BORAMEP Application to the Low Flow Conveyance Channel on the Middle Rio Grande, New Mexico

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Abstract. The Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) is a computer model that utilizes the Modified Einstein Procedure (MEP) to estimate the total sediment load in a hydraulic system. The effectiveness of BORAMEP has been evaluated by using sediment and hydraulic data from Low Flow Conveyance Channel (LFCC) on the Middle Rio Grande. The total load and sand load at three cross sections of the Low Flow Conveyance Channel were calculated using three different methods. The suspended sediment load was also calculated. BORAMEP total load results appear to be consistent with the total load estimates from the sampling sills at flow rates near 300 cfs but tend to underestimate the total load at flow rates near 600 cfs by at least a factor of two when compared to the total load estimates from the sampling sills. Sand load estimates from BORAMEP appear to be consistent with sand load estimates from the sampling sills at flow rates near 300 and 600 cfs.

1. Introduction

When evaluating hydraulic systems, it is important to quantify the amount of sediment transport. This is usually done by calculating the total load. The total load comes from two parts: the measured and unmeasured load. Since only part of the total load is measured in the field, it is important to get an accurate estimate of the total load from the field measurements. The Modified Einstein Procedure (MEP) is one method in which one can estimate the total load. It stems from the Einstein Method (Einstein 1950) which estimates the bed material discharge at different discharges using channel cross section geometry and sediment samples on a given reach at uniform flow (Simons and Senturk 1992). The Einstein Method was considered to be very labor intensive and time consuming and later, Colby and Hembree (1955) introduced the MEP (Holmquist-Johnson 2004). The Bureau of Reclamation later revised the MEP in 1966. The Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) is a computer program that uses the Bureau of Reclamation version of the Modified Einstein Procedure to estimate the total sediment load. BORAMEP has been used to quantify the amount of

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sediment transport of the Middle Rio Grande and the Low Flow Conveyance Channel (LFCC), see Figure 1.

Figure 1. USBR Aerial Photo of Rio Grande and LFCC

The effectiveness of BORAMEP was evaluated by comparing the results from the LFCC to the total load estimates from the total load sampling sills on the LFCC.

2. BORAMEP Total Load Analysis of the Low Flow Conveyance Channel

Current suspended sediment sampling techniques do not allow for the entire water column to be sampled with a depth integrated sampler, the unmeasured load must be estimated and added to the measured load to get the total load. Before running BORAMEP a variety of field data must be collected. At a given cross section it is desirable to divide the cross section into different subsections and then summing up the BORAMEP results for each subsection. At each subsection the following data must be collected: suspended sediment samples, bed material samples, temperature, sampled depth, unsampled depth, width, and average velocity. After the field data is collected, the suspended sediment concentration is measured and particle size distributions of the suspended sediment and bed material are created from sieving. The particle size distribution data is sorted such that the percent of sediment by weight in each size class (bin) is known. This data is then combined with the other hydraulic parameters. The data can be input into BORAMEP using the input form one at a time or a spreadsheet input file that follows a specific format (.csv) can be used so that multiple runs can be run at once (see Figure 2).

Part 1

***	bin1		bin2		bin3		bin4		bin5		bin6		
6	0.001	0.0625	0.0625	0.125	0.125	0.25	0.25	0.5	0.5	1	1	2	
Input Variables	Title	Date	Time	S_energy	g (ft/s2)	γ_{water} (lb/ft3)	$\gamma_{sediment}$ (lb/ft3)	Q (cfs)	Vavg (ft/s)	h (ft)	W (ft)	T (F)	dn (ft)
###	08354900	10/22/1975	1200	0.0008	32.17	62.4	165	153	2	0.92	85	49.1	0.3
###	08354900	3/3/1982	1200	0.0008	32.17	62.4	165	777	3.6	1.6	130	51.8	0.3
###	08354900	5/5/1982	1200	0.0008	32.17	62.4	165	4630	4	5.6	206	59	0.3
###	08354900	7/18/1985	1200	0.0008	32.17	62.4	165	2600	4.4	3.7	158	77	0.3

Part 2

Cs (ppm)	d65 (mm)	d35 (mm)	ds (ft)	susbin1	susbin2	susbin3	susbin4	susbin5	susbin6	bedbin1	bedbin2	bedbin3	bedbin4	bedbin5	bedbin6
655	0.238	0.206	0.92	0	31	40	4	0	0	4	76	20	0	0	0
2560	0.235	0.199	1.6	26	12	18	5	0	0	5	76	18	1	0	0
5210	0.392	0.243	5.6	20	12	7	9	0	0	5	33	49	9	4	0
1130	0.238	0.209	3.7	0	21	36	3	0	0	3	79	17	1	0	0

Figure 2. Sample BORAMEP Input Sheet (Holmquist-Johnson 2004)

When creating the .csv spreadsheet file, part 1 and part 2 should be all on one line with part 2 immediately following part 1.

When first using BORAMEP, the program prompts the user to specify whether the user wants to use the "Input File" (.csv spreadsheet that may contain multiple runs) or the "Input Form" (the user enters the input values one at a time on the user interface) and what values of the "Minimum % in bins to consider during z-calcs", see Figure 3. 5% is the default value but the user must use good judgment when selecting a value.

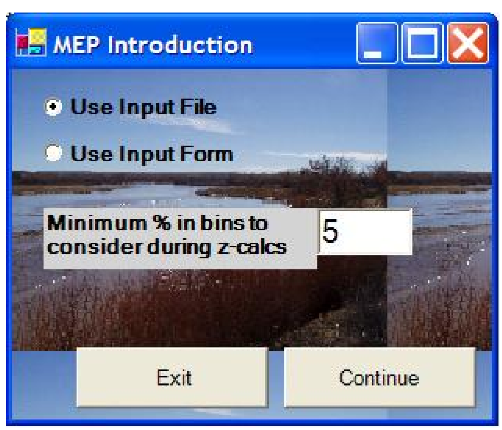

Figure 3. BORAMEP Startup Form (Holmquist-Johnson 2004)

Using a high percentage such as 5% limits the amount of data that is used in calculations and errors indicating that not enough overlapping bins are present between the suspended sediment and bed material samples exist. In order for BORAMEP to run there must be at least two overlapping bins between suspended sediment and bed material samples. This is complicated by the fact that that particles smaller than 0.0625 mm are not considered by BORAMEP during calculations because these particles are considered wash load. Using a low percentage such as 0 or 1% maximizes the potential amount of overlapping bins for calculations thus reducing the occurrence of the *"Not Enough Overlapping Bins"* error message but often causes another error to occur more frequently. This occurring error message is *"Fitted Z-Values Generated Negative Exponent, Not Continuing…"* and is caused when the relationship between the Z-value and fall velocity generated a negative exponent during the fitting of a power curve to the data. The Z-value is a theoretical exponent of the equation that describes the vertical distribution of suspended sediment of a size range and the power curve that is generated is used to calculate unmeasured load near the bed by the method of trial and error (Holmquist-Johnson 2004). When choosing a minimum percentage in bins to consider during the calculation of z-values, the highest possible percentage should be used that has the minimum occurrence of error messages to achieve the most sensible results.

BORAMEP was used to estimate the total load at three cross sections of the Low Flow Conveyance Channel (LFCC) on the Middle Rio Grande. Three runs were completed at each cross section (LF-11, LF-25, and LF-39) using BORAMEP four different ways: Method A, Method B, Method C, and the Cross Section Averaged (CSA) Method. Method A is the sum of the BORAMEP total load results for the subsections of each cross section. Method B is similar to Method A but the BORAMEP total load results are only used for the mobile bed section and the total suspended sediment load is used for the rip-rap side subsections. The suspended sediment load is calculated by:

$$Q_{ss} = 0.0027*Q*C \qquad (1)$$

Where Q_{ss} is the total suspended sediment load in tons per day, Q is the river discharge in cubic feet per second, and C is the suspended sediment concentration (from depth integrated sampler) in milligrams per liter. Method C is just the sum of the suspended sediment load results from all of the subsections within a cross section. For the CSA Method, the hydraulic parameters, suspended sediment samples, and bed material samples were averaged over the entire width of the cross section before they were input into BORAMEP. BORAMEP is very useful because it also estimates the sand load (bed material load) and the wash load along with the total load. For a significant number of runs, the two previously discussed error messages were prevalent. This made much of the BORAMEP results incomplete. To complete the results, the total suspended sediment load was supplemented into the results whenever an error message occurred.

The results from all four methods and all the three runs (A, B, and C) at each cross section at flow rates near 600 cfs were plotted along with the sample date and the discharge (see Figure 4).

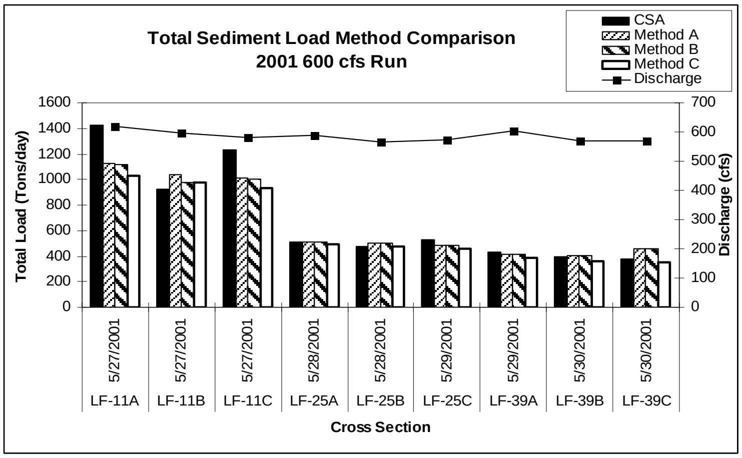

Figure 4. Total Sediment Load Comparison 600 cfs Run

From Figure 4, the BORAMEP total load results (Methods A and B) are always greater than the results from Method C (Suspended Sediment Load) which is expected; but sometimes the CSA results are less than the Method C results. This is because the input parameters were averaged over the width of the cross section.

Two total load sampling sills are located on two cross sections of the LFCC, the Foot Bridge (LF-FB) and the Vehicle Bridge (LF-VB). The presence of these sampling sills allows for the entire water column to be sampled with a depth integrated sampler. Multiplying the depth integrated suspended sediment concentration by the flow rate and the appropriate conversion factor (as in equation 1) returns an estimate of the total load. The total load estimates from the sampling sills and the total load estimates from the BORAMEP results (Method A) were plotted versus the flow rate (see Figure 5).

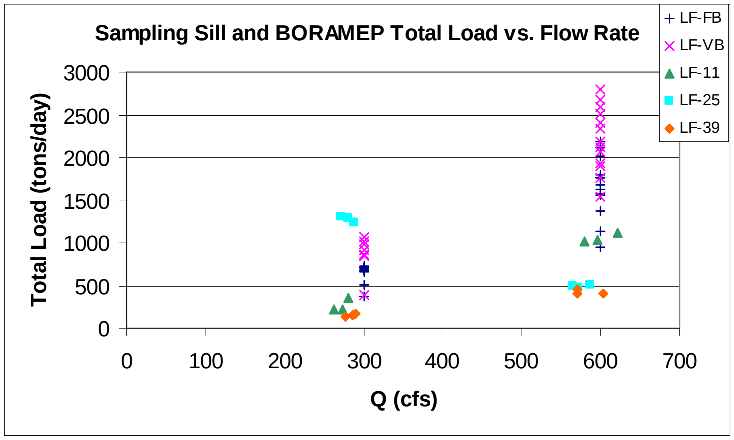

Figure 5. Sampling Sill and BORAMEP Total Load vs. Q

Because the total load may vary on any given day, comparing the results from the total load sampling sills to the BORAMEP results is not necessarily valid because most of the data was collected on different days. From Figure 5, it appears that the range of the BORAMEP total load results are consistent with the total load sampling sill results at 300 cfs but BORAMEP appears to underestimate the total load at flow rates near 600 cfs. BORAMEP does a satisfactory job of estimating the total load in the LFCC. In some cases, there was a lack in overlapping suspended sediment and bed material size fractions for BORAMEP to complete the MEP calculations. A better overlap between the bed material and suspended sediment data would result in better applications of BORAMEP.

3. Conclusions

By comparing the BORAMEP total load estimates to the results from the total load sampling sills it appears that BORAMEP does a satisfactory job of estimating the total load in the LFCC. The results are consistent with the estimates from the sampling sills at flow rates near 300 cfs but BORAMEP appears to underestimate the total load at 600 cfs when compared to the results from the sampling sills. The effectiveness of BORAMEP in estimating the total load of the LFCC can be impaired when there is a lack in overlapping suspended sediment and bed material size fractions. More research and testing of the BORAMEP procedure is ongoing at Colorado State University

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5. References

Colby, B. R. and Hembree, C. H. (1955). *Computations of Total Sediment Discharge Niobrara River near Cody, Nebraska*. Water Supply Paper 1357. Washington D.C., U.S. Geological Survey.

Einstein, H. A. (1950). *The Bed Load Function for Sediment Transport in Open Channel Flows.* Technical Bulletin no. 1026., Washington, D.C. U.S. Department of Agriculture, Soil Conservation Service.

Holmquist-Johnson, C. (2004), *Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) Program for Computing Total Sediment Discharge*, U.S. Bureau of Reclamation Technical Service Center, Denver, Colorado, 29 pages.

Simons, D. and Senturk, F. (1992), *Sediment Transport Technology*, Water Resources Publications, p. 639.