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Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) Program for Computing Total Sediment Discharge

U.S. Department of the Interior
Bureau of Reclamation

April 2009

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Cover Photo: View near Escondida, New Mexico taken on January 14, 2009. Courtesy of David Varyu, Bureau of Reclamation.

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Executive Summary

In 1950, Einstein presented a procedure for computing the total discharge of sediment of sizes found in appreciable quantities in the stream bed for a long reach of a stream channel. However, acquiring the data required by Einstein's procedure was very labor intensive and time consuming. In 1955, Colby and Hembree presented a modified version of Einstein's procedure that used data from a single cross section to calculate the total sediment discharge for a particular reach.

The modified Einstein method (MEP) of computing total sediment discharge in open channels is based on the original work of Einstein (1950) and is widely used by engineers and water resource managers. The MEP is considered an improvement over the original Einstein method because it is simpler in computation and it uses parameters more readily available from actual stream measurements. The modified method, however, requires a great deal of experience and judgment in order to obtain reliable results and often times the results are not easily replicated by multiple users. Computations are made for several ranges of particle sizes and involve many variables resulting in a very complex process of computing total sediment load. As a result, a simplified automated method of computing total sediment discharge for a given reach that can be reproduced by numerous users is of great interest.

The primary objective of this investigation was to create a computer program that would automate the process of computing total sediment discharge using the MEP procedure. The program would be applicable to a wide range of flow and sediment conditions and provide information to identify areas where additional research might be needed. This paper describes the Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) program and procedures that were used in order to automate the process of calculating total sediment load using the MEP procedure.

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1.0 INTRODUCTION

Developing a reliable and consistent method of computing total sediment discharge within a river is one of the most important practical objectives of research in fluvial processes (Burkham and Dawdy, 1980). The movement of sediment in an alluvial stream is complex and the ability to calculate the amount of sediment being transported by a given flow can be very complicated. The total sediment that is transported by a given discharge within a stream can be broken down in three ways (Julien 1995): measurement method, transport mechanism, or sediment source (Table 1 and Table 2). The size of the sediment (i.e. boulders, gravel, or sand) largely determines how the sediment is transported.

Table 1. Classification of the total sediment load for a sand bed stream

<table>
<tr><th>Measurement Method</th><th>Transport Mechanism</th><th>Sediment Source</th></tr>
<tr><td>Unmeasured Load</td><td>Bed Load</td><td rowspan="2">Bed Material Load</td></tr>
<tr><td rowspan="2">Measured Load</td><td rowspan="2">Suspended Load</td></tr>
<tr><td>Wash Load</td></tr>
</table>

Table 2. Classification of the total sediment load for a gravel bed stream

<table>
<tr><th>Measurement Method</th><th>Transport Mechanism</th><th>Sediment Source</th></tr>
<tr><td>Unmeasured Load</td><td rowspan="2">Bed Load</td><td rowspan="3">Bed Material Load</td></tr>
<tr><td rowspan="3">Measured Load</td></tr>
<tr><td rowspan="2">Suspended Load</td></tr>
<tr><td>Wash Load</td></tr>
</table>

Current techniques for suspended sediment collection do not allow sampling throughout the entire depth of flow and therefore the concentration and particle size distribution in only part of the flow can be determined from the suspended-sediment samples. The unsampled flow near the stream bed normally contains higher concentrations and coarser particle-size distributions than the flow in the sampled zone. Thus, the concentration of suspended-sediment samples is usually lower than the suspended-sediment concentration for the entire depth, and the particle sizes of the samples are usually smaller that the particle sizes for the entire depth.

The sediment discharge computed from the concentration of depth-integrated sediment samples and water discharge is called measured load, and the difference between the total load and the measured load is called the unmeasured load. Ratios of unmeasured load and the measured load are highly variable from stream to stream, cross section to cross section, and from time to time at a given cross section. They can vary with depth, velocity, sediment concentrations, particle size of the suspended and bed sediments, and other factors. The unmeasured load is composed mostly of sand or coarser sediments, and knowledge of the rate of discharge of sediment of these larger sizes is often more helpful in design and other problems than knowledge of the rate of discharge of the fine sediment. As a result, a method of computing sediment discharge in the unmeasured zone is of great importance.

In 1950, Einstein presented a procedure for computing the total discharge of sediment of sizes found in appreciable quantities in the stream bed for a long reach of a stream channel. However, acquiring the data required by Einstein's procedure was very labor intensive and time consuming. In 1955, Colby and Hembree presented a modified version of Einstein's procedure that used data from a single cross section to calculate the total sediment discharge for a particular reach.

The modified Einstein procedure (MEP) of computing total sediment discharge in open channels is based on the original work of Einstein (1950) and is widely used by engineers and water resource managers. The MEP is considered an improvement over the original Einstein method because it is simpler in computation and it uses parameters more readily available from actual stream measurements. The modified method, however, requires a great deal of experience and judgment in order to obtain reliable results and often times the results are not easily replicated by multiple users. Computations are made for several ranges of particle sizes and involve many variables resulting in a very complex process of computing total sediment load. As a result, a more simplified and automated method of computing total sediment discharge for a given reach that can be reproduced by numerous users is of great interest.

The primary objective of this investigation was to create a computer program that would automate the process of computing total sediment discharge using the MEP procedure. The program would be applicable to a wide range of flow and sediment conditions and provide information to identify areas where additional research might be needed. This paper describes the Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) program and procedures that were used in order to automate the process of calculating total sediment discharge using the MEP procedure.

1.1 Acknowledgements

The following persons contributed to this report:

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1.2 Acquiring BORAMEP

The latest information about BORAMEP is placed on the Web and can be found by accessing http://www.usbr.gov/pmts/sediment/model/boramep/index.html and following the links on the web page.

1.3 Disclaimer

The program BORAMEP and information in this manual are developed for use at the Bureau of Reclamation. Reclamation does not guarantee the performance of the program, nor help external users solve their problems. Reclamation assumes no responsibility for the correct use of BORAMEP and makes no warranties concerning the accuracy, completeness, reliability, usability, or suitability for any particular purpose of the software or the information contained in this manual. BORAMEP is a program that requires engineering expertise to be used correctly. Like other computer programs, BORAMEP is potentially fallible. All results obtained from the use of the program should be carefully examined by an experienced engineer to determine if they are reasonable and accurate. Reclamation will not be liable for any special, collateral, incidental, or consequential damages in connection with the use of the software

The BORAMEP program, methods, and accompanying forms, tables, and charts are presented to standardize and document the computations of the modified Einstein procedure currently used by the Bureau of Reclamation (BOR). The modified Einstein procedure for computing total sediment load was first presented by Colby and Hembree (1955) and later revised by the Bureau of Reclamation in 1966.

2.0 METHODS

2.1 Modified Einstein Equations and Procedure

The following presents the essential steps and fundamental equations used by the BORAMEP program for calculating total sediment load.

1) Compute the measured suspended load:

$$Q_s = 0.0027\, Q\, Conc\ \ (tons/day)$$ **Equation 1**

Where:

Q = *discharge (cfs);*

Conc = *suspended sediment concentration (mg/l).*

2) Compute the product of the hydraulic radius and friction slope assuming x = 1:

2a) First, compute the value of $\sqrt{(SR)}$ using Colby and Hembree 's (1955) equation E:

$$\sqrt{(RS_f} = \frac{V_{avg}}{32.63\log\left[12.27\dfrac{h}{k_s}x\right]}$$ **Equation 2**

Where:

V_{avg} = *average stream velocity (ft/s);*

h = *flow depth (ft);*

x = *dimensionless parameter; and*

k_s = *effective roughness* = d_{65} *(ft).*

2b) Compute the shear velocity:

$$U_* = \sqrt{g(RS_f)}$$ **Equation 3**

Where:

g = *acceleration due to gravity (ft/s*^{2}*); and*

SR = *slope-hydraulic radius function (ft).*

2c) Compute the laminar sublayer thickness δ:

$$\delta = \frac{11.6\nu}{U_*}$$ **Equation 4**

Where:

ν = *kinematic viscosity (ft^2/s); and*

U_* = *shear velocity (ft/s).*

2d) Recheck x to make sure that the initial guess is valid. Check Figure 1 (Einstein's Plate #3) for a value of x given k_s / δ or use the equation to determine the value of x. This is a trial and error process to determine the value of x and is carried out by the program using a solver routine.

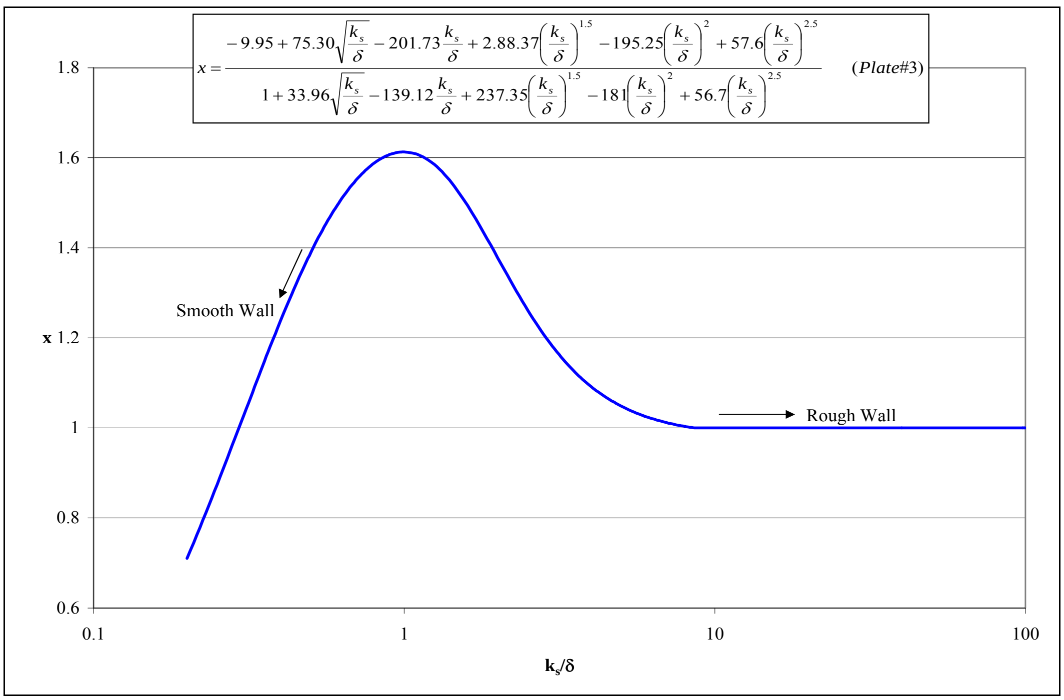

Figure 1. Correction x in the logarithmic friction formula in terms of k_s/δ.

3) Compute the value of P:

$$P = 2.303\log\left[30.2\frac{hx}{k_s}\right]$$ **Equation 5**

Where:

h = *flow depth (ft);*

x = *dimensionless parameter (from 2d above); and*

k_s = *effective roughness* $= d_{65}$ *(ft).*

4) Compute the fraction of the flow depth not sampled (A'):

$$A' = \frac{d_n}{d_s}$$ **Equation 6**

Where:

d_n = *vertical distance not sampled (ft); and*

d_s = *vertical distance sampled (ft).*

5) Compute the sediment discharge Q'$_s$ through the sampled zone. This is calculated using a percentage of the flow sampled determined from Figure 2 (Einsteins' Plate #4) or from the appropriate equation for the value of A' and P. Note: choose the equation below based on a P value closest to the computed P value from above.

$$Q'_{s\,total} = Q_s * \%\ flow\ sampled$$ **Equation 7**

For P = 4, % flow sampled =

$$\frac{100 - 2941.79A'^2 + 265357.48A'^4 + 64219.08A'^6 - 325482.24A'^8}{1 - 29.38A'^2 + 2621.48A'^4 + 5407.23A'^6 + 157.44A'^8 + 1272.32A'^{10}}$$ **Equation 8**

For P = 8, % flow sampled =

$$\frac{100 + 30991.16A'^2 + 21184.18A'^4 + 211800.14A'^6 - 263775.36A'^8}{1 + 325.87A'^2 + 1201.21A'^4 + 1872.11A'^6 + 5759.38A'^8 - 2976.45A'^{10}}$$ **Equation 9**

For P = 11, % flow sampled =

$$\frac{100.19 + 31425.83A'^2 - 54359.86A'^4 + 1566703.2A'^6 - 1543898.1A'^8}{1 + 336.12A'^2 + 444.29A'^4 + 15662.05A'^6 + 18936.5A'^8 - 5820.32A'^{10}}$$ **Equation 10**

For P = 14, % flow sampled =

$$\frac{100.31 + 45744.98A'^2 + 103307.39A'^4 + 635604.51A'^6 - 784215.44A'^8}{1 + 485A'^2 + 2934.57A'^4 + 7640.27A'^6 + 11737.99A'^8 - 3015.81A'^{10}}$$ **Equation 11**

Where:

Q_s = measured suspended load (tons/day); and

A' = fraction of the flow depth not sampled.

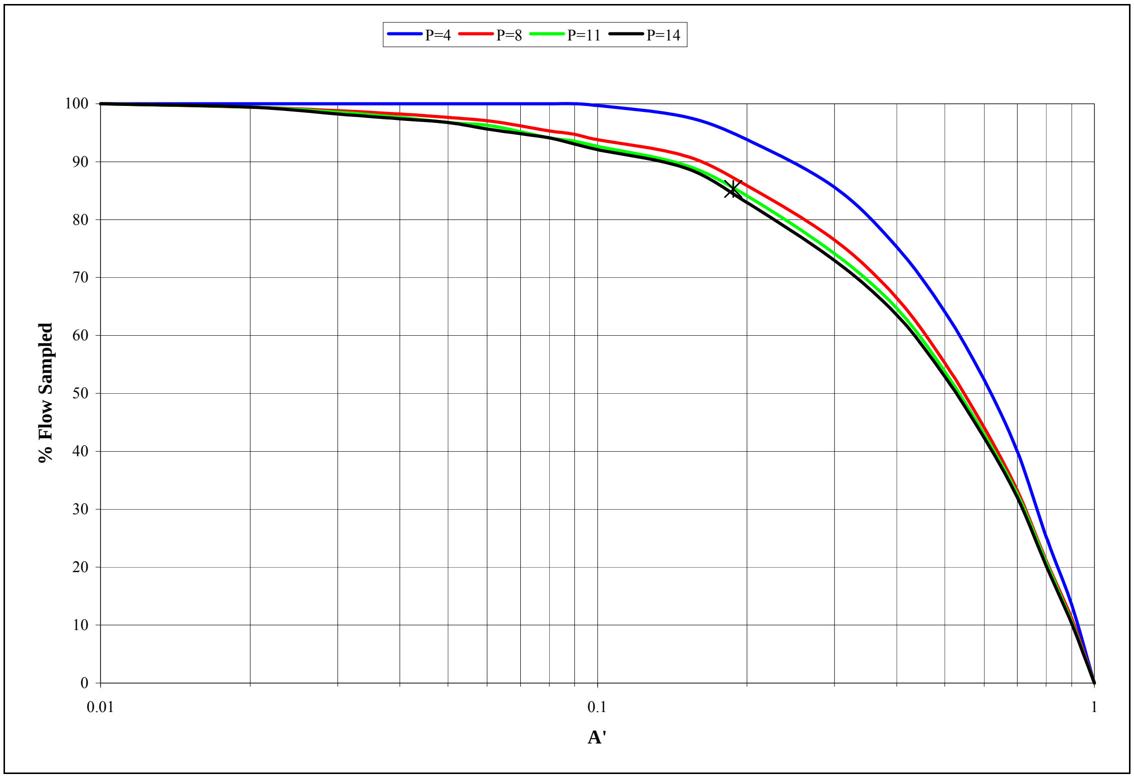

Figure 2. Vertical distribution of stream flow.

6) Compute the bed-load for each size fraction:

6a) The first step in computing the bedload is to calculate the shear intensity (ψ) for all particle sizes in the analysis. ψ is calculated using the greater of the following two equations for all size classes.

$$\psi = 1.65\left(\frac{d_{35}}{RS_f}\right) \quad or \quad 0.66\left(\frac{d_i}{RS_f}\right)$$ **Equation 12**

Where:

d_{35} = *particle size at which 35 percent of the bed material by weight is finer (ft);*

(SR) = *hydraulic radius-slope parameter (ft); and*

d_i = *the geometric mean for each size class (ft).*

6b) Compute the intensity of the bed-load transport (ϕ_*) using the following equation.

$$\phi_* = \frac{0.023p}{(1-p)}$$ **Equation 13**

Where p is the probability a sediment particle is entrained in the flow and is calculated using the following version of the Error Function (Yang, 1996):

$$p = 1 - \frac{1}{\sqrt{\pi}} \int_a^b e^{-t^2} dt$$ **Equation 14**

Where:

a = $-B_* \psi - \frac{1}{\eta_0}$; and

b = $B_* \psi - \frac{1}{\eta_0}$.

and B_* is equal to a value of 0.143 and η_0 is equal to a value of 0.5.

Note: The Error Function is computed as the following integral.

$$ERF = \frac{2}{\sqrt{\pi}} \int_a^b e^{-t^2} dt$$ **Equation 15**

Therefore, to compute the probability "p", evaluate the Error function from a to b. Then, multiply the Error Function by ½ and subtract it from 1. Microsoft Excel can be used to evaluated the error function form a to b by ERF(b) – ERF(a).

6c) Compute the unit bed-load for each size fraction using the following equation:

$$i_B q_B = 1200 d_i^{3/2} i_B \frac{\phi_*}{2}$$ **Equation 16**

Where:

d_i = *geometric mean diameter of a size range (ft);*

i_b = *fraction of bed material in a given size range; and*

ϕ_* = *intensity of bedload transport for individual grain size.*

6d) Compute the bed-load for each size fraction in tons/day by multiplying by the conversion factor 43.2 and the channel width.

$$i_B Q_B = i_B q_B (43.2W)$$ **Equation 17**

Where:

$i_b q_b$ = *sediment discharge through the bed layer (lb/s per foot of width) ; and*

W = *channel width (ft).*

7) Compute Suspended Load ($Q_s^{'}$) for each size fraction by multiplying the total sampled suspended load ($Q^{'}_{s,total}$) by the suspended load fractions for the sample.

$$Q_s^{'} = i_s \, Q^{'}_{stotal}$$ **Equation 18**

Where:

i_s = *fraction of suspended material in a given size range; and*

$Q^{'}_{s,total}$ = *total suspended sediment load (tons/day).*

8) Compute the theoretical exponent for vertical distribution of sediment (Z). This process is a trial and error method. **Note:** The original BOR method from 1955 provided a figure (Plate 8) to determine Z (termed Z' in the initial calculations) by computing the ratio of the suspended load ($Q_s^{'}$) to the bed-load ($i_B Q_B$) for each size class. However, Plate 8 was based solely on data from the Niobrara River near Cody, Nebraska. A subsequent study completed by the BOR in 1966 (Computation of Z's for use in the Modified Einstein Procedure) determined that using the regression line in Plate 8 produced errors on the order of 20% for the total load. As a result, the following guidelines for the selection of suspended and bed material limits (% in bin) for computation of Z values were established:

When computing total sediment load using the Bureau of Reclamation's Modified Einstein procedure, two rules and three guidelines apply for the selection of the suspended and bed material limits for computation of Z values. The rules are rigid and must be followed for the procedure to be applied. Failure to follow rules will result in computational failure. Guidelines should be adhered to if at all possible, but are flexible and may be stretched or adapted if measured data so requires:

Rules

- In order to fit a curve to determine Z values at least two suspended and bed material points must be included. Obviously, a curve cannot be fitted to a single point. Z limits must be chosen to include data from at least two overlapping suspended and bed material size classes to define the Z curve.
- Sediment must exist in at least two overlapping suspended and bed material size classes. This relates to the above rule that a minimum of two points are needed to define a curve. If a sample gradation contains bed sediment in a given size class but no suspended sediment (or if the converse is true), then data for that size class cannot be used in Modified Einstein computations.

Guidelines

- Do not include suspended or bed material size classes smaller than sand (0.0625 mm).
- Do not include size classes that contain less than about five percent of the total sample in a given size class. If less than five percent of a total sample is included in a particular size class, the significance and accuracy of that measurement becomes questionable. Does a percentage less than five truly

represent the sediment sizes that exist in a sample? Can less than five percent of a total sediment sample be accurately measured?

- Select Z limits that minimize the difference between the percentage of suspended and bed material in included size classes. A large discrepancy between the amount of bed and suspended material in a size class can incorrectly skew the Z value curve, producing incorrect results.

The above guidelines are generalized instructions for the selection of Z values. It is not always possible to satisfy all of the above guideline requirements. If one or more of the guidelines cannot be followed due to the characteristics of a particular data set, a decision must be made to either go outside of the guidelines or simply exclude that data set from the computations.

Therefore, the following process determines the Z-values only by trial and error. Reasonable assumptions should be bound between approximately 0.01 and 1.8 as this was the range of Z' from the original Plate 8.

8a) Compute the ratio $\frac{Q_s^{'}}{i_B Q_B}$ for all size classes with suspended load transport.

8b) Size classes that have calculated values for the ratio of the suspended load to the bed-load are used as the reference ranges for Z-value computations. However, if any of the ratios are for a size range less than 0.0625 mm they are not used. This is the break between suspended load and bed load; bed load (sizes less than 0.0625 mm) is not found in large quantities in the bed. The ratio of suspended load to bed-load is set equal to a function with the parameters $I_1^{''}, J_1^{''}, J_1^{'}, J_2^{'}$ as the following (BOR,1955):

$$\frac{Q_s^{'}}{i_B\ Q_B} = \frac{I_1^{''}}{J_1^{''}}\left(PJ_1^{'} + J_2^{'}\right)$$

Equation 19

Where:

I_1”	= *mathematical abbreviation that contains* J_1*” and A”;*
J_1”	= *mathematical abbreviation that contains A”;*
J_1’	= *mathematical abbreviation that contains A’;*
J_2’	= *mathematical abbreviation that contains A’; and*
P	= *mathematic abbreviation for equation 2-5.*

Due to the lack of computer resources available in 1955 to explicitly solve the integral form of the equations for $I_1^{''}, J_1^{'}, J_1^{''}, J_2^{'}$, these values were read from plates 9-11 from the 1955 BOR publication. However, current computer technology allows for an explicit solution to these integrals which results in a more precise answer to the parameters compared to reading the values off the plates. The dependent variables for these parameters are $A^{'}$ and $A^{''}$. $A^{'}$ has previously been computed.

$A^{'}$ has previously been computed. $A^{"}$ is calculated as the following for each size class that meets the criteria for the minimum percent of sediment contained in a size class that should be used in calculating the z-values:

$$A^{"} = \frac{2\,d_i}{h}$$

Equation 20

Where:

d_i = *geometric mean diameter of a size range (ft); and*

h = *flow depth (ft).*

For each size class that meets the minimm percent overlapping criteria an initial Z-value must be assumed and then the equations given below are used to determine the parameters contained in plates 9-11. In order to provide some guidance in the initial guess of the Z-value, the following equation is used (from Einstein's Plate #8):

$$Z_{guess} = -0.1465\ln\left(\frac{Q_s^{'}}{i_B Q_B}\right) + 1.0844$$

Equation 21

Using the initial guess for the Z-values and the equations given below for $I_1^{"}, J_1^{'}, J_1^{"}, J_2^{'}$, a trial and error process is carried out for each size class using a solver routine to determine the value of Z by minimizing the difference between the ratio $\frac{Q_s^{'}}{i_B\ Q_B}$ and $\frac{I_1^{"}}{J_1^{"}}\left(PJ_1^{'} + J_2^{'}\right)$.

$$I_1^{"} = 0.216\frac{A^{"(z-1)}}{(1-A^{"})^z}J_1^{"}$$ **Equation 22**

$$J_1^{'} = \int_{A'}^{1}\left(\frac{1-y}{y}\right)^z dy$$ **Equation 23**

$$J_1^{"} = \int_{A"}^{1}\left(\frac{1-y}{y}\right)^z \log_e(y)dy$$ **Equation 24**

$$-J_2^{'} = \int_{A'}^{1}\left(\frac{1-y}{y}\right)^z \log_e(y)dy$$ **Equation 25**

$$-J_2^{"} = \int_{A"}^{1}\left(\frac{1-y}{y}\right)^z \log_e(y)dy$$ **Equation 26**

8c) Once the Z-values have been determined for the suspended load, a log-log plot is made of the relationship between Z and the fall velocity for each size class. A power function equation is then developed such that $Z = a\ \omega^b$. The remaining Z-values for the bed-load are computed using this relationship. The fall velocity is computed using Rubey's Equation.

$$\omega = F\left[d_i\, g\left(\frac{\gamma_s - \gamma}{\gamma}\right)\right]^{1/2}$$ **Equation 27**

Where:

F = *mathematical abbreviation for equation 2-28;*

g = *acceleration due to gravity (ft/s^2);*

d_i = *geometric mean diameter of a size range (ft);*

ν = *kinematic viscosity;*

γ_s = *specific weight of sediment (lb/ft^3); and*

γ = *specific weight of water (lb/ft^3).*

$$F = \left[\frac{2}{3} + \frac{36\nu^2}{g\,d^3\left(\frac{\gamma_s}{\gamma} - 1\right)}\right]^{1/2} - \left[\frac{36\nu^2}{g\,d^3\left(\frac{\gamma_s}{\gamma} - 1\right)}\right]^{1/2}$$ **Equation 28**

Figure 3 is an example plot of three suspended load points indicating the power function regression relationship $Z = a\,\omega^b$ and the resulting Z-values that are calculating using the regression equation.

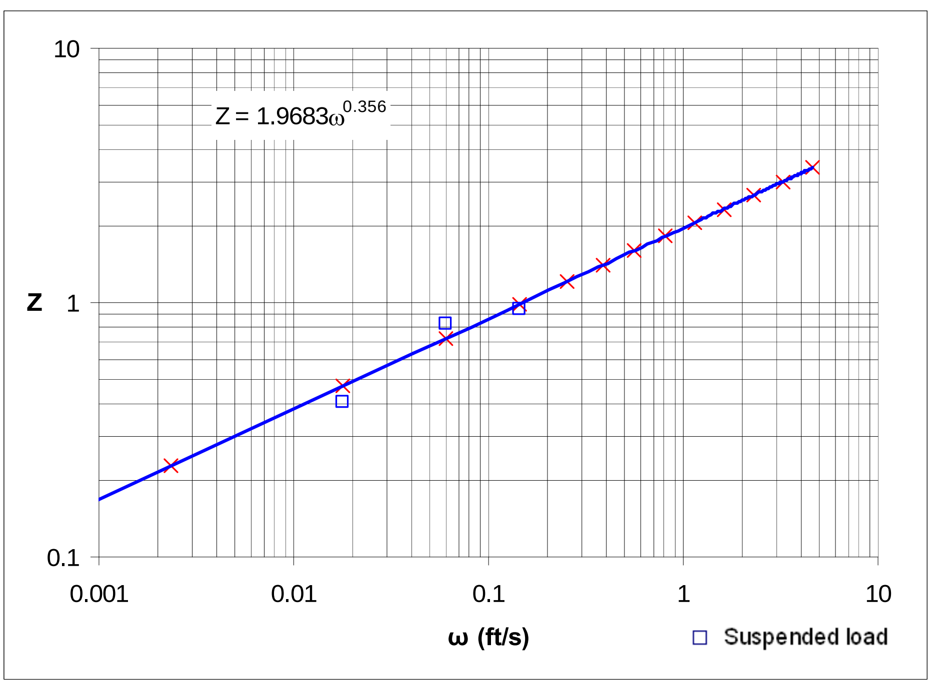

Figure 3. Z-value Regression Analysis.

9) Compute the total sediment load.

9a) Calculate the total load due to suspended sediment. Calculate the ratio $\frac{\left(P\,J_1^{"} + J_2^{"}\right)}{\left(P\,J_1^{'} + J_2^{'}\right)}$ for the size classes used in determining the z-values for suspended load and smaller and multiply this ratio by the computed suspended sediment for each size class as calculated in step 7 of this procedure to compute the total load due to suspended sediment.

$$Qs_{total\,suspended} = Q_s^{'}\,\frac{\left(P\,J_1^{"} + J_2^{"}\right)}{\left(P\,J_1^{'} + J_2^{'}\right)}$$ **Equation 29**

9b) The total load for the remaining size classes are calculated using the computed bed-load. Using the Z-values calculated with the power function from step 8c, calculate $I_1^{"}$ and $-I_2^{"}$ using the following equations:

$$I_1^{"} = 0.216\,\frac{A^{"(z-1)}}{(1-A^{"})^{z}}\,J_1^{"}$$ **Equation 30**

$$-I_2^{"} = 0.216\,\frac{A^{"(z-1)}}{(1-A^{"})^{z}}\,J_2^{"}$$ **Equation 31**

Then, compute the value $\left(P\,I_1^{"} + I_2^{"} + 1\right)$ and multiply by the computed bed-load for that size class to compute the total load due to bed-load.

$$Qs_{total\,bed} = i_B Q_B\,\left(P\,I_1^{"} + I_2^{"} + 1\right)$$ **Equation 32**

9c) The total load is then the sum of the total suspended or total bed load for each size class. Theoretically, either equation 2-29 or 2-32 can be used throughout all particle sizes. However, equation 2-29 is accurate for the ranges of fine particle sizes and equation 2-32 is accurate for the ranges of coarse particle sizes. Also, equation 2-29 is most applicable when Z is small and equation 2-32 is most applicable when Z is large because the percentage of variation in the calculated Z values changes the computed sediment discharges more in equation 2-29 when Z is large and more in equation 2-32 when Z is small (BOR, 1955 and Yang, 1996).

$$Qs_{total} = Qs_{total\,suspended} + Qs_{total\,bed}$$ **Equation 33**

2.2 BORAMEP Program

In order to automate the process of calculating the total load using the modified Einstein procedure presented above, a visual basic program was written to calculate the total load for numerous samples at one time. The following sections describe the input to the program, how to run the program, the output that is generated by the program, and how to interpret the output and results.

2.2.1 Program Input

The BORAMEP program can be used either for a single sample date entered by the user or an input file containing multiple sample dates.

If single sample data are entered; the input data that is required for the program is presented in Table 3 with example sediment and hydraulics values. A glossary of terms used is presented in Section 4.

Table 3. Input data for BORAMEP program

Constants/Properties:			Sediment:		
g =	32.17	ft/s^2	C_s =	2560	PPM
ν =	1.35E-05	ft^2/s	d_{65} =	0.235	mm
γ_w =	62.4	lb/ft^3	d_{35} =	0.199	mm
γ_s =	165	lb/ft^3	d_s =	1.6	ft
d_n =	0.3	ft	Particle Size	Susp	Bed
Hydraulics:			(mm)	%	%
Q =	777	ft^3/s	0.001 - 0.0625	65.00	0.00
V_{avg} =	3.6	ft/s	0.0625 - 0.125	12.00	5.00
h =	1.6	ft	0.125 - 0.25	18.00	76.00
W =	130	ft	0.25 - 0.5	5.00	18.00
A =	208	ft^2	0.5 - 1	0.00	1.00
T =	51.8	^{o}F	1 - 2	0.00	0.00

When the BORAMEP program is run, the user has the option to use an input file or an input form and enter a value for the minimum percent of sediment contained in a size class that should be used in calculating the z-values (Figure 4). A default value of 5% is used for the minimum percent overlap between suspended and bed material size classes. A value less than 5% is not recommended unless the user is familiar with the data being used and has proper justification for using such a small amount of overlap between suspended and bed material to estimate total sediment load.

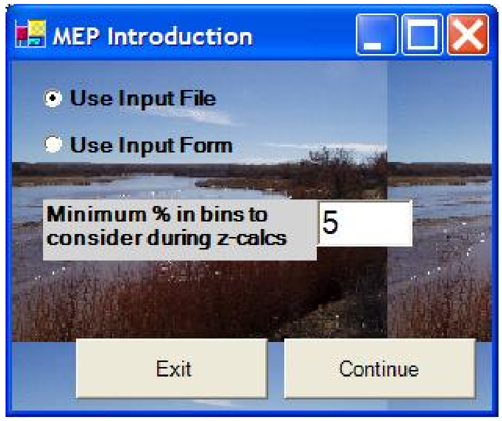

Figure 4. BORAMEP Startup form.

The input form option allows the user to calculate the total load for a single sample for data that is entered into the input form (Figure 5) by the user. The resulting total load and size class breakdowns are presented on the form itself as well as in an output file.

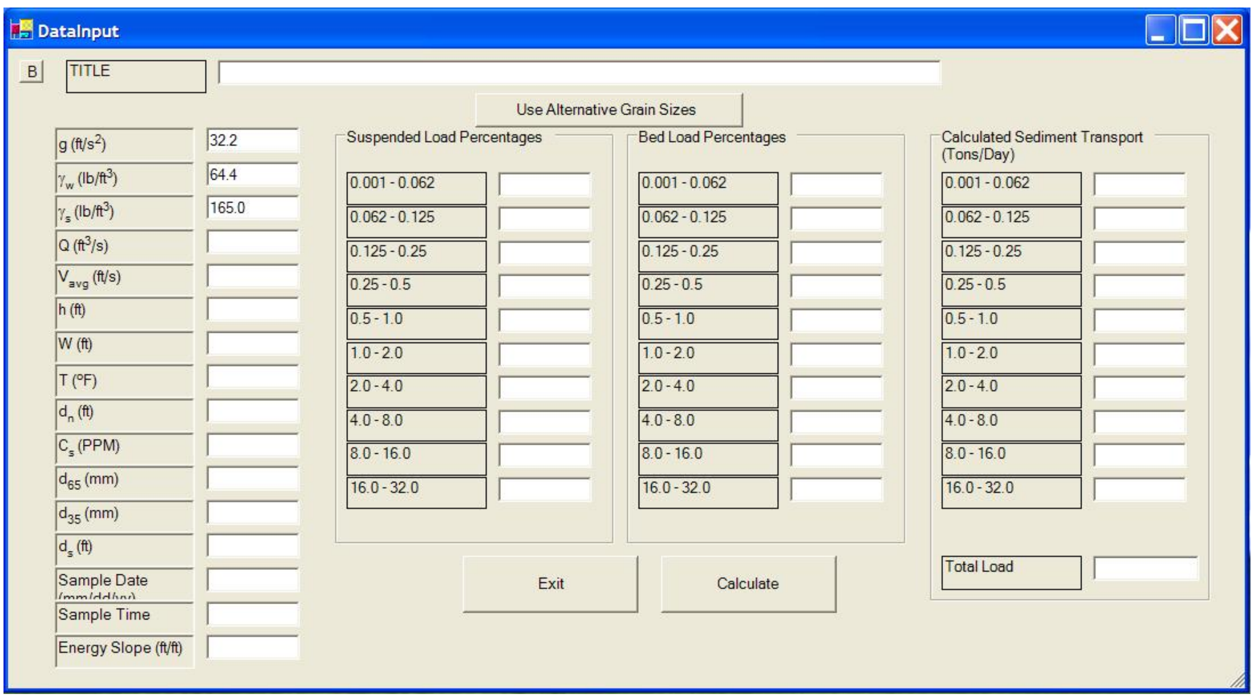

Figure 5. BORAMEP Input form for single sample.

The input file option allows the user to generate a comma separated file prior to running the BORAMEP program that contains the input data for multiple samples in a specified format. The BORAMEP program will run all the samples at one time.

If multiple sample dates are downloaded from the United States Geological Society (USGS) website or provided by USGS personnel, another program has been written to translate the USGS information into a format that can be input into the BORAMEP program. The USGS website has field/lab water quality samples that can be downloaded based on gage site number. The data should be downloaded as tab-separated data with expanded attributes and saved as a *.doc file extension. Data provided by USGS personnel will typically be a *.txt file. The file format for these files must be PC for the translate program to work.

The translate program is a visual basic program within a Microsoft Excel document (Figure 6). To start the program, select the CommandButton1. A new window is launched where the USGS gage data file will be selected. The button "Generate output for use with BORAMEP Program" must be selected as well as the period of record requested, the management of duplicate data, and output format.

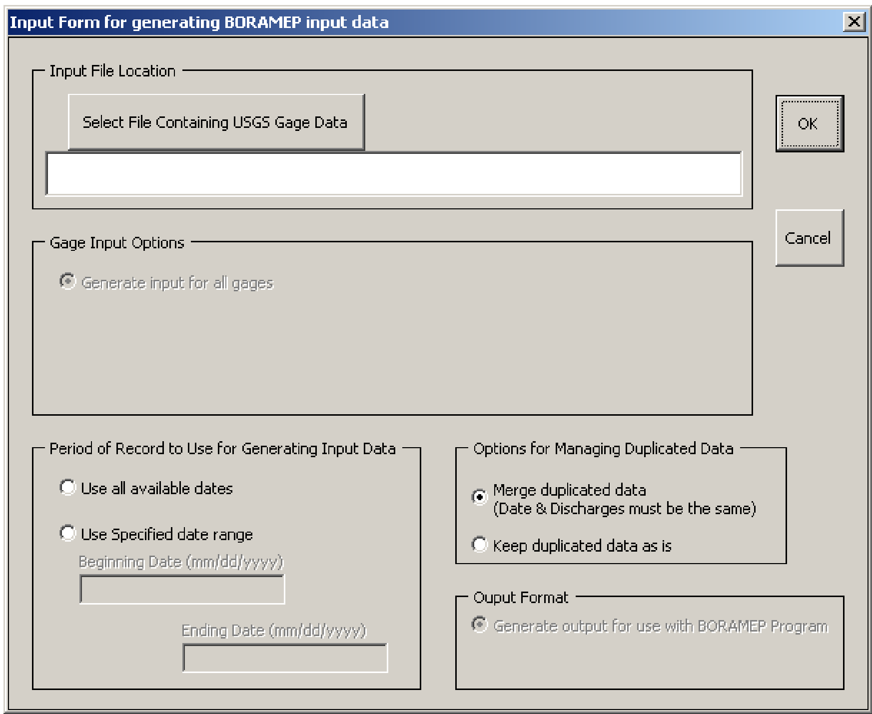

Figure 6. Input form to generate BORAMEP input file from USGS gage data.

The user will be asked to specify the name and location of the file generated. The default file name is identical to the name of the translate program excel file. Two files will be created in the location chosen. One file is an intermediate file, the other is a comma delimited file that will be saved as "Gage#Merged_MEPInput.csv". The gage number may be added to the file title and there is also a column in the *.csv file to include a gage site name for clarity and organization.

An input file can also be manually generated from other sample data. Figure 7 provides an example input format that is used by the program. As a result of the width of the input file, the input below has been broken into two parts. The first part contains the hydraulics and properties data and the second part contains the sediment data information. Note: When generating the input file, this data should all be contained on one line (part one immediately followed by part two) and not broken up as it is for this example.

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 7. Format for BORAMEP Input file.

The input file contains two specific input codes for a sample or set of samples: (***) and (###). The first parameter code *** is used to designate the beginning of input for a set of data associated with a specified number of sediment bins (Note: any text following *** on the same line is not read or used by the program and can be used for notes or heading information) and requires two additional lines of information to define the format of the sample data being used:

1. The first line to follow the *** code designates the number of sediment bins used and the size class breakdowns for each bin in mm.

2. The second line to follow the *** code provides a description of the input variables (see Table 4) and must adhere to the formats shown in Figure 7 and be comma separated.

Whenever the number of sediment bins used to define the suspended and bed material changes, it must be identified using the *** code described above in order for the BORAMEP program to know that the number of sediment bins has changed. The second parameter code ### is used to designate sample data and must follow the input format described above. A value of -9999 should be used for data that is missing or unknown.

Table 4. Explanation of input variables in BORAMEP input file format.

Column Order	Heading	Description
1	Input variables	###
2	Title	Name of sample location (USGS Gage site number, if applicable)
3	Date	Sample date (mm/dd/yyyy)
4	Time	Sample time
5	S_energy[1]	Energy slope (ft/ft)
6	g (ft/s^2)	Gravity constant = 32.17
7	γ_w (lb/ft^3)	Specific weight of water constant = 62.4
8	γ_s (lb/ft^3)	Specific weight of sediment = 165
9	Q (cfs)	Discharge at sample cross section on sample date
10	V_{avg} (ft/sec)	Average velocity at sample location on sample date
11	h (ft)	Depth of water at sample location
12	W (ft)	Width of channel at sample location
13	T (F)	Water temperature on sample date

14	dn (ft)	Vertical distance not sampled; the distance between the bottom of the sampled zone and the streambed as defined by the sampler used
15	Cs (ppm)	Sediment concentration at sample location
16	d35 (mm)	Particle size at which 35 percent of the bed material by weight is finer
17	d65 (mm)	Particle size at which 65 percent of the bed material by weight is finer
18	ds (ft)	Vertical distance sampled; the average of the total depths recorded at the sampling verticals
19-xx (depends on # of classes)	susbin#	Percent of suspended load in particle class #
xx-yy (depends on # of classes	bedbin#	Percent of bed load in particle class #

[1] While slope is listed above, it is not used on the total load calculation and therefore is not required by the program to run.
[2] The number of input variables changes depending on the number of sediment bins used to define the sample data. Variables 1 thru 18 will always be used while variables 19 and on will change depending on the number of sediment bins defined in part a.

Once the input file has been generated manually or through the translate program, the BORAMEP program can be run for multiple samples. The user will be prompted to select the input file using windows explorer (Figure 8).

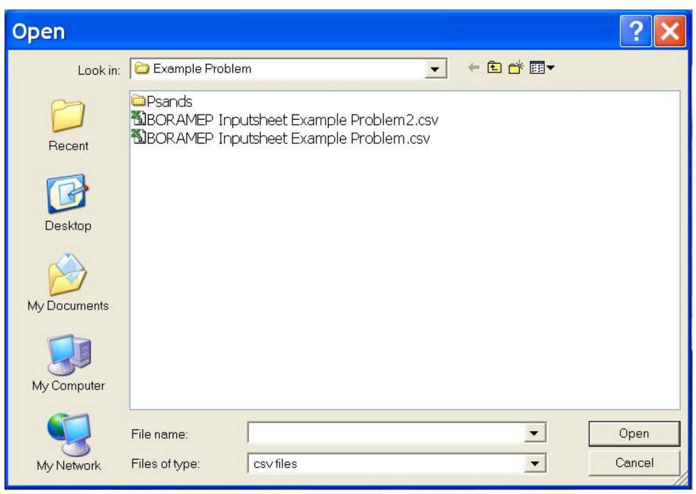

Figure 8. Example open input file message box.

Once the input file is selected the user is then prompted to select a file name and location for the output files generated by the program (Figure 9).

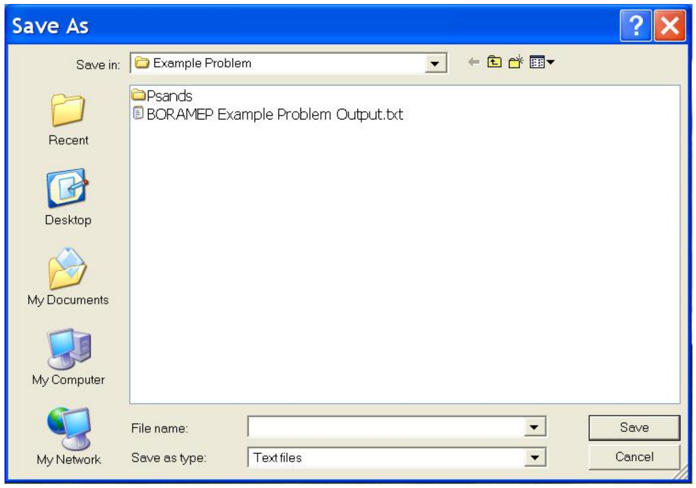

Figure 9. Example save output file message box.

After the output file name and location is selected, the program starts calculating total load for each record contained in the input file. Once the program is finished, it will prompt the user with a dialog box stating the program is complete and list the number of errors that were generated (Figure 10).

Figure 10. Example program complete message box.

Once the program runs successfully, there are three output files that are generated and can be used for additional analysis. The information contained in each of the output files is described in the following section.

2.2.2 Program Output

As mentioned in Section 2.1, when the Modified Einstein Procedure was first introduced, "Z" values were determined by applying the 0.7 power to the fall velocities. This exponent was determined to only be applicable to the Niobrara River near Cody, Nebraska. For the BORAMEP program, "Z" values are computed differently. "Z" values are computed for size ranges that have both suspended and bed load sediments using a trial and error procedure. The other "Z" values are computed by finding a power relationship between the fall velocity and "Z" value and applying this relationship to all other size ranges.

The BORAMEP program generates three output files: *.txt, *.txt.sum, and *.txt.err. The first file called *filename*.txt (Figure 11) contains output in a format that is similar to output from a previous program (Psands or KPsands) used by the Bureau of Reclamation. This output allows previous users of the Psands program to view the output in a format that they are familiar with as well as new users to view the input data for a sample and the results generated from the MEP calculations.

```
                                  OUTPUT
                                  08319000 - RIO GRANDE AT SAN FELIPE

METHOD OF COMPUTATION   MODIFIED EINSTEIN   DATE OF COMPUTATION 7/14/2008
DATE OF SAMPLE     5/10/1971      TIME OF SAMPLE       1200              TEMPERATURE         64.4     SLOPE OF ENERGY GRADIENT       0.001
D65 =     0.2866594
                 mm   D35 =      0.2029478
                                          mm
Velocity (ft/s) =   4        Width (ft) =        163      Depth (ft) =         1.8
Dn (ft) =           0.3      Ds (ft) =           1.8

    SIZE FRACTION        PERCENT OF MATERIAL IBQB      QPRIME        Z-VALUES       COMPUTATIONAL FACTORS    COMPUTED
    IN MILLIMETERS       SUSPENDED BED       T/D       SUBS(T/D) COMPUTED FITTED       F(J)      F(I)+1       TOTAL LOAD

     0.001   0.002        15        0        -9999      236.030  -9999    0.054       1.190     -9999          280.838
     0.002   0.004        2         0        -9999      31.471   -9999    0.082       1.207     -9999          37.991
     0.004   0.016        4         0        -9999      62.941   -9999    0.154       1.258     -9999          79.205
     0.016   0.0625       15        0        -9999      236.030  -9999    0.353       1.471     -9999          347.256
     0.0625  0.125        17        10         9.473    267.500   0.660   0.650       2.164      67.008        578.854
     0.125   0.25         38        50         133.974  597.942   0.892   0.926       3.832      14.543        2291.146
     0.25    0.5          9         30         227.360  141.618   1.206   1.180       7.342      6.321         1437.232
     0.5     1            0         8          111.729  0        -9999    1.383     -9999       4.308         481.3
     1       2            0         2          24.351   0        -9999    1.567     -9999       3.474         84.598
     2       4            0         0        -9999      0        -9999    1.752     -9999     -9999           0
     4       8            0         0        -9999      0        -9999    1.951     -9999     -9999           0
     8       16           0         0        -9999      0        -9999    2.168     -9999     -9999           0
     16      32           0         0        -9999      0        -9999    2.409     -9999     -9999           0
     32      64           0         0        -9999      0        -9999    2.676     -9999     -9999           0
     64      128          0         0        -9999      0        -9999    2.972     -9999     -9999           0
     128     256          0         0        -9999      0        -9999    3.301     -9999     -9999           0

    TOTAL                                                                                                  5618.419
```

Figure 11. Example *filename*.txt output for one sample date.

The output file lists each sample date and either the calculated values or an error message associated with the date. The calculated values include z-values, the computed total load, the total load for each size fraction, and other values used throughout the modified Einstein procedure.

The second file called *filename*.txt.sum contains a comma separated summary of the output data that was generated by the program. This file can easily be imported into an Excel spreadsheet and used to view the results of the MEP calculations and determine which samples provided errors. An example of the data presented in a *filename*.txt.sum file is presented in Figure 12.

***		Discharge	Conc	Suspended	d65	d35
Location	Date	(cfs)	(PPM)	Sample (tons/day)	(mm)	(mm)
08319000 - RIO GRANDE AT SAN FELIPE	5/10/1971	1180	565	1800.09	0.2866594	0.2029478
08319000 - RIO GRANDE AT SAN FELIPE	3/24/1972	1170	1600	5054.4	0.3493135	0.2005669
08319000 - RIO GRANDE AT SAN FELIPE	11/17/1972	986	1590	4232.898	0.2057127	0.1509518
…						

Temp	Computed total load by size fraction (tons/day)					Total Load	Total Sand Load
F	0.001 - 0.002	0.002 - 0.004	0.004 - 0.016	0.016 - 0.0625	0.0625 - 0.125	(tons/day)	(>0.625mm)(tons/day)
64.4	280.8385	37.99134	79.20501	347.2555	578.8538	5618.4192	4873.128914
50.9	771.9286	155.2965	210.6068	785.2655	1178.378	6981.12795	5058.030491
41	174.2772	0	45.22285	553.3947	2646.114	7857.72977	7084.834976
…							

Figure 12. Example *filename*.txt.sum output.

Note: As a result of the width of the output file, the output was been broken into two parts. The output file will all be contained on one line (part one immediately followed by part two).

The output file contains the title, date, discharge, concentration, d65, d35, and temperature from the input file. In addition included in the file is the calculated suspended sample (tons/day), the total load, total sand load (which is the load with a sediment size greater than 0.625 mm), and total load divided into the sediment size fractions.

The third file called *filename*.txt.err contains a comma separated summary of any errors that were encountered by the program as well as output for samples that did not meet the MEP criteria but might be able to be used with additional analysis. An example of the data presented in a *filename*.txt.sum file is presented in Figure 13.

Title	Date		Error
08319000 - RIO GRANDE AT SAN FELIPE	5/19/1970	-9999	THERE WAS AN ERROR DURING FILE INPUT
08319000 - RIO GRANDE AT SAN FELIPE	6/1/1970	-9999	THERE WAS AN ERROR DURING FILE INPUT
08319000 - RIO GRANDE AT SAN FELIPE	9/20/1971	-9999	THERE WAS AN ERROR DURING FILE INPUT
08319000 - RIO GRANDE AT SAN FELIPE	9/20/1974	-9999	NOT ENOUGH OVERLAPPING BINS FOR MEP
08319000 - RIO GRANDE AT SAN FELIPE	4/17/1973	-9999	THERE WAS AN ERROR DURING FILE INPUT
…			

Figure 13. Example *filename*.txt.err output.

2.2.3 Error Checking

There are a number of error checking routines within the algorithms of BORAMEP. The error checking routines were largely designed to identify input errors while allowing user flexibility in use of the software and the codes returned are given in Table 5. Many of the input errors occurring during the use of BORAMEP have been documented by Jay et. al. (2005) and Shah (2006) who included recommendations for error messages. These have been included in the error codes returned by BORAMEP.

First, each field in either the input form or the input file is checked such that the type of variable expected has been entered. There have been some occurrences where a date value (not used for anything other than labeling the output and for user identification) has caused problems with execution. Further checks are made to ensure that the suspended sediment load is not be greater than the total sediment load. The value of d_{35} entered must be less than or equal to d_{65}. The input values of d_{35} and d_{65} are checked against the particle size distribution (this check returns an error if the values differ by greater than 20%). The continuity equation, Q=VA, is checked (this check returns an error if the values differ by greater than 20%). The measured and unmeasured depths are checked such that they add to the total depth (this check returns an error if the values differ by greater than 1 ft). The temperature entered must be within a range of 32 to 80 ^{o}F. The user supplies a percentage value that suspended and bed sediment must overlap in a size fraction in order to use the algorithm. If this threshold is not met then an error is generated. If a *z* value is calculated in an unrealistic manner (*e.g.,* negative) or not obtained then an error is also generated.

At the completion of execution, there is a check such that the total load is set to zero if the concentration, depth, width, discharge, and / or velocity are zero. If the shear stress is less than the critical shear stress then the sediment transport is zero.

Table 5. Error codes returned by BORAMEP.

ERR Number OR CODE	Indication
1	Not enough overlapping bins in particle size distributions for MEP calculations
2, 1112	A realistic value of z was failed to be obtained
3	Temperature Error
4	Continuity is not satisfied within tolerance
5	Measured and unmeasured depths do not add to total depth within tolerance
6	The values of d35 and / or d65 do not check against the input particle size distribution
7	Shear stress is less than critical shear stress
8	The value of d35 is greater than d65
9	Suspended sediment load is greater than the total sediment load
98, 99	Error in read of input file

3.0 SAMPLE PROCEDURE

A single sample is calculated using both the Modified Einstein Procedure and the BORAMEP program. In addition multiple samples are calculated using the BORAMEP Program. Table 6 and Table 7 have the parameters for the single sample.

Table 8 has the multiple samples' parameters.

Table 6. Hydraulic data and properties for sampled data.

Hydraulics:			Constants/Properties		
Q =	777	ft3/s	g =	32.17	ft/s2
V_{avg} =	3.6	ft/s	ν =	1.35E-05	ft2/s
h =	1.6	ft	γw =	62.4	lb/ft3
W =	130	ft	γs =	165	lb/ft3
A =	208	ft2	d_n =	0.3	ft
T =	51.8	oF	$X_{assumed}$ =	1.535	

Table 7. Sediment size fractions for sampled data

Sediment:						
	C_s =	2560	PPM	d_s =	1.6	ft
	d_{65} =	0.235	mm	d_{65} =	0.00077	ft
	d_{35} =	0.199	mm	d_{35} =	0.00065	ft
	Particle Size		Susp	Bed	Geometric Mean	
Bin#	(mm)		%	%	(mm)	(feet)
1	0.001	0.002	26.00	0.00	0.0014	0.000005
2	0.002	0.004	8.00	0.00	0.0028	0.000009
3	0.004	0.016	12.00	0.00	0.008	0.000026
4	0.016	0.0625	19.00	0.00	0.0316	0.000104
5	0.0625	0.125	12.00	5.00	0.0884	0.00029
6	0.125	0.25	18.00	76.00	0.1768	0.00058
7	0.25	0.5	5.00	18.00	0.3536	0.00116
8	0.5	1	0.00	1.00	0.7071	0.00232
9	1	2	0.00	0.00	1.4142	0.00464
10	2	4	0.00	0.00	2.8284	0.00928

Table 8. Hydraulic and Sediment data for BORAMEP calculations.

Note: As a result of the width of the input file, the input was broken into five parts. The input file will all be contained on one line (part 1 followed immediately by part 2, etc.)

***	bin1		bin2		bin3		bin4	
10	0.001	0.002	0.002	0.004	0.004	0.016	0.016	0.0625
Input Variables	Title	Date	Time	S_energy	g (ft/s2)	gamma_w (lb/ft3)	gamma_s (lb/ft3)	Q (cfs)
###	08330000 - Sample1	3/3/1982	1200	0.0008	32.17	62.4	165	777
###	08330000 - Sample2	5/8/1969	1200	0.0008	32.17	62.4	165	4570
###	08330000 - Sample3	9/2/1969	1200	0.0008	32.17	62.4	165	788
###	08330000 - Sample4	9/30/1969	1200	0.0008	32.17	62.4	165	558
###	08330000 - Sample5	7/27/1971	1200	0.0008	32.17	62.4	165	5460
***	bin1		bin2		bin3		bin4	
9	0.001	0.002	0.002	0.004	0.004	0.016	0.016	0.0625
Input Variables	Title	Date	Time	S_energy	g (ft/s2)	gamma_w (lb/ft3)	gamma_s (lb/ft3)	Q (cfs)
###	08330000 - Sample6	7/7/1969	1200	0.0008	32.17	62.4	165	317
###	08330000 - Sample7	10/5/1970	1200	0.0008	32.17	62.4	165	-9999
###	08330000 - Sample8	2/16/1971	1200	0.0008	32.17	62.4	165	865
###	08330000 - Sample9	7/27/1971	1200	0.0008	32.17	62.4	165	460
###	08330000 - Sample10	3/19/1973	1200	0.0008	32.17	62.4	165	1130
***	bin1		bin2		bin3		bin4	
13	0.001	0.002	0.002	0.004	0.004	0.016	0.016	0.0625
Input Variables	Title	Date	Time	S_energy	g (ft/s2)	gamma_w (lb/ft3)	gamma_s (lb/ft3)	Q (cfs)
###	08330000 - Sample11	7/30/1973	1200	0.0008	32.17	62.4	165	3270
###	08330000 - Sample12	1/22/1979	1200	0.0008	32.17	62.4	165	964
***	bin1		bin2		bin3		bin4	
16	0.001	0.002	0.002	0.004	0.004	0.016	0.016	0.0625
Input Variables	Title	Date	Time	S_energy	g (ft/s2)	gamma_w (lb/ft3)	gamma_s (lb/ft3)	Q (cfs)
###	08330000 - Sample13	12/3/1979	1200	0.0008	32.17	62.4	165	1680
###	08330000 - Sample14	4/5/1996	1200	0.0008	32.17	62.4	165	437

bin5		bin6		bin7		bin8		bin9		bin10
0.0625	0.125	0.125	0.25	0.25	0.5	0.5	1	1	2	2
Vavg (ft/s)	h (ft)	W (ft)	T (F)	dn (ft)	Cs (ppm)	d65 (mm)	d35 (mm)	ds (ft)	susbin1	susbin2
3.6	1.6	130	51.8	0.3	2560	0.2350684	0.1994948	1.6	26	8
4.48	5	206	10.2	0.3	3200	0.3822299	0.2337722	5	8	1
2.29	1.3	263	73.4	0.3	5880	0.2475072	0.2157136	1.3	57	10
-9999	-9999	-9999	71.6	0.3	922	-9999	-9999	-9999	37	4
4.6	3.9	300	63.5	0.3	39900	0.4158953	0.2666196	3.9	34	17
bin5		bin6		bin7		bin8		bin9		
0.0625	0.125	0.125	0.25	0.25	0.5	0.5	1	1	2	
Vavg (ft/s)	h (ft)	W (ft)	T (F)	dn (ft)	Cs (ppm)	d65 (mm)	d35 (mm)	ds (ft)	susbin1	susbin2
1.53	1	202	78.8	0.3	236	0.4160884	0.2613029	1	0	0
-9999	-9999	-9999	60	0.3	-9999	0.2897394	0.2185397	-9999	-9999	-9999
2.4	1.4	253	56.3	0.3	1220	0.2628688	0.202773	1.4	7	1
4.6	3.9	300	63.5	0.3	39900	0.4158953	0.2666196	3.9	34	17
2.8	1.6	260	44.6	0.3	2780	0.2483769	0.1907277	1.6	10	2
bin5		bin6		bin7		bin8		bin9		bin10
0.0625	0.125	0.125	0.25	0.25	0.5	0.5	1	1	2	2
Vavg (ft/s)	h (ft)	W (ft)	T (F)	dn (ft)	Cs (ppm)	d65 (mm)	d35 (mm)	ds (ft)	susbin1	susbin2
3.8	2.9	300	69.8	0.3	2570	0.2325281	0.377907	2.9	8	1
2.3	1.6	260	39.2	0.3	912	0.3953113	0.2483168	1.6	49	7
bin5		bin6		bin7		bin8		bin9		bin10
0.0625	0.125	0.125	0.25	0.25	0.5	0.5	1	1	2	2
Vavg (ft/s)	h (ft)	W (ft)	T (F)	dn (ft)	Cs (ppm)	d65 (mm)	d35 (mm)	ds (ft)	susbin1	susbin2
2.7	2	305	40.1	0.3	1620	0.2955199	0.2221283	2	2	0
1.95	1.7	129	46.94	0.3	920	0.6321284	0.4046905	1.7	0	0

4										
susbin3	susbin4	susbin5	susbin6	susbin7	susbin8	susbin9	susbin10	bedbin1	bedbin2	bedbin3
12	19	12	18	5	0	0	0	0	0	0
3	14	35	29	10	0	0	0	0	0	0
19	9	2	3	0	0	0	0	0	0	0
11	12	9	21	6	0	0	0	-9999	-9999	-9999
22	19	4	3	1	0	0	0	0	0	0
susbin3	susbin4	susbin5	susbin6	susbin7	susbin8	susbin9	bedbin1	bedbin2	bedbin3	bedbin4
0	54	25	21	0	0	0	0	0	0	1
-9999	-9999	-9999	-9999	-9999	-9999	-9999	0	0	0	1
3	15	31	38	5	0	0	0	0	0	1
22	19	4	3	1	0	0	0	0	0	3
5	25	33	22	3	0	0	0	0	0	2
	bin11		bin12		bin13					
4	4	8	8	16	16	32				
susbin3	susbin4	susbin5	susbin6	susbin7	susbin8	susbin9	susbin10	susbin11	susbin12	susbin13
4	14	18	28	13	13	1	0	0	0	0
8	10	4	17	5	0	0	0	0	0	0
	bin11		bin12		bin13		bin14		bin15	
4	4	8	8	16	16	32	32	64	64	128
susbin3	susbin4	susbin5	susbin6	susbin7	susbin8	susbin9	susbin10	susbin11	susbin12	susbin13
1	1	2	89	0	5	0	0	0	0	0
0	3	1	5	45	36	10	0	0	0	0

bedbin4	bedbin5	bedbin6	bedbin7	bedbin8	bedbin9	bedbin10			
1	5	76	18	0	0	0			
1	7	33	46	11	2	0			
1	2	65	31	1	0	0			
-9999	-9999	-9999	-9999	-9999	-9999	-9999			
3	2	27	52	13	3	0			
bedbin5	bedbin6	bedbin7	bedbin8	bedbin9					
2	30	50	12	5					
3	55	34	5	2					
8	54	34	3	0					
2	27	52	13	3					
11	53	29	5	0					
bedbin1	bedbin2	bedbin3	bedbin4	bedbin5	bedbin6	bedbin7	bedbin8	bedbin9	bedbin10
0	0	0	1	5	37	43	12	2	0
0	0	0	1	1	34	52	11	1	0
bin16									
128	256								
susbin14	susbin15	susbin16	bedbin1	bedbin2	bedbin3	bedbin4	bedbin5	bedbin6	bedbin7
0	0	0	0	0	0	1	2	55	35
0	0	0	0	0	0	0	1	11	44

bedbin11	bedbin12	bedbin13						
0	0	0						
0	0	0						
bedbin8	bedbin9	bedbin10	bedbin11	bedbin12	bedbin13	bedbin14	bedbin15	bedbin16
7	0	0	0	0	0	0	0	0
31	5	1	1	0	6	0	0	0

3.1 Modified Einstein Procedure

1) Compute the measured suspended load in Tons/day using Equation 1:

$$Q_s = 0.0027\, Q\, Conc\ \ (tons/day)$$

$$Q_s = 0.0027 * (777) * (2650) = 5{,}371\ \frac{tons}{day}$$

2) Compute the product of the hydraulic radius and friction slope assuming x = 1.535:

2a) First, compute the value of $\sqrt{(SR)}$ using Equation 2:

$$\sqrt{(SR)} = \frac{V_{avg}}{32.63 \log\left[12.27 \frac{h}{k_s} x\right]}$$

$$\sqrt{(SR)} = \frac{3.6}{32.63 \log\left[12.27 * \frac{1.6}{0.00077} * 1.535\right]} = 0.024$$

2b) Compute the shear velocity using Equation 3:

$$U_* = \sqrt{g(SR)}$$

$$U_* = \sqrt{32.17} * (0.024) = 0.1363\ \frac{ft}{s}$$

2c) Compute the laminar sublayer thickness δ using Equation 4:

$$\delta = \frac{11.6 v}{U_*}$$

$$\delta = \frac{11.6 * (1.35 * 10^{-5})}{0.1363} = 0.00115\ \ ft$$

2d) Recheck x to make sure that the assumption of 1.535 is valid using $k_s = d_{65}$:

$$\frac{k_s}{\delta} = \frac{0.00077}{0.00115} = 0.67$$

Check Figure 1 (Einstein's Plate #3) for a value of $k_s / \delta = 0.67$ or use the equation to determine the value of x. The value of x is approximately 1.5346. Therefore, the assumption of x=1.535 is good. This is a trial and error process to determine the value of x and is carried out by the program using a solver routine to determine the value of x.

3) Compute the value of P using Equation 5:

$$P = 2.303\log\left[30.2\frac{hx}{k_s}\right]$$

$$P = 2.303\log\left[30.2\frac{(1.6)*(1.5346)}{0.00077}\right] = 11.48$$

4) Compute the fraction of the flow depth not sampled (A') using Equation 6:

$$A' = \frac{d_n}{d_s}$$

$$A' = \frac{0.3}{1.6} = 0.1875$$

5) Compute the sediment discharge $Q'_{s,total}$ through the sampled zone from Equation 7. This is calculated using a percentage of the flow sampled determined from (Einstein's Plate #4) or from the appropriate equation for the value of A' and P (Equation 8 through Equation 11). For an A' of 0.1875 and P of 11.48, the percentage of sampled is approximately 85.5% (Figure 2).

For P=11:

$$\%\,flowsampled = \frac{100.19 + 31425.83A'^2 - 54359.86A'^4 + 1566703.2A'^6 - 1543898.1A'^8}{1 + 336.12A'^2 + 444.29A'^4 + 15662.05A'^6 + 18936.5A'^8 - 5820.32A'^{10}}$$

with A'=0.1875, the % flow sampled = 0.85 and

$$Q'_{s,total} = Q_s \ \%\ flow\ sampled$$

$$Q'_{s,total} = 5{,}371*(0.85) = 4{,}592\frac{tons}{day}$$

6) Compute the bed-load for each size fraction from Table 7:

6a) The first step in computing the bedload is to calculate the shear intensity (ψ) for all particle sizes in the analysis. ψ is calculated using the greater of the following two equations (Equation 12) for all size classes.

$$\psi = 1.65\left(\frac{d_{35}}{RS_f}\right) \quad or \quad 0.66\left(\frac{d_i}{RS_f}\right)$$

The d_i used in the second equation is the geometric mean for each size class.

$$\psi = 1.65\left(\frac{0.00065}{0.000576}\right) = 1.858, \text{ or } \psi = 0.66\left(\frac{0.00029}{0.000576}\right) = 0.33$$

Table 9. Shear Intensities for Size Classes.

Size Classes	Geometric Mean	Shear Intensity (ψ)
(mm)	(mm)	
0.001 - 0.002	0.0014	N/A
0.002 - 0.004	0.0028	N/A
0.004 - 0.016	0.0080	N/A
0.016 - 0.0625	0.0316	N/A
0.0625 - 0.125	0.0884	1.858
0.125 - 0.25	0.1768	1.858
0.25 - 0.5	0.3536	1.858
0.5 - 1	0.7071	2.653
1 - 2	1.4142	N/A
2 - 4	2.8284	N/A

6b) Compute the intensity of the bed-load transport (ϕ_*) using Equation 13. ϕ_* can also be determined from Einstein's Plate #5 (a relationship between ψ and ϕ_*):

$$\phi_* = \frac{0.023p}{(1-p)}$$

where p is the probability a sediment particle is entrained in the flow and is calculated using Equation 14 and Equation 15. Therefore, to compute the probability "p", evaluate the Error function from a to b. Then, multiply the Error Function by ½ and subtract it from 1. The following table shows the values computed for ϕ_* and $\phi_*/2$ using Error Function evaluation.

Table 10. Intensity of Bed-Load Transport (ϕ_*).

Geometric Mean (mm)	Shear Intensity (ψ)	Intensity of Bed-Load (ϕ_*)	½ ϕ_*
0.0014	N/A	N/A	N/A
0.0028	N/A	N/A	N/A
0.0080	N/A	N/A	N/A
0.0316	N/A	N/A	N/A
0.0884	1.858	3.563	1.781
0.1768	1.858	3.563	1.781
0.3536	1.858	3.563	1.781
0.7071	2.653	2.152	1.076
1.4142	N/A	N/A	N/A
2.8284	N/A	N/A	N/A

6c) Compute the unit bed-load for each size fraction using Equation 16:

$$i_B q_B = 1200 d_i^{3/2} i_B \frac{\phi_*}{2}$$

$$i_B q_B = 1200(0.00029)^{3/2} * (0.05) * (1.781) = 0.002 \frac{lb/s}{ft}$$

Table 11. Unit Bed-Load.

Geometric Mean (mm)	$1200\, d_i^{3/2}$	i_B	½ ϕ_*	Unit Bed-Load, $i_B q_B$ (lb/s)/ft
0.0014	N/A	0	N/A	N/A
0.0028	N/A	0	N/A	N/A
0.0080	N/A	0	N/A	N/A
0.0316	N/A	0	N/A	N/A
0.0884	0.006	0.05	1.781	0.00053
0.1768	0.017	0.76	1.781	0.0227
0.3536	0.047	0.18	1.781	0.0152
0.7071	0.13	0.01	1.076	0.0014
1.4142	N/A	0	N/A	N/A
2.8284	N/A	0	N/A	N/A

6d) Compute the bed-load for each size fraction in tons/day by multiplying by the conversion factor 43.2 and the channel width (Equation 17).

$$i_B Q_B = i_B q_B (43.2W)$$

$$i_B Q_B = (0.00053) * (43.2) * (130) = 2.96 \frac{Tons}{day}$$

Table 12. Computed Bed-Load.

Geometric Mean (mm)	i_B	Unit Bed-Load, $i_B q_B$ (lb/s)/ft	Bed-Load, $i_B Q_B$ (Tons/day)
0.0014	0	N/A	0.00
0.0028	0	N/A	0.00
0.0080	0	N/A	0.00
0.0316	0	N/A	0.00
0.0884	0.05	0.00053	2.96
0.1768	0.76	0.0227	127.44
0.3536	0.18	0.0152	85.37
0.7071	0.01	0.0014	8.10
1.4142	0	N/A	0.00
2.8284	0	N/A	0.00

7) Compute Suspended Load ($Q_s^{'}$) for each size fraction by multiplying the total sampled suspended load ($Q_{s,total}^{'}$) by the suspended load fractions for the sample (Equation 18).

$$Q_s^{'} = i_s \, Q^{'}_{s,total}$$

$$Q_s^{'} = (0.12) * (4592) = 551 \frac{Tons}{day}$$

Table 13. Computed Suspended Load.

Geometric Mean	Suspended Load Fractions (i_S)	Suspended Load in sampled zone ($Q'_{s\,total}$)	Suspended Load ($Q_s^{'}$)
(mm)	(%)	(Tons/day)	(Tons/day)
0.0014	0.26	4,592	1,194
0.0028	0.08	4,592	367
0.0080	0.12	4,592	551
0.0316	0.19	4,592	872
0.0884	0.12	4,592	551
0.1768	0.18	4,592	827
0.3536	0.05	4,592	230
0.7071	0.00	0	0
1.4142	0.00	0	0
2.8284	0.00	0	0

8) Compute the theoretical exponent for vertical distribution of sediment (Z). This process is a trial and error method.

8a) Compute the ratio $\frac{Q_s^{'}}{i_B Q_B}$ for all size classes with suspended load transport:

$$\frac{Q_s^{'}}{i_B\ Q_B} = \frac{(551)}{(2.96)} = 186.1$$

Table 14. Ratio of Suspended Load to Bed-Load.

Geometric Mean	Suspended Load ($Q_s^{'}$)	Bed-Load $i_B Q_B$	$\frac{Q_s^{'}}{i_B\ Q_B}$
(mm)	(Tons/day)	(Tons/day)	
0.0014	1,194	0.00	0.00
0.0028	367	0.00	0.00
0.0080	551	0.00	0.00
0.0316	872	0.00	0.00
0.0884	551	2.96	185.906
0.1768	827	127.44	6.486
0.3536	230	85.37	2.690
0.7071	0	8.10	0.00
1.4142	0	0.00	0.00
2.8284	0	0.00	0.00

8b) There are three size classes that have calculated values for the ratio of the suspended load to the bed-load. None of the ratios is for a size range less than sand/silt split of 0.0625 and should not be used. Therefore, all three size classes will be used as the reference ranges for Z-value computations. The ratio of suspended load to bed-load is set equal to a function with the parameters $I_1^{''}, J_1^{''}, J_1^{'}, J_2^{'}$ using Equation 19 (BOR,1955):

$$\frac{Q_s'}{i_B\, Q_B} = \frac{I_1''}{J_1''}\left(PJ_1' + J_2'\right)$$

The dependent variables for the integral form of the equations for I_1'', J_1'', J_1', J_2' are A', A'', and Z. A' has previously been computed. A'' is calculated as the following for each size class (Equation 20):

$$A'' = \frac{2\, d_i}{h}$$

$$A'' = \frac{2*(0.00029)}{(1.6)} = 0.00036$$

For each size class an initial Z-value must be assumed. In order to provide some guidance in the initial guess of the Z-value, Equation 21 is used (from Einstein's Plate #8):

$$Z_{guess} = -0.1465 \ln\left(\frac{Q_s'}{i_B Q_B}\right) + 1.0844$$

For the size class 0.062 mm – 0.125 mm an initial Z-value of 0.32 was calculated. For this Z-value, Equation 22 through Equation 26 were used to determine the parameters contained in plates 9-11.

Substituting these values into the right side of Equation 19 gives the following:

$$\frac{I_1''}{J_1''}\left(P\, J_1' + J_2'\right) = \frac{(56.3)}{(1.18)}\left[(11.48)*(0.73) + (-0.57)\right] = 372.793$$

372.793 is not "relatively" close to 186.15, therefore, another guess at a Z-value must be computed in order to provide better results. This is a trial and error process that is carried out by the program using a solver routine to determine the value of Z by minimizing the difference between the ratio $\frac{Q_s'}{i_B\, Q_B}$ and $\frac{I_1''}{J_1''}\left(PJ_1' + J_2'\right)$.

Through the minimization process, a Z-value of 0.406 computes a close match with a difference of only 8.94E-05. Therefore, a Z-value of 0.406 is selected for this size class. The same technique is applied to the remaining two sizes classes. The final results are presented in the following table:

Table 15. Z-value Determination for Suspended Load

Grain Size (mm)	A'	A''	Z	I_1''	J_1''	J_1'	$-J_2'$	$\frac{Q_s'}{i_B\, Q_B}$	$\frac{I_1''}{J_1''}\left(P\, J_1' + J_2'\right)$
0.0884	0.1875	0.00036	0.406	31.514	1.316	0.729	0.597	185.906	185.906
0.1768	0.1875	0.00072	0.823	2.571	3.308	0.795	0.786	6.486	6.486
0.3536	0.1875	0.00145	0.946	1.404	4.58	0.839	0.864	2.690	2.69

8c) Once the Z-values have been determined for the suspended load, a log-log plot is made of the relationship between Z and the fall velocity for each size class. A power function equation is then developed such that $Z = a\,\omega^b$. The remaining Z-values for the bed-load are computed using this relationship. In this example, the fall velocity has been computed using Rubey's Equation (Equation 26 and Equation 28).

$$F = \left[\frac{2}{3} + \frac{36\nu^2}{g\,d_i^3\left(\frac{\gamma_s}{\gamma} - 1\right)}\right]^{1/2} - \left[\frac{36\nu^2}{g\,d_i^3\left(\frac{\gamma_s}{\gamma} - 1\right)}\right]^{1/2}$$

$$F = \left[\frac{2}{3} + \frac{36 * \left(1.35 * 10^{-5}\right)^2}{(32.17) * (0.00029)^3 * \left(\frac{(165)}{(62.4)} - 1\right)}\right]^{1/2} - \left[\frac{36 * \left(1.35 * 10^{-5}\right)^2}{(32.17) * (0.00029)^3 * \left(\frac{(165)}{(62.4)} - 1\right)}\right]^{1/2} = 0.1433$$

$$\omega = F\left[d_i\,g\left(\frac{\gamma_s - \gamma}{\gamma}\right)\right]^{1/2}$$

$$\omega = (0.1433) * \left[(0.00029) * (32.17) * \left(\frac{(165) - (62.4)}{(62.4)}\right)\right]^{1/2} = 0.01774\,\frac{ft}{s}$$

Table 16 presents the complete summary of fall velocities and Z-values for all sizes classes. Figure 14 is the plot of the three suspended load points indicating the power function regression relationship $Z = a\,\omega^b$ and the resulting Z-values that were calculating using the regression equation; where **a** is equal to a value of 2.2944 and **b** is equal to a value of 0.415.

Table 16. Summary of Z-values and Fall Velocities.

d_i	F	ω	Z_{assume}	Z_{calc}
(mm)		ft/s		
0.0014	0.0003	0.00000	-	0.015
0.0028	0.0008	0.00002	-	0.024
0.0080	0.0040	0.00015	-	0.059
0.0316	0.0317	0.00235	-	0.186
0.0884	0.1433	0.01774	0.406	0.430
0.1768	0.3439	0.06023	0.823	0.715
0.3536	0.5819	0.14414	0.946	1.026
0.7071	0.7229	0.25323	-	1.298
1.4142	0.7820	0.38742	-	1.548
2.8284	0.8041	0.56339	-	1.808

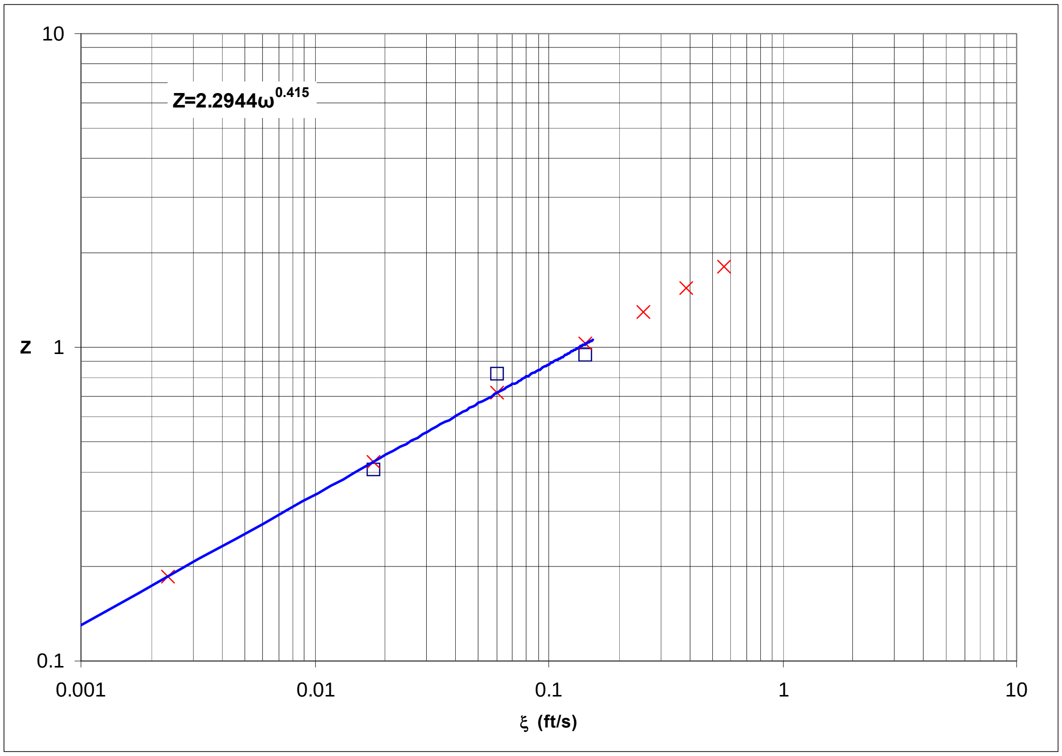

Figure 14. Z-value Regression Analysis.

9) Compute the total sediment load.

9a) Calculate the total load due to suspended sediment. Calculate the ratio $\frac{\left(P J_1^{''} + J_2^{''}\right)}{\left(P J_1^{'} + J_2^{'}\right)}$ for the size classes used in determining the z-values for suspended load and smaller (0.001mm to 0.5mm). Multiply this ratio by the computed suspended sediment for each size class as calculated in step 7 of this procedure to compute the total load due to suspended sediment (Equation 29).

$$\frac{\left(P J_1^{''} + J_2^{''}\right)}{\left(P J_1^{'} + J_2^{'}\right)} = \frac{[(11.48)*(1.365)+(-2.68)]}{[(11.48)*(0.73)+(-0.61)]} = 1.673$$

$$Q_{s,total\ suspended} = Q_s^{'} \frac{\left(P J_1^{''} + J_2^{''}\right)}{\left(P J_1^{'} + J_2^{'}\right)}$$

$$Q_{s,total\ suspended} = (551)*(1.673) = 921.77 \frac{tons}{day}$$

9b) The total load for the remaining size classes are calculated using the computed bed-load. Using the Z-values calculated with the power function from step 8c, calculate $I_1^{''}$ and $-I_2^{''}$ using Equation 30 and Equation 31:

$$I_1'' = 0.216 \frac{A''^{(z-1)}}{(1-A'')^z} J_1''$$

$$-I_2'' = 0.216 \frac{A''^{(z-1)}}{(1-A'')^z} J_2''$$

Then, compute the value $\left(P\, I_1'' + I_2'' + 1\right)$ and multiply by the computed bed-load for that size class to compute the total load due to bed-load (Equation 32).

$$Q_{s,total\ bed} = i_B Q_B \left(P\, I_1'' + I_2'' + 1\right)$$

$$Q_{s,total\ bed} = (8.103) * [(11.48) * (0.53) + (-2.13) + 1] = 40.43 \frac{Tons}{day}$$

9c) The total load is then the sum of the total suspended or total bed load of each size class (Equation 33).

$$Q_{s,total} = \sum Q_{s,totalsuspended} + \sum Q_{s,total\ bed}$$

Table 17 is shows the complete total load:

Table 17. Computed Total Load.

Geometric Mean	Q_s'	iBQB	$\frac{\left(P\, J_1'' + J_2''\right)}{\left(P\, J_1' + J_2'\right)}$	$\left(P\, I_1'' + I_2'' + 1\right)$	Total Load
(mm)	(Tons/day)	(Tons/day)			(Tons/day)
0.0014	1,194	0.00	1.196		1427.87
0.0028	367	0.00	1.202		441.48
0.0080	551	0.00	1.224		674.61
0.0316	872	0.00	1.328		1158.82
0.0884	551	2.96	1.673	256.359	921.77
0.1768	827	127.44	2.580	36.307	2132.63
0.3536	230	85.37	5.151	9.502	811.17
0.7071	0	8.10		4.989	40.43
1.4142	0	0.00			0
2.8284	0	0.00			0
Total Load =					7,608.8

In this example, the suspended load equation was used for size classes smaller than 0.25 mm and the total bed load equation was used for the larger size classes. The total load computed was 7,608.8 tons/day. The same example problem was also input into BORAMEP for comparison.

3.2 BORAMEP Program Solution

3.2.1 Single Sample

Using the input form method, the sample is used to show how the input form can be used to calculate total sediment load. Figure 15 shows the input form and Figure 16 shows the results of the calculations.

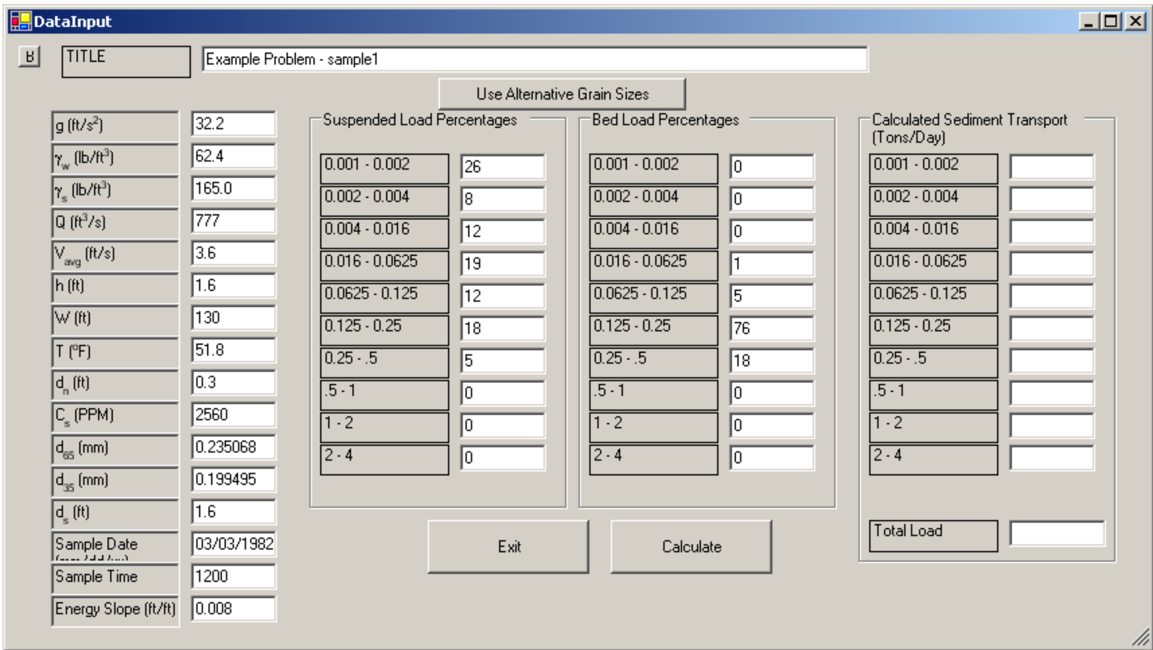

Figure 15. Example problem using BORAMEP input form.

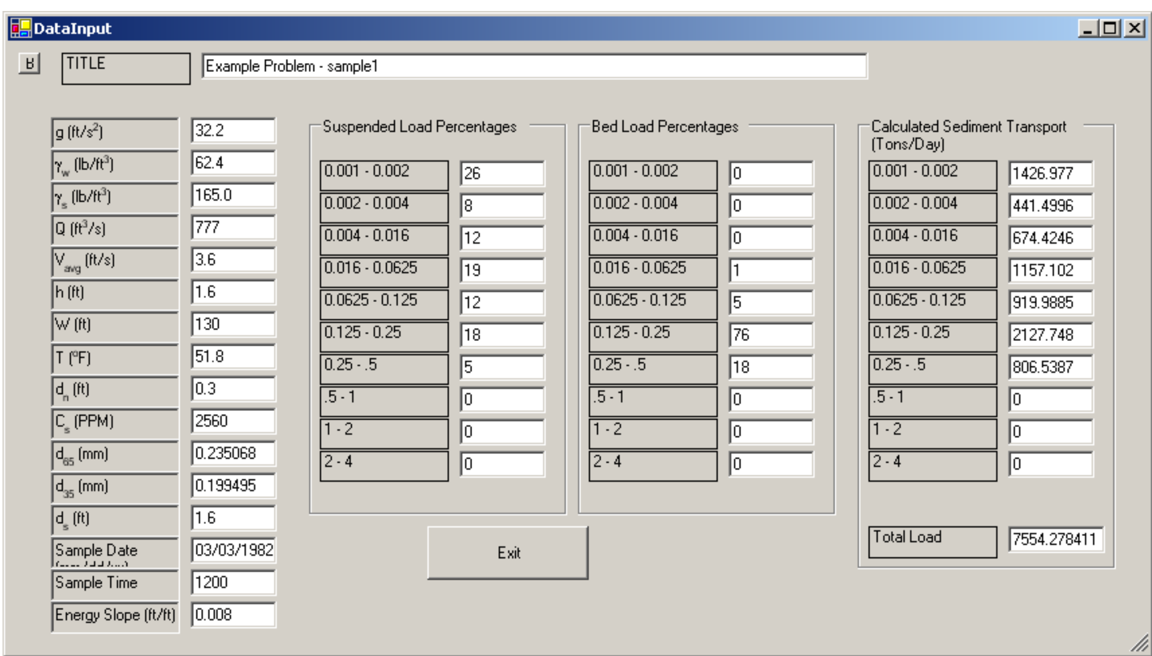

Figure 16. Example problem total load results using BORAMEP input form.

The total load computed in BORAMEP was 7554.3 tons/day which is 54.5 tons/day different than the 7,608.8 tons/day calculated in the step-by-step procedure. The differences are due to small differences in z-value calculations and regression analysis.

3.2.2 Multiple Samples

Using the input file method, total sediment load is calculated for all the samples given in

Table 8 at the same time. Figure 17 thru Figure 18 show the steps required to run the BORAMEP program using the file input method.

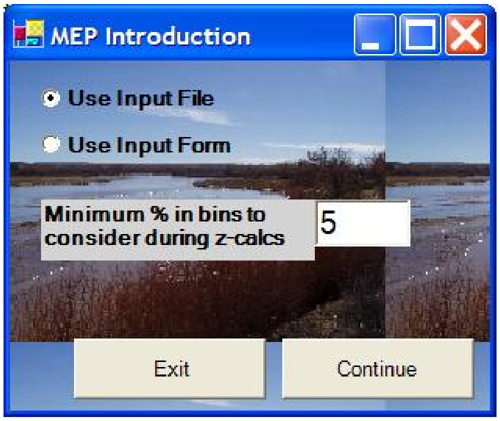

Figure 17. BORAMEP Startup Form.

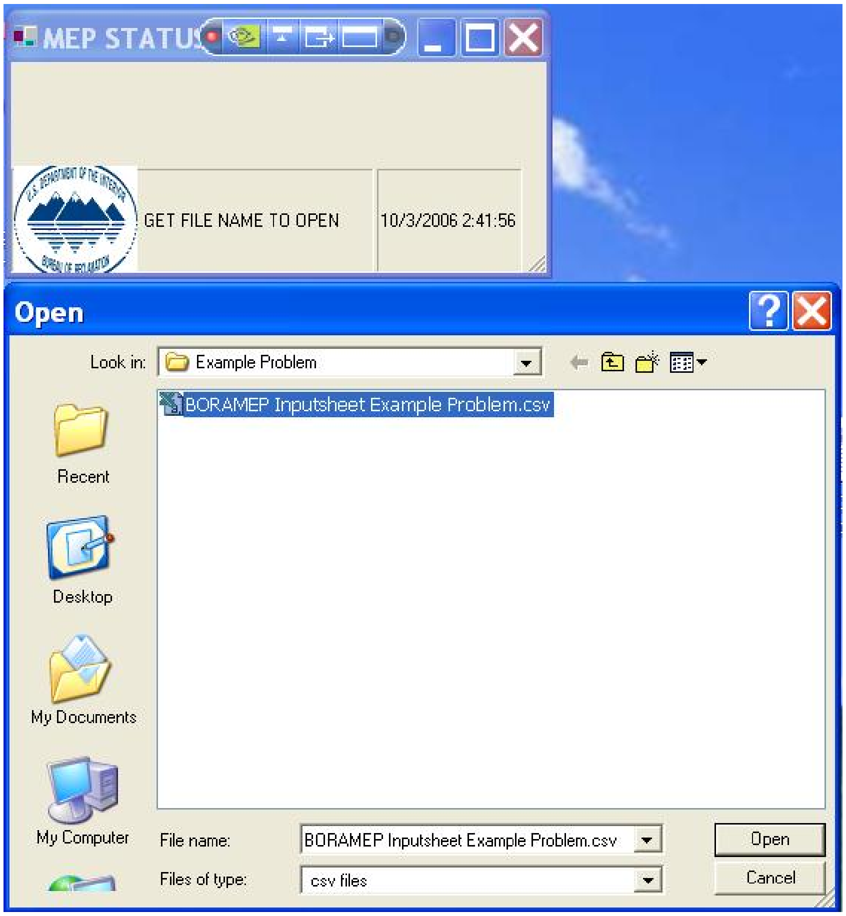

Figure 18. Open Input File Message Box.

Once the input file is selected the user is then prompted to select a file name and location for the output files generated by the program (Figure 19). After the output file name and location is selected, the program starts calculating total load for each record contained in the input file (Figure 20).

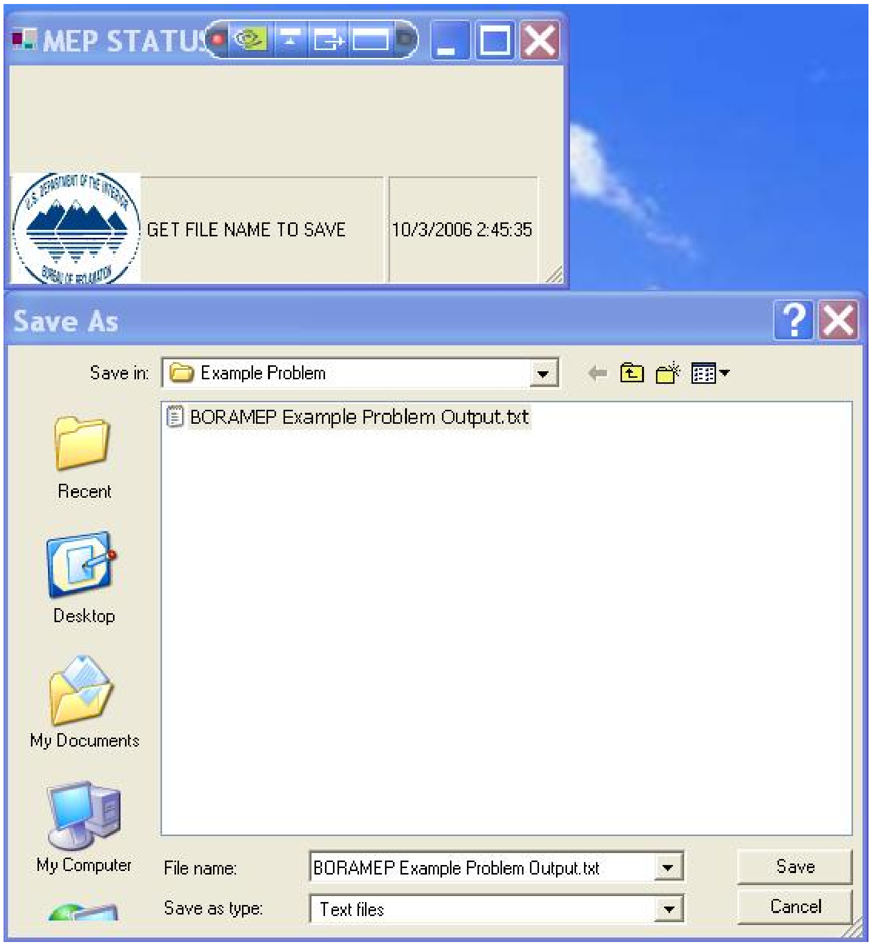

Figure 19. Save output file message box.

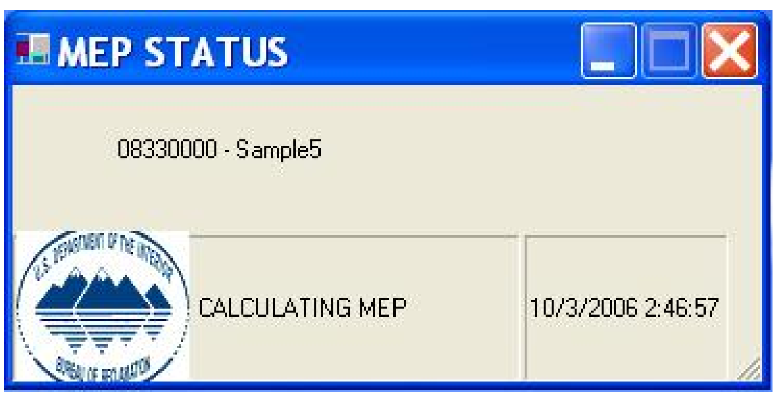

Figure 20. BORAMEP status message box.

Once the program is finished, it will prompt the user with a dialog box stating the program is complete and list the number of errors that were generated (Figure 21).

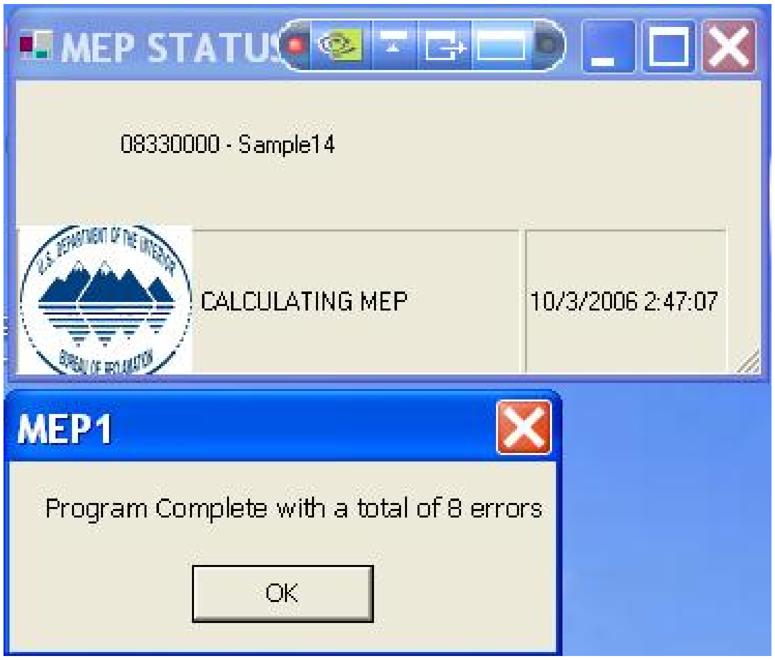

Figure 21. Program complete message box.

Once the program has finished, the file called *filename*.txt.sum is easily imported into an Excel spreadsheet and used to view the results of the MEP calculations and carry out additional analysis (Figure 22 and Figure 23). Due to the width of the output file that is generated, the output has been broken into two parts: Part 1 contains the first 13 columns of data and part 2 contains the remaining columns.

***		Discharge	Conc	Suspended	d65	d35	Temp	Computed total load by size fraction (tons/day)				
Location	Date	(cfs)	(PPM)	Sample (tons/day)	(mm)	(mm)	F	0.001 - 0.00	0.002 - 0.00	0.004 - 0.016	0.016 - 0.062	0.0625 - 0.12
08330000 - Sample1	3/3/1982	777	2560	5370.624	0.2351	0.1995	51.8	1426.98	441.50	674.43	1157.13	920.00
08330000 - Sample2	5/8/1969	4570	3200	39484.8	0.3822	0.2338	10.2	3176.42	397.52	1197.42	5693.75	15092.72
***		Discharge	Conc	Suspended	d65	d35	Temp	Computed total load by size fraction (tons/day)				
Location	Date	(cfs)	(PPM)	Sample (tons/day)	(mm)	(mm)	F	0.001 - 0.00	0.002 - 0.00	0.004 - 0.016	0.016 - 0.062	0.0625 - 0.12
08330000 - Sample8	2/16/1971	865	1220	2849.31	0.2629	0.2028	56.3	202.58	29.00	87.82	463.32	1163.61
08330000 - Sample10	3/19/1973	1130	2780	8481.78	0.2484	0.1907	44.6	861.45	172.56	434.41	2269.70	3575.15
***		Discharge	Conc	Suspended	d65	d35	Temp	Computed total load by size fraction (tons/day)				
Location	Date	(cfs)	(PPM)	Sample (tons/day)	(mm)	(mm)	F	0.001 - 0.00	0.002 - 0.00	0.004 - 0.016	0.016 - 0.062	0.0625 - 0.12
08330000 - Sample12	1/22/1979	964	912	2373.754	0.3953	0.2483	39.2	1181.88	169.36	195.75	259.08	124.83
***		Discharge	Conc	Suspended	d65	d35	Temp	Computed total load by size fraction (tons/day)				
Location	Date	(cfs)	(PPM)	Sample (tons/day)	(mm)	(mm)	F	0.001 - 0.00	0.002 - 0.00	0.004 - 0.016	0.016 - 0.062	0.0625 - 0.12
08330000 - Sample13	12/3/1979	1680	1620	7348.32	0.2955	0.2221	40.1	150.62	0.00	77.13	81.67	183.32

Figure 22. filename.txt.sum output part 1 (imported into Excel).

						Total Load	Total Sand Load						
0.125 - 0.2	0.25 - 0.5	0.5 - 1	1 - 2	2 - 4		(tons/day)	(>0.625mm)(tons/day)						
2127.73	806.54	0	0	0		7554.3	3854.3						
14493.62	7184.38	944.63	106.05	0		48286.5	37821.4						
					Total Load	Total Sand Load							
0.125 - 0.2	0.25 - 0.5	0.5 - 1	1 - 2		(tons/day)	(>0.625mm)(tons/day)							
2232.29	782.01	42.78	0		5003.4	4220.7							
3957.51	927.77	104.75	0		12303.3	8565.2							
									Total Load	Total Sand Load			
0.125 - 0.2	0.25 - 0.5	0.5 - 1	1 - 2	2 - 4	4 - 8	8 - 16	16 - 32		(tons/day)	(>0.625mm)(tons/day)			
808.84	659.74	136.08	3	0	0	0	0		3538.4	1732.3			
												Total Load	Total Sand Load
0.125 - 0.2	0.25 - 0.5	0.5 - 1	1 - 2	2 - 4	4 - 8	8 - 16	16 - 32	32 - 64	64 - 128	128 - 256		(tons/day)	(>0.625mm)(tons/day)
9585.01	0.00	864.11	0	0	0	0	0	0	0	0		10941.9	10632.4

Figure 23. filename.txt.sum output part 2 (imported into Excel).

Figure 24 provides an example of a total sediment load rating curve that was generated using results from the BORAMEP program.

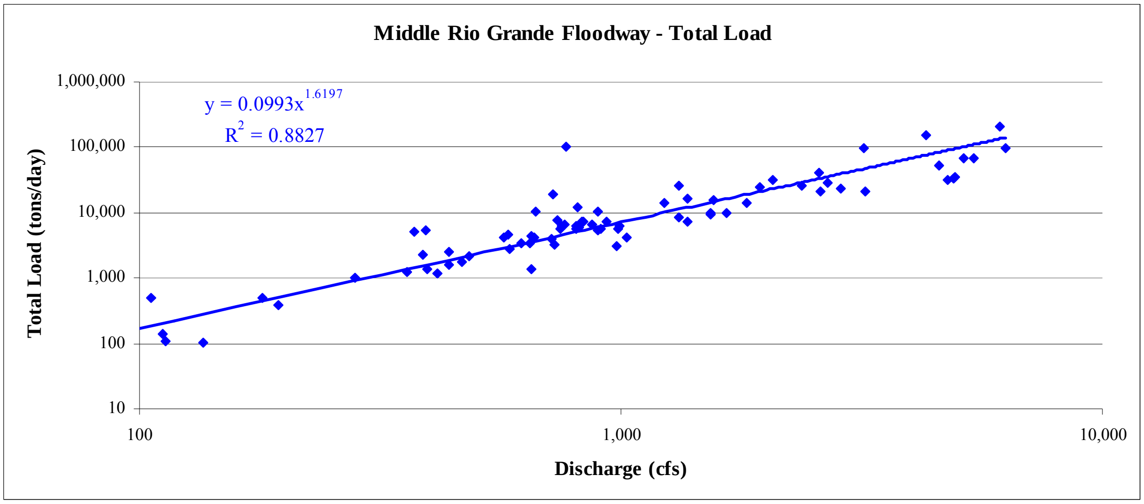

Figure 24. Example of total load rating curve analysis.

The file called *filename*.txt.err provides a summary of errors that were encountered by the program and can be used to determine if any samples might be able to be used if additional data is available or known. An example of the error file generated is shown in Figure 25.

```
08330000 - Sample2,5/8/1969, ERRORCODE:3,TEMPERATURE NOT BETWEEN 32 and 80
DEGREES F

08330000 - Sample3,9/2/1969, ERRORCODE:1,NOT ENOUGH OVERLAPPING BINS FOR
MEP

08330000 - Sample4,9/30/1969, ERRORCODE:98,THERE WAS AN ERROR DURING FILE
INPUT, MISSING DATA

08330000 - Sample5,7/27/1971, ERRORCODE:1,NOT ENOUGH OVERLAPPING BINS FOR
MEP

08330000 - Sample6,7/7/1969, ERRORCODE:1,NOT ENOUGH OVERLAPPING BINS FOR
MEP

08330000 - Sample7,10/5/1970, ERRORCODE:98,THERE WAS AN ERROR DURING FILE
INPUT, MISSING DATA

08330000 - Sample9,7/27/1971, ERRORCODE:4,CONTINUITY NOT SATISFIED

08330000 - Sample11,7/30/1973, ERRORCODE:8,D65 < D35

08330000 - Sample14,4/5/1996, ERRORCODE:1112,FITTED Z-VALUES GENERATED
NEGATIVE EXPONENT, NOT CONTINUING...
```

Figure 25. Example filename.error.txt.err output.

From the error file and codes provided, sample 11 appears that it could be used if the discrepancy between the d65 and d35 was looked into. For this example, the d65 and d35 values were switched, therefore if they are switched back the program is able to calculate total load for this sample. This is just one way that the error file can be used to understand why a sample might generate an error within the program.

4.0 GLOSSARY OF TERMS

‘	Single prime mark on A, J, or Q designates association with the sampling depth
“	Double prime mark on A, J, I, or Q designates association with the total depth through which suspended sediment is discharged
A	Stream cross-section area in square feet
A'	Ratio of d_n to d_s
A''	Ratio of $2d_i$ to h
B_*	Constant, 0.143
Conc or Cs	Measured suspended-sediment concentration
h	Mean depth of water
d_n	Vertical distance not sampled; the distance between the bottom of the sampled zone and the streambed as defined by the sampler used
d_s	Vertical distance sampled; the average of the total depths recorded at the sampling verticals
d_i	Geometric mean diameter of a size range
d_{35}	Particle size at which 35 percent of the bed material by weight is finer
d_{65}	Particle size at which 65 percent of the bed material by weight is finer
d_{90}	Particle size at which 90 percent of the bed material by weight is finer
ERF	Error Function integral
F	A mathematical abbreviation
g	Acceleration of gravity, 32.2 feet per second per second
h	flow depth in feet
i_B	Fraction of bed material in a given size range
i_s	Fraction of suspended material in a given size range
$i_B q_B$	Sediment discharge through the bed layer of particles of a given size range, in pounds per second per foot of width

$i_B Q_B$	Sediment discharge through the bed layer of particles of a given size range, in tons per day
I''_1	A mathematical abbreviation that contains J''_1
J'_1	A mathematical abbreviation
J''_1	A mathematical abbreviation
J'_2	A mathematical abbreviation, always negative
k	Effective height of the roughness elements of the channel
k_s	Equivalent sand roughness for a particular roughness k, that particle size of the bed material for which 65 percent by weight is finer
p	Probability of a particle of a diameter D being eroded
P	Mathematical abbreviation
Q	Water discharge through a cross section, in cubic feet per second
Q_s	Discharge of suspended sediment through a cross section, in tons per day
Q'_s	Discharge of suspended sediment of a size range through a cross section, in tons per day
$Q_{s,total\ suspended}$	Total suspended sediment load through a cross section, in tons per day
$Q_{s,total\ bed}$	Total bed sediment load through a cross section, in tons per day
$Q'_{s,total}$	Total sediment load through a cross section, in tons per day
R	Hydraulic radius
(SR)	Slope-hydraulic radius function
t	Water temperature in degrees Fahrenheit
V_{avg}	Mean cross-sectional velocity of flow
V_s	Fall velocity for the geometric mean size for a size range
U_*	Mean cross-sectional shear velocity; equals $\sqrt{g\ (R\ S_f)}$
W	Width of the channel in feet
x	Dimensionless paramenter
Z	A theoretical exponent of the equation that describes the vertical distribution of suspended sediment of a size range
δ	Thickness of laminar sublayer
γ_s	Specific weight of solids
γ_w	Specific weight of water

η_0	Constant, 0.5
ϕ_*	Intensity of bedload transport for individual grain size for the modified Einstein procedure
ψ	Intensity of shear on particles; function for correlating the effects of flow with the intensity of bedload transport
ν	Kinematic viscosity
ω	Fall velocity, in feet per second; calculated using Rubey's equation

5.0 REFERENCES

Bureau of Reclamation. (1955 revised). *Step Method for Computing Total Sediment Load by the Modified Einstein Procedure*. Prepared by Sedimentation Section Hydrology Branch Project Investigation Division Bureau of Reclamation.

Bureau of Reclamation. (1966). *Computation of "Z's" for Use in the Modified Einstein Procedure*. Prepared by Joe Lara, Hydraulic Engineer. Division of Project Investigations Hydrology Branch Sedimentation Section.

Bureau of Reclamation. (1969). *Guide for Application of Total Sediment Load Computer Program*. Prepared by Sedimentation Section Hydrology Branch Project Investigation Division Bureau of Reclamation.

Burkham, D.E., and Dawdy, D.R. (1980). *General Study of the Modified Einstein Method of Computing Total Sediment Discharge.* USGS Water Supply Paper 2066.

Colby, B.R., and Hembree, C.H. (1955). *Computations of Total Sediment Discharge Niobrara River Near Cody, Nebraska.* USGS Water Supply Paper 1357.

Einstein, H.A. (1950). *The bed-load function for sediment transportation in open channel flows*. U.S. Department of Agriculture, Soil Conservation Service, Technical Bulletin No. 1026.

Jay, Forrest, Albert, J., and Julien, P.Y., 2005, "Low Flow Conveyance Channel BORAMEP Total Load Analysis" Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado.

Julien (1995). *Erosion and Sedimentation.* Cambridge University Press.

Shah, Seema C., 2006, "Variability in Total Sediment Load Using BORAMEP on the Rio Grande Low Flow Conveyance Channel" Masters Thesis, Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado.

Yang, C.T. (1996). *Sediment Transport Theory and Practice.* The McGraw-Hill Companies, Inc.