceptable range. This river is very shallow with flow depths that are less one ft. and it has medium coarse sand (0.25 - 0.5 mm) in the channel bed. Since the depths are so shallow, this model may be applicable to the river. On the other hand, the river does not have a wide range of flow and, therefore, the results in Table 1(c) may be misleading.

Modified Einstein Method Although it is the most complex method, it tends to be the method that is most applicable for all of the rivers. The method tends to overcompute the sediment discharge yet the relationship between the computed and observed sediment discharge is linear. Table 1(d) indicates that $\bar{D}_R$ for all river data is 1.36 and has a S_d of 0.41. Also 93% of all the data falls within the acceptable D_R range.

Toffaleti's Method Although this method is designed to compute sediment discharge on large deep rivers, it also does well on some smaller rivers. The method performs adequately in the acceptable D_R range on all rivers except the Atchafalaya and Middle Loup rivers. The method tends to undercompute the sediment discharge on these two rivers considerably. On the Atchafalaya River, $\bar{D}_R$ is 0.83 and only 62% of the data points fall within the acceptable range. The method undercomputes the BML on this river because of the large amounts of silt in the channel bed. If the data sets containing more than 10% silt in the channel bed are omitted, the results improve with $\bar{D}_R$ being 0.90 and 76% of the data sets falling in the acceptable range. It is also noted tat 48% of the data sets do not overcompute or undercompute BML by more than 25%. The Middle Loup River, on the other hand, is a very small and shallow river with large sediment grain sizes. Only 47% of the data fall within the acceptable range with $\bar{D}_R$ being 0.56. This river has flow depths of less than 1 ft. which may be outside of the range of rivers for which this method can compute BML.

Yang's Method This method is designed to compute BML. Table 1(f) indicates that the method performs well on all rivers except the Atchafalaya River, Mississippi River at Tarbert Landing and Red River. Each of these rivers contains sediment sizes smaller than 0.125 mm. It is clear that Yang's method is not capable of handling this type of sediment. Table 1(f) also shows that on the smaller rivers which all contain large sediment sizes, the method tends to slightly undercompute the BML. Yet an average of 88% of the data points on these rivers fall in the acceptable D_R range with a $\bar{D}_R$ of 0.88 and S_d of 0.35. It is also noted that half of those points do not overcompute or undercompute the observed BML by more than 25%. The sediment discharge may also be computed using D_{35} instead of D_{50}.

Prediction Study

The results of the prediction study are shown in Table 2 which represents the analyses of D_R for each method on BML respectively.

Ackers & White Method Table 2(a) shows that Ackers and White's method when using an average D_{35}, performs well on all rivers except the Atchafalaya and Red Rivers which have large amounts of very fine sand and silt in the channel bed. The method overpredicts the BML on all rivers except these two with more than 70% of the data points falling in the acceptable range. Using an average D_{50} instead of D_{35} improves the results on all rivers except the Atchafalaya River and Mississippi River at Tarbert Landing. On the other rivers, more than 80% of the data points fall in the acceptable range. For the same

reasons discussed in the applicability study, this method is not applicable for use in the Atchafalaya River. The Mississippi River at Tarbert Landing has a large amount of very fine sand in the channel (but not in the bed), and therefore, needs the smaller effective grain size (D_{35}) to predict more BML. On the other hand, the Red River has a large amount of very fine silt in the channel bed, and needs the larger D_{50} size to predict less BML. On this river, more than 80% of the data points fall in the acceptable range and $\overline{D}_R$ is 0.83 when D_{50} is used while only 62% fall in the acceptable range with $\overline{D}_R$ being 1.83 when D_{35} is used.

Meyer-Peter and Muller Method For the same reasons mentioned in the applicability study, this method is not capable of predicting the sediment discharge on the data used in this study. Table 2(c) verifies this result.

Modified Einstein Method The method does very poorly on all rivers when predicting BML where average sediment parameters are used instead of the actual ones. Table 2(d) indicates the method overpredicts the BML by 60% on the Niobrara River with 80% of the data falling within the acceptable D_R range. Since this is the river that the model was developed on, the results may be somewhat biased. This method is highly dependent on observed data, i.e., the grain size distribution of the bed material as well as the suspended load and the sediment concentration. Since in most cases, this information is not available, the method is not very reliable when predicting the sediment discharge.

Toffaleti's Method When using average sediment parameters, Table 2(e) indicates that this method does not perform adequately. The $\overline{D}_R$ value is 0.58 for all rivers, and only 44% of the data falls within the acceptable range. However, the S_d is about 0.38. This implies that there is little scatter between the points on the data plots. If all of the data is plotted for all rivers, a linear relationship is determined. The data on all the rivers are linearized by a best-fit technique and shifted to the 45° line (perfect correlation) to correct the computed sediment discharges. The following correction equation is obtained:

$$QS_{MT} = 10^{(\log(QS_T) + 0.352)}$$

where QS_{MT} is the sediment discharge computed by Toffaleti's method and then modified (the modified Toffaleti Method), and QS_T is the sediment discharge computed by Toffaleti's method. Table 2(f) indicates that this method when modified, performs very well on all rivers including the Atchafalaya River which contains large amounts of silt. Overall, this method, after modification, has a $\overline{D}_R$ of 1.30 and S_d of 0.88 with 77% of the data points falling in the acceptable D_R range. Since the adjustment is not constant in Cartesian coordinates, S_d should not be the same. The modified Toffaleti method should have more scatter than the Toffaleti method. It is important to note that the modified Toffaleti method performs well regardless of river or sediment size.

Yang's Method When an average D_{50} is used to predict the BML, the method tends to underpredict the sediment discharge. It does well on all of the rivers without any very fine sand or silt in them. On the small rivers the $\overline{D}_R$ value is 0.87 with 88% of the data points falling in the acceptable range. It is also noted that 44% of the data sets do not overpredict or underpredict the BML by more than 25%.

Sensitivity Study

Ackers and White's method is very sensitive to errors in depth and discharge measurements. A +5% error in depth causes a reduction in the computed sediment discharge by more than 15%. Likewise a +25% error in the discharge measurement results in an increase in the computed sediment discharge by more than 40%. The method is also sensitive to errors in grain size measurements. It is better to have a D_{35} value that is too large rather than too small. Although the method is sensitive to errors in temperature and slope, the change in sediment discharge is not significant, .i.e., 10% error in temperature produces less than 10% change in the sediment discharge. The Modified Einstein Procedure is sensitive to errors in depth and discharge measurements; however 25% errors in measurements produce less than 25% changes in the computed sediment discharge. The method is not sensitive to errors due to measurement of the temperature, d_{65}, or slope. Toffaleti's

method is sensitive to all of the parameters used in the study. Errors in the measurement of all of the parameters produce changes in the sediment discharge on the same order of magnitude, except for the D_{65} parameter which is less sensitive.

Summary

Five sediment transport models have been studied and assessed to determine their applicability and their ability to predict the sediment discharge in natural channels. A total of 330 data sets from six rivers in the U.S. has been used. On some of the rivers the measured sediment dishcarge is not representative of the entire cross section. A procedure by Toffaleti (1968) is used to account for the sediment discharge in the unmeasured zone. The summation of the sediment discharge in the measured and unmeasured zones produce the the total sediment discharge. The discrepancy ratio (D_R) is used to assess how well a method performs. If 65% or more of the data sets on a particular river have D_R values in the range of 0.5 - 2.0, the method is considered acceptable. Five tests have been done to determine model sensitivity to temperature, slope, sediment size, depth, and discharge (velocity) due to errors in measurement. Finally a set of guidelines have been determined based on this research as is shown in the conclusions which follow.

Conclusions

Results The following results were obtained from this study:

(1) With the exception of the Meyer-Peter and Muller Equation which is not applicable for the field data used in this study, each of the models is capable of computing the sediment discharge within it's limitations.

(2) The factor found to be most important when deciding which model to use is the type of sediment in the river. All four models computed the sediment discharge when there is no significant amount of very fine sand in the channel. However, Yang's Method is not capable of computing the sediment discharge when very fine sediment is present in the channel bed. Acker's and White's Method deteriorates when there is a significant amount of silt in the channel.

(3) All four models are capable of computing the sediment discharge within the limitations of the models. The Modified Einstein Procedure performed best, but it required an excesssive amount of observed data.

(4) The best model for predicting the sediment discharge is Toffaleti's Method with the following adjustment:

$$QS_{MT} = 10^{(\log(QS_T) + c)}$$

where QS_{MT} is the sediment discharge computed by Toffaleti's Method and adjusted, QS_T is the sediment discharge computed by Toffaleti's Method, and c is an adjustment factor (aproximately 0.35). Ackers and White's Method is capable of predicting the sediment discharge within the limits of the model The Modified Einstein Procedure is not capable of predicting the sediment discharge.

(5) Although the models have been found to be quite sensitive to their key input parameters, it has been found that the error in the input does not hurt the overall accuracy of the model when compared with actual data.

Suggested Method Selection Guidelines

Applicability Study The following guidelines for method applicability may be drawn from this analysis:

(a) Use the Modified Einstein Procedure if all of the required data are available.

(b) If the data are not available for the Modified Einstein Procedure, use Ackers and White's method with D_{50}. If there is a significant amount of silt in the bed, this method cannot compute BML.

(c) If the grain size distribution or a gradation coefficient is available, use Toffaleti's method to compute BML. Although this method does not perform as well as Ackers and White's method, it is capable of handling the very fine sand and silt sediment sizes.

(d) Use Yang's method to compute BML on rivers for which the wash load consists of all sediment sizes smaller than 0.125 mm. This method performs as well as Ackers and White's method and Toffaleti's method wherever it is applicable.

Prediction Study When predicting the sediment discharge, the following method selection guidelines should be heeded:

(a) With an average grain size distribution and average D_{65}, use the adjusted Toffaleti method to compute BML.

(b) On rivers that do not have a significant amount of silt in the bed, use Ackers and White's method to compute BML. An average D_{50} should be used as the effective grain diameter. This method performs as well as the modified Toffaleti method wherever it is applicable.

(c) Yang's method may be used to predict BML on rivers for which the effective grain size is larger than 0.125 mm.

Study Limitations

This study is limited to only five sediment discharge formulas with data on six rivers. These rivers range in size from very small rivers with shallow depths (<100 ft wide and <1 ft deep) to very large and deep rivers (>3,000 ft wide and >50 ft deep). The flow regime for all rivers is subcritical flow. All the rivers in this study have mild bottom slopes (<10 ft/mi). Some of the rivers used in this study contain large unmeasured zones, and therefore, the total observed sediment discharge is less than it should be. This study accounts for the unmeasured zone by the method used by Toffaleti (1968). The bed material load dischage is obtained by omitting the sediment discharge in the grain size ranges smaller than 10% of what is in the bed. For the applicability study, actual data input is obtained from the original sources. For the prediction study, average sediment data is used instead of the actual data. The sensitivity study is limited to only five parameters, i.e., temperature, slope, sediment size, flow depth, and discharge.

Recommendation for Further Research

Further research to enhance the present study would include testing more sediment transport formulas and using field data on more rivers. Sensitivity of other parameters, e.g., sediment size distribution, would also enhance this study. Also, since the modified Toffaleti Method was found to be the best method for predicting the sediment discharge it would be desireable to verify the method using flume data in addition to other river data. Since the present study used data in the subcritical flow regime, another enhancement would be to include data in the supercritical flow regime. It would also be desirable to incorporate these sediment transport formulas to a dynamic streamflow model so that the effect that changes in the channel bed have on the flow depth can be accounted for.

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TABLE 1 - ANALYSIS OF DISCREPANCY RATIO ON BML LOAD FOR EACH MODEL
(ACTUAL SEDIMENT PARAMETERS USED)

(a) - ACKERS AND WHITE (D35)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	2.03	5.01	5%	17%	40%	44%	18%	40%
TARBERT LDG	1.92	1.78	7%	24%	49%	67%	47%	3%
ST. LOUIS	1.94	1.16	8%	22%	33%	58%	62%	4%
RED	3.49	4.73	13%	24%	41%	44%	51%	6%
RIO GRANDE-A2	1.94	0.64	0%	10%	31%	52%	68%	0%
RIO-GRANDE-F	1.51	0.42	0%	10%	42%	94%	57%	0%
MIDDLE LOUP	1.27	0.44	29%	52%	70%	94%	29%	0%
NIOBRARA	1.72	0.92	0%	26%	53%	66%	46%	0%
SMALL RIVERS	1.61	0.67	7%	24%	48%	77%	51%	0%
BIG RIVERS	2.13	3.26	8%	21%	39%	55%	46%	14%
ALL RIVERS	2.02	2.91	7%	22%	41%	60%	47%	11%

(b) - ACKERS AND WHITE (D50)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.64	0.70	1%	8%	28%	36%	11%	59%
TARBERT LDG	1.41	1.15	18%	32%	67%	83%	26%	5%
ST. LOUIS	1.32	0.71	16%	32%	62%	79%	32%	5%
RED	1.28	1.32	6%	27%	65%	65%	13%	20%
RIO GRANDE-A2	1.36	0.40	15%	31%	57%	100%	42%	0%
RIO-GRANDE-F	1.24	0.31	21%	36%	78%	94%	15%	5%
MIDDLE LOUP	1.01	0.35	17%	41%	88%	100%	11%	0%
NIOBRARA	1.26	0.57	20%	26%	73%	86%	26%	0%
SMALL RIVERS	1.22	0.43	18%	34%	74%	95%	24%	1%
BIG RIVERS	1.15	0.95	11%	25%	55%	67%	23%	21%
ALL RIVERS	1.17	0.87	13%	27%	59%	73%	23%	17%

(c) - MEYER-PETER, MULLER

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.36	0.39	0%	2%	21%	23%	1%	76%
TARBERT LDG	0.90	0.67	7%	16%	37%	52%	24%	37%
ST. LOUIS	1.50	2.19	11%	16%	42%	46%	23%	33%
RED	2.09	2.96	6%	10%	31%	34%	41%	27%
RIO GRANDE-A2	0.88	1.09	0%	5%	15%	15%	21%	63%
RIO-GRANDE-F	0.65	0.82	0%	5%	15%	21%	15%	68%
MIDDLE LOUP	1.64	1.01	5%	11%	41%	70%	52%	5%
NIOBRARA	1.98	0.84	6%	26%	46%	60%	53%	0%
SMALL RIVERS	1.27	1.12	2%	11%	28%	37%	34%	37%
BIG RIVERS	1.25	1.90	5%	12%	33%	43%	25%	41%
ALL RIVERS	1.25	1.77	4%	12%	32%	41%	26%	40%

(d) - MODIFIED EINSTEIN

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	1.32	0.27	11%	40%	81%	98%	18%	0%
TARBERT LDG	1.38	0.44	2%	16%	39%	93%	55%	4%
ST. LOUIS	1.35	0.52	9%	23%	66%	88%	28%	5%
RED	1.40	0.17	3%	13%	75%	100%	24%	0%
RIO GRANDE-A2	1.55	0.20	0%	0%	47%	94%	52%	0%
RIO-GRANDE-F	1.61	0.35	0%	15%	57%	84%	42%	0%
MIDDLE LOUP	1.20	0.27	29%	52%	76%	100%	23%	0%
NIOBRARA	1.10	0.30	60%	66%	86%	100%	13%	0%
SMALL RIVERS	1.38	0.36	20%	31%	65%	94%	34%	0%
BIG RIVERS	1.35	0.42	7%	25%	66%	93%	30%	3%
ALL RIVERS	1.36	0.41	10%	26%	66%	93%	31%	2%

(e) - TOFFALETI

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.83	0.58	18%	36%	60%	62%	7%	31%
TARBERT LDG	0.82	0.53	11%	32%	73%	73%	5%	20%
ST. LOUIS	0.97	0.64	12%	24%	61%	69%	15%	22%
RED	0.99	0.36	20%	48%	82%	89%	10%	6%
RIO GRANDE-A2	0.81	0.30	21%	47%	84%	89%	5%	10%
RIO-GRANDE-F	0.68	0.16	0%	36%	89%	89%	0%	10%
MIDDLE LOUP	0.56	0.19	5%	23%	47%	47%	0%	52%
NIOBRARA	0.89	0.52	6%	46%	73%	80%	13%	13%
SMALL RIVERS	0.73	0.33	8%	38%	74%	77%	4%	21%
BIG RIVERS	0.90	0.58	15%	31%	66%	70%	10%	23%
ALL RIVERS	0.87	0.54	13%	33%	67%	72%	9%	22%

(f) - YANG (D50)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.11	0.09	0%	0%	1%	1%	0%	98%
TARBERT LDG	0.34	0.18	1%	1%	15%	15%	0%	84%
ST. LOUIS	0.89	0.57	9%	28%	64%	71%	12%	22%
RED	0.29	0.23	0%	0%	10%	10%	0%	89%
RIO GRANDE-A2	0.92	0.36	26%	57%	78%	84%	5%	15%
RIO-GRANDE-F	0.69	0.22	15%	26%	84%	84%	0%	15%
MIDDLE LOUP	0.88	0.38	5%	29%	82%	88%	5%	11%
NIOBRARA	1.07	0.32	20%	60%	86%	100%	13%	0%
SMALL RIVERS	0.88	0.35	17%	42%	82%	88%	5%	11%
BIG RIVERS	0.50	0.52	4%	12%	31%	34%	5%	63%
ALL RIVERS	0.58	0.51	6%	18%	42%	46%	5%	52%

(g) - YANG (D35)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.15	0.15	1%	1%	4%	4%	0%	95%
TARBERT LDG	0.36	0.19	0%	3%	16%	16%	0%	83%
ST. LOUIS	0.92	0.55	12%	33%	68%	76%	11%	19%
RED	0.38	0.33	3%	6%	13%	17%	3%	82%
RIO GRANDE-A2	1.11	0.44	21%	47%	73%	84%	15%	10%
RIO-GRANDE-F	0.79	0.26	10%	42%	94%	94%	0%	5%
MIDDLE LOUP	1.07	0.43	23%	29%	76%	94%	23%	0%
NIOBRARA	1.32	0.43	6%	33%	73%	86%	26%	0%
SMALL RIVERS	1.06	0.44	15%	38%	80%	90%	15%	4%
BIG RIVERS	0.54	0.51	6%	15%	35%	38%	5%	59%
ALL RIVERS	0.65	0.54	8%	20%	44%	49%	7%	47%

TABLE 2 - ANALYSIS OF DISCREPANCY RATIO ON BML LOAD FOR EACH MODEL
(AVERAGE SEDIMENT PARAMETERS USED)

(a) - ACKERS & WHITE (D35)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	1.20	1.40	8%	13%	28%	42%	31%	39%
TARBERT LDG	1.46	0.80	9%	32%	56%	83%	39%	3%
ST. LOUIS	1.49	0.87	15%	35%	55%	76%	39%	4%
RED	1.96	1.01	17%	37%	44%	62%	55%	0%
RIO GRANDE-A2	1.87	0.59	0%	10%	36%	63%	63%	0%
RIO GRANDE-F	1.47	0.37	0%	5%	47%	100%	52%	0%
MIDDLE LOUP	1.24	0.38	41%	58%	76%	94%	23%	0%
NIOBRARA	1.65	0.76	0%	33%	53%	73%	46%	0%
SMALL RIVERS	1.56	0.59	10%	25%	52%	82%	47%	0%
BIG RIVERS	1.46	1.06	12%	29%	47%	66%	39%	13%
ALL RIVERS	1.48	0.98	12%	28%	48%	70%	40%	10%

(b) - ACKERS & WHITE (D50)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.68	0.70	10%	22%	45%	47%	5%	48%
TARBERT LDG	1.14	0.59	15%	41%	75%	86%	16%	7%
ST. LOUIS	1.10	0.67	11%	40%	72%	82%	19%	8%
RED	0.89	0.37	20%	37%	86%	89%	6%	6%
RIO GRANDE-A2	1.33	0.40	21%	36%	63%	94%	36%	0%
RIO GRANDE-F	1.23	0.30	21%	31%	78%	94%	15%	5%
MIDDLE LOUP	0.99	0.32	11%	52%	88%	100%	11%	0%
NIOBRARA	1.22	0.47	20%	40%	73%	93%	26%	0%
SMALL RIVERS	1.20	0.39	18%	40%	75%	95%	22%	1%
BIG RIVERS	0.98	0.66	13%	35%	67%	74%	13%	18%
ALL RIVERS	1.02	0.62	14%	36%	69%	79%	15%	14%

(c) - MEYER-PETER AND MULLER

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.34	0.38	0%	7%	24%	26%	1%	73%
TARBERT LDG	0.91	0.70	7%	13%	35%	52%	26%	37%
ST. LOUIS	2.32	2.87	6%	19%	42%	50%	44%	13%
RED	2.10	3.00	3%	10%	31%	34%	41%	27%
RIO GRANDE-A2	0.87	1.06	0%	5%	15%	15%	21%	63%
RIO GRANDE-F	0.66	0.82	0%	5%	15%	21%	15%	68%
MIDDLE LOUP	1.88	1.24	0%	11%	41%	58%	52%	5%
NIOBRARA	1.98	0.84	0%	26%	46%	60%	53%	0%
SMALL RIVERS	1.30	1.16	0%	11%	28%	37%	34%	37%
BIG RIVERS	1.48	2.31	4%	13%	35%	42%	28%	36%
ALL RIVERS	1.44	2.12	3%	13%	33%	41%	30%	36%

(d) - MODIFIED EINSTEIN

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	5.77	8.59	8%	21%	34%	37%	60%	4%
TARBERT LDG	3.53	2.59	7%	16%	33%	41%	66%	0%
ST. LOUIS	4.04	4.08	7%	11%	25%	44%	73%	0%
RED	3.18	3.07	10%	10%	31%	37%	65%	3%
RIO GRANDE-A2	3.02	1.95	5%	5%	15%	36%	84%	0%
RIO GRANDE-F	2.81	1.73	5%	10%	15%	52%	84%	0%
MIDDLE LOUP	2.11	0.87	0%	11%	29%	58%	70%	0%
NIOBRARA	1.60	0.46	0%	6%	46%	80%	53%	0%
SMALL RIVERS	2.43	1.54	2%	8%	25%	55%	74%	0%
BIG RIVERS	4.30	5.46	8%	15%	30%	41%	67%	1%
ALL RIVERS	3.91	4.96	6%	13%	29%	44%	69%	1%

(e) - TOFFALETI

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.57	0.38	2%	17%	42%	44%	4%	53%
TARBERT LDG	0.81	0.49	7%	18%	58%	66%	11%	30%
ST. LOUIS	0.59	0.38	11%	23%	45%	45%	1%	52%
RED	0.48	0.18	3%	6%	37%	37%	0%	62%
RIO GRANDE-A2	0.43	0.10	0%	0%	21%	21%	0%	78%
RIO GRANDE-F	0.55	0.21	5%	15%	68%	68%	0%	31%
MIDDLE LOUP	0.28	0.08	0%	0%	0%	0%	0%	100%
NIOBRARA	0.45	0.38	0%	6%	13%	20%	6%	80%
SMALL RIVERS	0.43	0.24	1%	5%	27%	28%	1%	71%
BIG RIVERS	0.62	0.40	7%	19%	46%	48%	4%	49%
ALL RIVERS	0.58	0.38	6%	16%	42%	44%	3%	53%

(f) - MODIFIED TOFFALETI

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	1.29	0.86	20%	40%	63%	81%	28%	7%
TARBERT LDG	1.82	1.11	5%	20%	47%	62%	49%	3%
ST. LOUIS	1.33	0.86	13%	28%	59%	76%	33%	7%
RED	1.08	0.39	17%	51%	86%	93%	10%	3%
RIO GRANDE-A2	0.97	0.22	52%	63%	94%	94%	0%	5%
RIO GRANDE-F	1.23	0.47	0%	21%	68%	89%	26%	5%
MIDDLE LOUP	0.62	0.18	5%	29%	52%	52%	0%	47%
NIOBRARA	1.01	0.85	0%	40%	73%	80%	13%	13%
SMALL RIVERS	0.97	0.53	15%	38%	72%	80%	10%	17%
BIG RIVERS	1.39	0.91	14%	32%	61%	76%	32%	6%
ALL RIVERS	1.30	0.86	14%	33%	63%	77%	27%	8%

(g) - YANG (D50)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.11	0.10	0%	0%	1%	1%	0%	98%
TARBERT LDG	0.33	0.16	0%	1%	15%	15%	0%	84%
ST. LOUIS	0.82	0.56	12%	29%	60%	66%	10%	29%
RED	0.27	0.17	3%	3%	6%	6%	0%	93%
RIO GRANDE-A2	0.90	0.33	21%	57%	78%	84%	5%	15%
RIO GRANDE-F	0.68	0.21	10%	31%	84%	84%	0%	15%
MIDDLE LOUP	0.87	0.36	5%	29%	82%	88%	5%	11%
NIOBRARA	1.05	0.29	26%	66%	86%	100%	13%	0%
SMALL RIVERS	0.87	0.33	15%	45%	82%	88%	5%	11%
BIG RIVERS	0.47	0.49	5%	13%	29%	32%	4%	66%
ALL RIVERS	0.55	0.49	7%	20%	40%	44%	4%	54%

(h) - YANG (D35)

RIVER	MEAN	STAND DEV.	DISCREPANCY RATIO RANGE 0.90-1.10	0.75-1.25	0.50-1.50	0.50-2.00	>1.50	<0.50
ATCHAFALAYA	0.13	0.12	0%	0%	1%	1%	0%	98%
TARBERT LDG	0.35	0.17	1%	1%	15%	15%	0%	84%
ST. LOUIS	0.85	0.58	11%	29%	60%	66%	11%	27%
RED	0.33	0.21	0%	3%	13%	13%	0%	86%
RIO GRANDE-A2	1.09	0.39	31%	52%	73%	89%	15%	10%
RIO GRANDE-F	0.78	0.24	10%	47%	94%	94%	0%	5%
MIDDLE LOUP	1.05	0.41	0%	29%	82%	94%	11%	5%
NIOBRARA	1.30	0.39	20%	33%	73%	93%	26%	0%
SMALL RIVERS	1.04	0.40	15%	41%	81%	92%	12%	5%
BIG RIVERS	0.50	0.50	5%	13%	30%	33%	5%	64%
ALL RIVERS	0.62	0.53	7%	19%	41%	45%	6%	51%