CALIBRATION OF THE WATBAL SEDIMENT AND WATER YIELD MODEL CLEARWATER NATIONAL FOREST

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Abstract: WATBAL is the Clearwater National Forest watershed response model used to simulate the likely cumulative sediment and water yield effects of roads, timber harvest and fire. The model estimates are based upon the soil, hydrologic and geomorphic characteristics of over 160 landtypes on the Clearwater National Forest. This paper documents a recent calibration of the model to improve its accuracy and predictability for the Forest. Two previous validations of the WATBAL model, the first in 1997 and the last in 2002 showed the model tending to under-predict sediment delivery. The 1997 validation indicated the model estimated only 27 percent of the measured sediment in Lolo Creek and 56 percent of measured sediment in Pete King Creek. The 2002 validation examined six watersheds and found the model estimating between 32 and 78 percent of the actual sediment measured.

In 2005, over 18,000 suspended sediment and 600 bedload sediment measurements collected between 1978 and 2004 were analyzed from seven different watersheds. Watersheds were selected with a variety of management intensity, underlying geology and long-term data sets that could be paired to evaluate WATBAL model runs. Validation tests of sediment data collected showed the model estimating between 31 percent of measured sediment in Elk Creek, a watershed dominated by general granitic and grussic-granitic parent materials associated with the Idaho Batholith and low relief rolling hills landforms; and 103 percent in Swamp Creek, a watershed dominated by Belt Series quartzite parent materials. Overall, the model estimated 62 percent of the measured sediment in the seven watersheds with a correlation coefficient of the regression (r^2) for predicted versus measured sediment of 0.46.

Three adjustments were made to WATBAL's landtype input files to recalibrate the model. On five landtypes that have a high occurrence of landslides related to a 20-year flood event, the mass wasting coefficients were increased from "high" (40 t/mi^2/yr.) to "very high" (80 t/mi^2/yr.); on highly erosive grussic-granitic and micaceous schist parent materials the landtype surface and mass wasting coefficients were doubled; and on general granitic landtypes, the surface and mass wasting coefficients were increased by 150 percent. When the model was run with the calibrated landtype coefficients, it estimated 64 percent of measured sediment in Lolo Creek to 126 percent in Deadman Creek. The overall mean accuracy for the seven watersheds combined improved to 99 percent. The resulting r^2 was 0.60.

The WATBAL model continues to under-predict sediment in watersheds such as Lolo Creek and Elk Creek with high percentages of low relief rolling hills and over-predicts sediment in watersheds such as Deadman Creek with higher percentages of over-steepened breaklands. Watershed predictive models, including WATBAL, are not expected to be perfect due to the extraordinary variability of natural watershed systems; however the accuracy has improved as long-term sediment data became available. In any case, the value of the model for its primary purpose of identifying change and comparing watersheds or alternatives is improved.

INTRODUCTION

WATBAL is the Clearwater National Forest cumulative watershed response model used to simulate the likely cumulative sediment and water yield effects that result from typical forest management disturbances, such as roads, timber harvest and fire. The model estimates are based upon the watershed characteristics of over 160 landtypes characterized on the Clearwater National Forest, Wilson, et al. (1983). The purpose of this paper is to document the calibration of the Clearwater National Forest's WATBAL sedimentation model as recommended in *Validation of the WATBAL Sediment Model*, Jones (2002). The intent of this paper is not to explain the concepts of the R1-R4 or WATBAL watershed model. These are well documented in *Guide for Predicting Sediment Yields from Forested Watersheds*, Cline, et al. (1981) and in *Watershed Response Model for Forest Management, WATBAL Technical Users Guide*, Patten (1989); Patten and Jones (2001); and Patten and Jones (2005).

Two previous papers dealt with the validation of WATBAL; *Evaluating the WATBAL Sediment Loading Model, Clearwater National Forest, Idaho,* Hickey (1997) and *Validation of the WATBAL Sediment Model, Clearwater National Forest,* Jones (2002). Both validations indicated that WATBAL was tending to under-predict sediment.

Hickey performed his test of predicted versus actual sediment in two watersheds; Lolo Creek and Pete King Creek. The Lolo Creek test included nine years of predicted versus measured sediment between 1984 and 1994. The Pete King test included 19 years of predicted versus measured sediment between 1975 and 1994. Hickey found that, for the periods of records analyzed, WATBAL under-predicted sediment by 22.1 t/mi^2/yr in Lolo Creek (27% of measured sediment) and 28.0 t/mi^2/yr in Pete King Creek (56% of measured sediment).

In *Validation of the WATBAL Sediment Model,* Jones analyzed predicted versus actual sediment in six watersheds; Fish, Swamp, Deadman, Pete King, Lolo and Canyon creeks. Between nine and 23 years of discharge and sediment data were used depending on the length of record in each watershed. WATBAL under-predicted sediment from 20.6 t/mi^2/yr (32% of measured sediment) in Lolo Creek to 4.5 t/mi^2/yr (78% of measured sediment) in Swamp Creek. For all six test watersheds combined, WATBAL under-predicted measured sediment by 14.9 t/mi^2/yr (56%). Because WATBAL consistently under-predicted sediment in all watersheds, these recommendations were made to calibrate the model:

- Re-calculate the runoff coefficients and distributions in the model to reflect the annual hydrograph for the most representative gauging stations Jones (2002). This step was completed as part of *Validation of the WATBAL Sediment Model in 2002;*

- Adjust the natural surface and mass erosion coefficients in the external WATBAL support files for landtypes (the subject of this paper).

METHODOLOGY

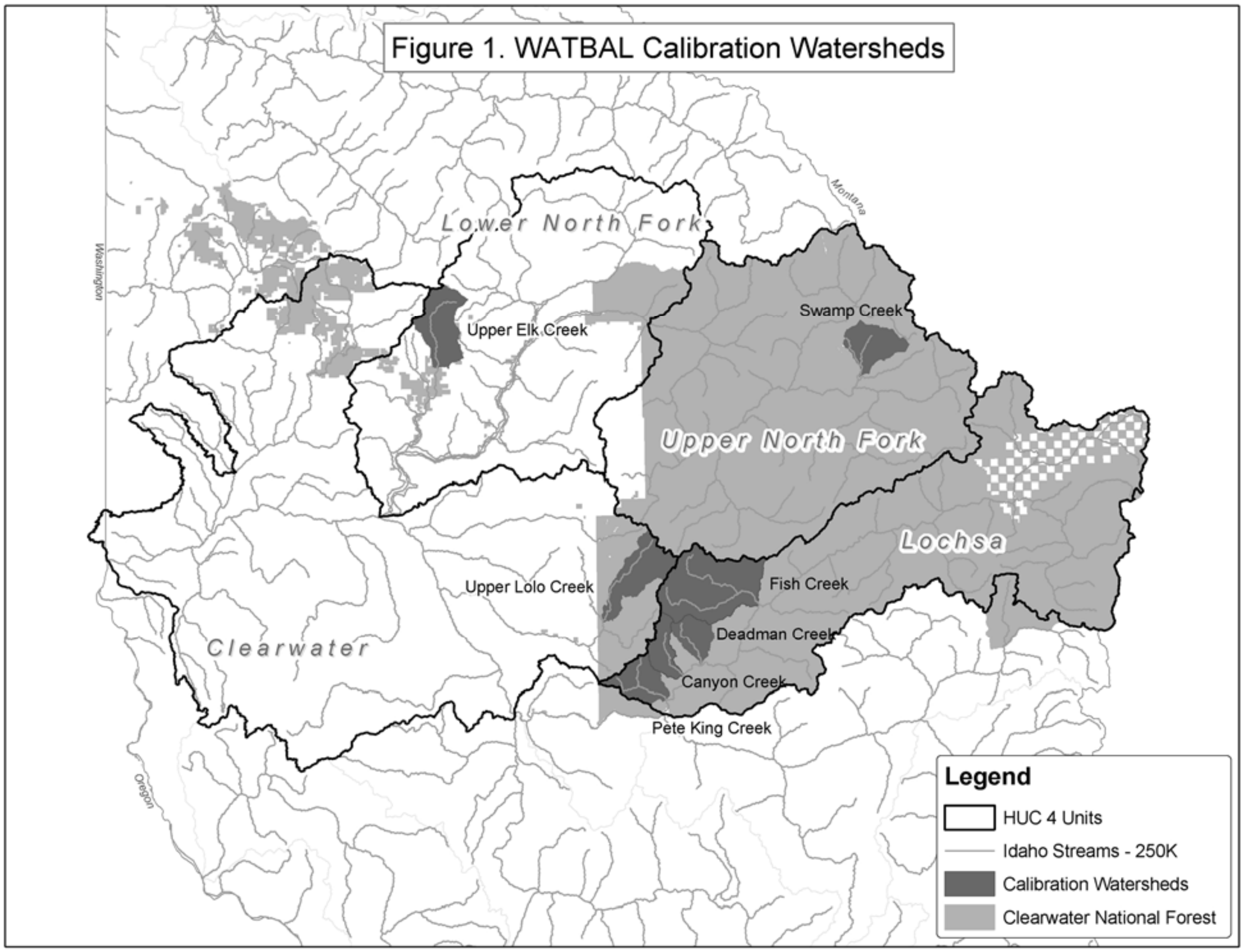
The Clearwater National Forest is rich in stream discharge and suspended sediment data. In 1978, the first automated suspended sediment sampler was installed at the Pete King Creek gaging station. Since that time, stage recorders and automated suspended sediment samplers have been installed in six other watershed for the purpose of model calibration. In this calibration, over 18,000 suspended and 600 bedload sediment samples were used from seven different established water quality stations. To derive the total annual sediment load at a station, both bedload and suspended load samples were analyzed. First, each bedload measurement (with a Helley-Smith sampler) was converted to its relative percent of the depth integrated suspended load measured (with a DH-48 sampler) that same day. Since far fewer bedload measurements were taken than suspended load, this bedload ratio was then added to the daily composited suspended load measurements (from an automated ISCO device) for each day when no bedload measurement was taken to determine the *total* load estimate for that day. The annual calculation of these total load estimates was then compared to the WATBAL estimates.

For selecting calibration watersheds, the criteria used were: 1) a broad range of management intensities; 2) a variety of parent materials and landforms; 3) long-term periods of record of stream discharge and suspended sediment; and 4) a WATBAL run driven by a comprehensive set of disturbance activities. Seven watersheds met these requirements and they were used for this calibration exercise. The calculated total sediment, derived from measured instream data, was compared to WATBAL modeled outputs of total sediment. Data are presented in *tons per square mile of watershed per year* (t/mi^2/yr) and ratios as percentages. The analysis included the watersheds in Figure 1.

The *Fish Creek* watershed is located within the Lochsa River Subbasin. Fish Creek was the largest watershed analyzed at 88 square miles (mi^2). Management intensity is light (e.g., road density is less than 0.1 miles per square mile of watershed (mi/mi^2) and harvest intensity is less than 2 percent of the watershed). The geology is dominated by undifferentiated parent materials[1] (38%) and grussic[2] and other granitic rocks of the Idaho Batholith (58%). Landforms consist of low relief rolling hills (33%), mountain slopelands (31%) and steep breaklands (31%). A

[1] Undifferentiated parent materials consist of mapping units where the type of parent material does not influence the interpretative criteria for the units.
[2] Highly weathered granitic rocks.

combination of WATBAL runs on upper Fish Creek (below Hungery Creek) was used to compare to the measured data at the Fish Creek gaging station near its mouth.



The *Swamp Creek* watershed is located within the Upper North Fork Clearwater River Subbasin. The watershed area is 16 mi^2. Management intensity is light (e.g., road density is less than 1 mi/mi^2 and harvest intensity is less than 1 percent of the watershed). The geology is dominated by Belt series quartzites (47%) and undifferentiated parent material (52%). Landforms consist of low relief rolling hills (18%), mountain slopelands (55%) and steep breaklands (27%).

The *Deadman Creek* watershed is located within the Lochsa River Subbasin. The watershed area is 20 mi^2. Management intensity is moderate (e.g., road density is nearly 2 mi/mi^2 and harvest intensity 13 percent). The geology is dominated by granitic and grussic-granitic rocks (79%) and undifferentiated parent material (20%). Landforms consist of low relief rolling hills (49%), mountain slopelands (15%) and steep breaklands (34%).

The *Elk Creek* watershed (above Partridge Creek) is located within the Lower North Fork Clearwater River Subbasin. The watershed area is 35 mi^2. Management intensity is heavy (e.g., road density is nearly 4 mi/mi^2 and harvest intensity greater than 20 percent). The geology is a mixture of granitic and grussic-granitic rocks (52%), Belt series quartzites (21%), Border Zone micaceous schists (19%) and alluvial deposition (5%). Landforms consist of low relief rolling hills (52%) and mountain slopelands (44%).

The *Pete King Creek* watershed is located within the Lochsa River Subbasin. The watershed area is 28 mi^2. Management intensity is heavy (e.g., road density greater than 5 mi/mi^2 and harvest intensity is nearly 30 percent).

The geology is dominated by Border Zone[3] micaceous schist parent material (75%). Landforms consist of low relief rolling hills (41%), mountain slopelands (19%), steep breaklands (34%) and mass wasted slopes (5%). This was the most erosive watershed studied for both surface and mass erosion.

The *Lolo Creek* watershed (above Musselshell Creek) is located within the Clearwater River Subbasin. The watershed area is 32 mi^2. Management intensity is heavy (e.g., road density is 5 mi/mi^2 and harvest intensity greater than 40 percent). The geology is dominated by granitic rocks (66%) and alluvial deposition (15%). Landforms consist of low relief rolling hills (72%) and mountain slopelands (26%).

The *Canyon Creek* watershed is located within the Lochsa River Subbasin. The watershed area is 20 mi^2. Management intensity is heavy (e.g., road density greater than 5 mi/mi^2 and harvest intensity near 50 percent). The geology is dominated by granitic and grussic-granitic rocks (78%) and Border Zone micaceous schist parent material (15%). Landforms consist of low relief rolling hills (56%), mountain slopelands (14%), mass wasted slopes (7%) and steep breaklands (21%).

RESULTS

The *Fish Creek* water quality station was in operation in 1980 for one year and continuously from 1992 through 2004. During the same period, mean annual discharge was 216 *cubic feet per second* (cfs) with a standard deviation of 61.2 cfs and a coefficient of variation of 28 percent (Table 1). Over 2,000 suspended sediment samples collected between 1980 and 2004 were used in this composite analysis. Thirteen sets of bedload and suspended load sediment samples collected between 1980 and 1994 indicated that the bedload component was 8.1 percent of the total sediment load. Measured mean annual sediment was 21.9 $t/mi^2/yr$ for the period of record. Standard deviation was 29.9 $t/mi^2/yr$ while the coefficient of variation was 136 percent. WATBAL-2002 under-predicted sediment seven out of 14 years, estimating 54.8 percent of measured sediment over the period of record (Table 2)

Table 1 Management intensity, mean annual discharge, and sediment load for all stations.

Watershed	Management Intensity	Annual Discharge (cfs)			Annual Sediment Load ($t/mi^2/yr$)		
		Mean	Std	CV %	Mean	Std	CV %
Fish Creek	Light	216	61.2	28	21.9	29.9	136
Swamp Creek	Light	36.5	10.2	28	19.0	15.8	83
Deadman Creek	Moderate	37.5	9.4	25	28.1	28.0	100
Elk Creek	Heavy	81.4	29.9	37	24.3	18.8	77
Pete King Creek	Heavy	43.5	13.9	32	46.6	42.0	90
Lolo Creek	Heavy	91.1	26.6	29	27.5	15.7	57
Canyon Creek	Heavy	44.7	16.8	38	28.9	49.4	171

The *Swamp Creek* water quality station was in operation between 1980 and 1994. During the same period, mean annual discharge was 36.5 cfs with a standard deviation of 10.2 cfs and a coefficient of variation of 28 percent. Over 1,700 suspended sediment samples collected between 1980 and 1994 were used in the analysis. Over 50 sets of bedload and suspended load sediment samples collected between 1979 and 1991 indicated that the bedload component was 10.1 percent of total sediment load. Measured mean annual sediment was 19.0 $t/mi^2/yr$ for the period of record. Standard deviation was 15.8 $t/mi^2/yr$ while the coefficient of variation was 83 percent. WATBAL-2002 under-predicted sediment five out of 15 years, estimating 102.6 percent of measured sediment over the period of record.

The *Deadman Creek* water quality station has been in operation since 1989.[4] During the same period, mean annual discharge was 37.5 cfs with a standard deviation of 9.4 cfs and coefficient of variation of 25 percent. Over 2,000 suspended sediment samples collected between 1989 and 2004 were used in the analysis. Over 100 sets of bedload and suspended load sediment samples collected between 1979 and 1992 indicated that the bedload component was

[3] The contact between intrusive granites and metasediments in north Idaho.
[4] Data was not collected at Deadman Creek in 1996 because a flood destroyed the station.

30.7 percent of total sediment load. Measured mean annual sediment was 28.1 t/mi^2/yr for the period of record. Standard deviation was 28.0 t/mi^2/yr while the coefficient of variation was 100 percent. WATBAL-2002 under-predicted sediment nine out of 15 years, estimating 68.2 percent of measured sediment over the period of record.

Table 2 Measured versus WATBAL-2002 modeled sediment for all stations.

Watershed	Total Measured Sediment (t/mi^2/yr)	WATBAL-2002 Predicted Sediment (t/mi^2/yr)	WATBAL-2002 Predicted Sediment (%)
Fish Creek	21.9	12.0	54.8
Swamp Creek	19.0	19.5	102.6
Deadman Creek	28.1	19.1	68.2
Elk Creek	24.3	7.4	30.6
Pete King Creek	46.6	29.8	63.9
Lolo Creek	27.5	10.3	37.5
Canyon Creek	28.9	23.8	82.3
Mean for all watersheds	28.0	17.4	62.1

The *Elk Creek* water quality station was in operation between 1982 and 1987 and 1990 and 2003.[5] During the same period, mean annual discharge was 81.4 cfs with a standard deviation of 29.2 cfs and coefficient of variation of 37 percent. Over 3,000 suspended sediment samples collected between 1982 and 2003 were used in the analysis. Over 150 sets of bedload and suspended load sediment samples collected between 1978 and 2004 indicated that the bedload component was 8.8 percent of total sediment load. Measured mean annual sediment was 24.3 t/mi^2/yr for the period of record. Standard deviation was 18.8 t/mi^2/yr while the coefficient of variation was 77 percent. WATBAL-2002 under-predicted sediment 19 out of 20 years, estimating 30.6 percent of measured sediment over the period of record.

The *Pete King Creek* water quality station has been in operation since 1978. During the same period, mean annual discharge was 43.5 cfs with a standard deviation of 13.9 cfs and coefficient of variation of 32 percent. Over 4,000 suspended sediment samples collected between 1978 and 2004 were used in the analysis. Over 100 sets of bedload and suspended load sediment samples collected between 1975 and 1993 indicated that the bedload component was 40.3 percent of total sediment load. Measured mean annual sediment was 46.6 t/mi^2/yr for the period of record. Standard deviation was 42.0 t/mi^2/yr while the coefficient of variation was 90 percent. WATBAL-2002 under-predicted sediment 17 out of 27 years, estimating 63.9 percent of measured sediment over the period of record.

The *Lolo Creek* water quality station has been in operation since 1985. During the same period, mean annual discharge was 91.1 cfs with a standard deviation of 26.6 cfs and coefficient of variation of 29 percent. Nearly 3,000 suspended sediment samples collected between 1985 and 2004 were used in the analysis. Over 150 sets of bedload and suspended load sediment samples collected between 1980 and 2004 indicated that the bedload component was 16.1 percent of total sediment load. Measured mean annual sediment was 27.5 t/mi^2/yr for the period of record. Standard deviation was 15.7 t/mi^2/yr while the coefficient of variation was 57 percent. WATBAL-2002 under-predicted sediment 19 out of 20 years, estimating 37.3 percent of measured sediment over the period of record.

The *Canyon Creek* water quality station has been in operation since 1992. During the same period, mean annual discharge was 44.7 cfs with a standard deviation of 16.8 cfs and coefficient of variation of 38 percent. Over 2,000 suspended sediment samples collected between 1992 and 2000 were used in the analysis. Eighteen sets of bedload and suspended load sediment samples collected between 1992 and 1994 indicated that the bedload component was 19.4 percent of total sediment load. Measured annual sediment was 28.9 t/mi^2/yr for the period of record. Standard deviation was 49.4 t/mi^2/yr while the coefficient of variation was 171 percent. WATBAL-2002 under-predicted sediment six out of 13 years, estimating 82.3 percent of measured sediment over the period of record.

[5] All discharge data was lost in 2004 because the stage recorder failed.

It was noted that for all stations, WATBAL-2002 estimates of annual sediment were always within the range of variability of the annual measured total sediment load; however, WATBAL-2002 consistently under-predicted sediment in six of the seven watersheds. The model estimates for total sediment was best for the Swamp Creek watershed and least accurately in the Lolo Creek and Elk Creek watersheds. The overall mean of predicted versus measured sediment was 62.1 percent, with a range of 30.6 percent (Elk Creek) to 102.6 percent (Swamp Creek).

WATBAL-2002 appeared to have the largest discrepancies in terms of total sediment in watersheds with alluvial deposition and granitic and grussic parent materials in combination with low relief rolling hills and mountain slopeland landforms i.e., Elk Creek and Lolo Creek watersheds. WATBAL-2002 predicted adequately in the Pete King Creek and Canyon Creek watersheds, despite high levels of mass wasting in those watersheds. This suggests that the existing accelerated mass wasting coefficients in WATBAL-2002 are performing well.

The predictability of the pre-calibrated WATBAL-2002 model, or the correlation coefficient of the regression of measured versus predicted sediment (r^2), was 0.46. Based upon the preceding results, a decision was made to calibrate the model to improve its overall performance.

CALIBRATION

WATBAL uses the mass and surface erosion coefficients from an external support file for landtypes. Natural sediment yield coefficients for each landtype are based on the landtype risk factors (e.g., potentials for debris avalanche and rotational mass wasting; and erosion hazards for surface soils, sub soils, and parent materials). The risk factors are used to adjust known sediment rates to develop one mass erosion sediment coefficient and one surface sediment coefficient for each landtype. The landtype coefficients are combined and then they are weighted by landtype area and aggregated for the watershed by WATBAL to provide an estimate of natural sediment production. Natural sediment from mass wasting processes is assumed to vary from essentially zero to 80 t/mi^2/yr (very high). Natural sediment from surface erosion processes varies from 5 (low) to 25 t/mi^2/yr (very high). When the watershed is disturbed from roads, harvest or fire, the mass erosion is assumed to be accelerated up to 250 times the natural erosion rate in WATBAL. The same disturbances are assumed in WATBAL to induce sediment from surface erosion that varies from 0 to 67,500 t/mi^2/yr., depending on the activity type, landtype and time since the disturbance, Patten and Jones (2005).

Three adjustments were made to the external support file for landtypes to calibrate the WATBAL-2005 model:

1) For each landtype, the frequency of landslides that occurred during the 1995-1996 flood events was determined McClelland, et al. (1997). Five landtypes had very high mass wasting frequencies, ranging from 0.64 to 2.69 landslides per square mile[6], yet the mass erosion hazard was only rated “high” in the external support file. All other landtypes had landslide densities of 0.38 or less. The authors have chosen to increase the mass erosion hazard from “high” (40 t/mi^2/yr) to “very high” (80 t/mi^2/yr) on these five landtypes.

2) The authors have chosen to increase the mass and surface erosion coefficients for grussic granitic and micaceous schist parent materials landtypes by 100 percent. A revised value up to 80 t/mi^2/yr was used for mass wasting for each landtype with those parent materials.

3) The authors have chosen to increase the mass and surface erosion coefficients for general granitic parent material landtypes by 150 percent. A revised value up to 80 t/mi^2/yr was used for mass wasting for each landtype with that parent material.

Pre- and Post Calibration results for each of the seven test watersheds are compared in Table 3.

After calibration, WATBAL-2005 accuracy improved from 55 to 101 percent of measured sediment in Fish Creek. The calibrated WATBAL-2005 under-predicted sediment five out of 14 years.

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[6] The number of landslides that occurred on each landtype on the Forest was divided by the total area in square miles of the landtype to determine the frequency. Stream breaklands with undifferentiated or grussic-granitic parent materials were the landtypes with the highest frequency of landslides.

Table 3 Measured versus original and calibrated WATBAL modeled sediment for all stations.

Watershed	Total Measured Sediment ($t/mi^2/yr$)	Original WATBAL-2002 Predicted Sediment ($t/mi^2/yr$)	Original WATBAL-2002 Predicted Sediment (%)	Calibrated WATBAL-2005 Predicted Sediment ($t/mi^2/yr$)	Calibrated WATBAL-2005 Predicted Sediment (%)
Fish Creek	21.9	12.0	54.8	22.0	100.5
Swamp Creek	19.0	19.5	102.6	21.5	113.2
Deadman Creek	28.1	19.1	68.0	35.5	126.3
Elk Creek	24.3	7.4	30.5	17.8	73.3
Pete King Creek	46.6	29.8	63.9	43.4	93.1
Lolo Creek	27.5	10.3	37.5	17.6	64.0
Canyon Creek	28.9	23.8	82.4	36.1	124.9
Mean for all watersheds	28.0	17.4	62.1	27.7	98.8

After calibration, WATBAL-2005 went from estimating 103 to 113 percent of measured sediment in Swamp Creek. The calibrated WATBAL-2005 under-predicted sediment six out of 15 years.

After calibration, WATBAL-2005 accuracy improved from 68 to 126 percent of measured sediment in Deadman Creek. The calibrated WATBAL-2005 under-predicted sediment three out of 15 years.

After calibration, WATBAL-2005 accuracy improved from 31 to 73 percent of measured sediment in Elk Creek. The calibrated WATBAL-2005 under-predicted sediment ten out of 20 years.

After calibration, WATBAL-2005 accuracy improved from 64 to 93 percent of measured sediment in Pete King Creek. The calibrated WATBAL-2005 under-predicted sediment nine out of 27 years.

After calibration, WATBAL-2005 accuracy improved from 38 to 64 percent of measured sediment in Lolo Creek. The calibrated WATBAL-2005 under-predicted sediment 14 out of 20 years.

After calibration, WATBAL-2005 went from estimating 82 to 125 percent of measured sediment in Canyon Creek. The calibrated WATBAL-2005 under-predicted sediment two out of 13 years.

By modifying the mass and surface erosion coefficients, WATBAL-2005 estimates improved from 62 to 99 percent of measured sediment for all watersheds combined. Under predictions improved from six to only three of seven test watersheds. The model's predictability (correlation coefficient of the regression - r^2) of measured versus calibrated sediment improved from 0.46 to 0.60.

CONCLUSIONS

Modifying the mass and surface erosion coefficients in the external landtype file improved the predictability of the WATBAL model from 62 to 99 percent when the results of the seven stations were averaged together. The correlation of measured versus calibrated sediment (r^2), improved from 0.46 to 0.60. WATBAL-2005 most accurately predicts the long-term average sediment in Fish Creek (100.5%), Pete King Creek (93.1%) and Swamp Creek (113.2%). It somewhat over-predicts long-term average sediment in Canyon Creek (124.9%) and Deadman Creek (126.3%) and under-predicts sediment in Lolo Creek (64.0%) and Elk Creek (73.3%).

The WATBAL-2005 user and land management decision maker should recognize that the model estimates sediment within a range of 60 percent to 130 percent of long-term measured averages for watersheds similar to the test watersheds. The model still tends to somewhat under-predict sediment in watersheds with extensive rolling hills and mountain slopeland landforms and over-predict sediment in watersheds with high percentages of breakland landforms.

We recommend that calibration re-assessments should occur every five years as data becomes available and test watersheds meet the calibration selection criteria.

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