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Sediment Parameter and Calibration Guidance for HSPF

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For AQUA TERRA, Mr. Tony Donigian and Mr. Brian Bicknell were the primary authors, with significant input and review provided by Mr. Jason Love and Mr Paul Duda. The sediment calibration and parameter guidance contained in this document was derived from numerous other HSPF modeling and source documents (e.g. ARM/NPS user manuals, USLE reports, ASCE Sedimentation Engineering) and based on many years of sediment modeling with HSPF. However, the material contained in this document should be viewed as ***general*** guidance which will continue to evolve and change as the sediment modeling technology and data bases expand and improve with time.

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BASINS Technical Note 8:
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Introduction

This technical note provides BASINS users with guidance on how to estimate the input parameters in the SEDMNT, SOLIDS, and SEDTRN sections of the Hydrological Simulation Program Fortran (HSPF) watershed model. It also outlines suggested procedures for sediment calibration, using a variety of graphical and statistical measures. For each input parameter, this guidance includes a parameter definition, the units used in HSPF, and how the input value may be determined (e.g. initialize with reported values, estimate, measure, and/or calibrate). Where possible, the note discusses how to estimate initial values using the data and tools included with BASINS. Also discussed, where appropriate, is the physical basis of each parameter and the corresponding algorithms as described in the HSPF Users Manual (Bicknell, et al, 2001) and earlier literature sources. In addition to the guidance provided below, model users are directed to other sources, including *Sediment Calibration Procedures And Guidelines For Watershed Modeling* (Donigian and Love, 2003) (Reproduced in the Appendix), the ARM Model User Manual (Donigian and Davis, 1978) and the *HSPF Application Guide* (Donigian et al., 1984).

Summary tables are attached that provide 'typical' and 'possible' (i.e. maximum 'expected') ranges for the parameters discussed below, based on both the parameter guidance and experience with HSPF over the past two decades on watersheds across the U. S. and abroad (Donigian, 1998). **The overarching principal in parameter estimation should be that the estimated values must be realistic, i.e. make 'physical' sense, and must reflect conditions on the watershed.** If the values estimated by the model user and/or derived from the guidance below, do not agree with the value ranges in the summary table, the user should question and re-examine the estimation procedures. The estimated values may still be appropriate, but the user needs to confirm that the parameter values reflect unusual conditions on the watershed.

Another source of parameter information is the HSPF Parameter Database (HSPFParm) (US EPA, 1999) http://www.epa.gov/waterscience/ftp/basins/HSPFParm . HSPFParm consists of parameter values from previous applications of HSPF across North America assimilated into a single database, and with a customized graphical user interface for viewing and exporting the data. The pilot HSPFParm Database contains parameter values for model applications in over 40 watersheds in 14 states. The parameter values, contained in the database, characterize a broad variety of physical settings, land use practices, and water quality constituents. The database has been provided with a simplified interactive interface that enables modelers to access and explore the HSPF parameter values developed and calibrated in various watersheds across the United States, and to assess the relevance of the parameters to their own watershed setting.

Sediment Calibration Overview

Sediment is one of the most difficult water quality constituents to accurately represent in current watershed and stream models. Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes.

Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources on the watershed, delivery to the waterbody, and transport behavior within the channel system. Rarely is there sufficient observed local data at sufficient spatial detail to accurately calibrate all parameters for all land uses and each stream and waterbody reach. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. This type of 'weight-of-evidence' approach is rapidly becoming the standard practice in watershed modeling.

Sediment calibration must be done after the hydrologic calibration is completed, and it is extremely sensitive to the hydrology, particularly the amount and timing of surface runoff that is predicted by the model. Calibration of the parameters involved in simulation of watershed sediment erosion is more uncertain than hydrologic calibration due to less experience with sediment simulation in different regions of the country. The process is analogous; the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. However, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year.

As noted above, sediment calibration for watershed models involves numerous steps from initial estimates of model parameters, all the way to mimicking transport behavior within the channel system and at the watershed outlet. These steps usually include:

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, land use, and management practices
2. Calibrating the model loading rates to the target rates
3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies
4. Analyzing sediment bed behavior (i.e. bed depths) and transport in each channel reach as compared to field observations
5. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network
6. Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available
7. Repeating steps 1 through 6 as needed to develop a reasonable overall representation of sediment sources, delivery, and transport throughout the watershed system

Parameter guidance is given for each of the modules required to simulate sediment delivery from the landscape (i.e. SEDMNT, SOLIDS) and instream transport (i.e., SEDTRN) and the parameters are grouped as required in each UCI table.

<u>Sediment Erosion Calibration</u>

Sediment loadings to the stream channel are estimated by land use category from literature data, local Extension Service sources, or procedures like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and then adjusted for delivery to the stream with estimated sediment delivery ratios (SDRs). This delivery adjustment is needed because HSPF, like most watershed-scale (lumped parameter) models, represents landscape loadings to the stream channel, which are less than the field-scale estimates from USLE. These estimated loading rates then become ***'calibration targets'*** for the watershed model.

Model parameters are then adjusted so that model-calculated loadings are consistent with these estimated ***'calibration targets'*** and loading ranges. The model-calculated loadings are further evaluated in conjunction with the instream sediment transport calibration (discussed below) that extends to a point in the watershed where sediment concentration and/or load data are available. The overall objective is to represent the overall sediment behavior of the watershed, with knowledge of the morphological characteristics of the stream (i.e. aggrading or degrading behavior), using sediment loading rates that are consistent with the ***calibration targets*** and modeled concentrations that provide a reasonable match with instream sediment data.

In HSPF, the erosion process on pervious land areas is represented as the net result of detachment of soil particles by raindrop impact on the land surface, and then subsequent transport of these fine particles by overland flow. On impervious surfaces (e.g. parking lots, driveways), soil splash by raindrop impact is neglected and solids washoff is often controlled by the rate of accumulation of solid materials. The primary sediment erosion parameters are the coefficients in the soil detachment equation for pervious areas, the coefficients in the sediment washoff equations for pervious and impervious areas, and the accumulation rate of solids on impervious surfaces.

In general, sediment calibration involves the development of an approximate equilibrium or balance between the accumulation and generation of sediment particles on one hand and the washoff or transport of sediment on the other hand. Thus, the accumulated sediment on the land surface (i.e., DETS and SLDS) should not be continually increasing or decreasing throughout the calibration period. Extended dry periods will produce increases in surface sediment accumulations, and extended wet periods will produce decreases. However, the overall trend should be relatively stable from year to year. This equilibrium must be developed on both pervious and impervious surfaces, and must exist in conjunction with the accurate simulation of monthly and storm event sediment loss, depending on the data available for calibration. Donigian and Love (2003) (see Appendix) provide additional discussion of sediment calibration procedures.

<u>Instream Sediment Transport Calibration</u>

Once the sediment loading rates are calibrated to provide the expected input to the stream channel, the sediment calibration then focuses on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations to be compared with observations. The initial steps in instream calibration involve dividing the input sediment loads into appropriate size fractions, estimating initial parameter values and storages for all reaches, and a preliminary model run to calculate shear stress timeseries in each reach to estimate critical scour and deposition values.

The eroded material is fractionated into sand, silt, and clay prior to entering a model reach using available soils information; typically, a single fractionation scheme is used for all reaches unless soils and land surface variations within the watershed support use of reach-specific fractions. The fractions should reflect the relative percent of the surface material (i.e., sand, silt, clay) available for erosion in the surrounding watershed, but also should include an enrichment factor of silt and clay to represent the likelihood of these finer materials reaching the channel.

The sand, silt and clay fractions of total eroded sediment are specified in the MASS-LINK block. Each unique fractionation scheme will require a separate table in the MASS-LINK block. An example MASS-LINK table containing the sediment fractionation is shown below, with the sand, silt, clay fractions shown as 0.05, 0.70, and 0.25, respectively.

```
  MASS-LINK        1
PERLND     PWATER PERO          0.0833     RCHRES         INFLOW IVOL
PERLND     SEDMNT SOSED  1        0.05     RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED  1        0.70     RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED  1        0.25     RCHRES         INFLOW ISED   3
PERLND     PWTGAS POHT             1.0     RCHRES         INFLOW IHEAT
  END MASS-LINK    1
```

For HSPF, initial sediment parameters, such as particle diameter, particle density, settling velocity, bed depth and composition, and beginning calibration parameter values can be evaluated from local/regional data, past experience, handbook values, etc., and then adjusted based on available site specific data and calibration. Bed composition data are especially important so that the model results can be adjusted to reflect localized aggradation (deposition) or degradation (scour) conditions within the stream system.

In HSPF, the transport of the sand (non-cohesive) fraction is commonly calculated as a power function of the average velocity in the channel reach in each timestep. This transport capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in suspension within the channel reach.

For the silt and clay (cohesive) fractions, shear stress calculations are performed by the hydraulics (HYDR) module, and then in the SEDTRN module they are compared to user-defined critical, or threshold, values for deposition and scour for each size (shown in Figure 1). When the shear stress for a timestep is greater than the critical value for scour, the bed is scoured at a user-defined erodibility rate and transport through the reach occurs; when the shear stress is less than the critical deposition value, the silt or clay fraction deposits at a settling rate input by the user for each size. If the shear stress falls between the critical scour and deposition values, the incoming suspended material is transported through the reach.

In HSPF, the hydraulic characteristics of a stream reach are represented by a function table (FTABLE) that includes the relationships between stage, storage (volume), surface area, and discharge. The accuracy of the FTABLE for a specific reach will be a **critical factor** in adequately representing the average velocity and hydraulic radius and calculated shear values, as a function of the stage, or depth of flow. This is especially evident for simulations of flood flows that exceed bankfull discharges; improper extension of the FTABLES can lead to erroneous velocities and shears and scour conditions during high flow events, and have major impacts on the model simulations for those events.

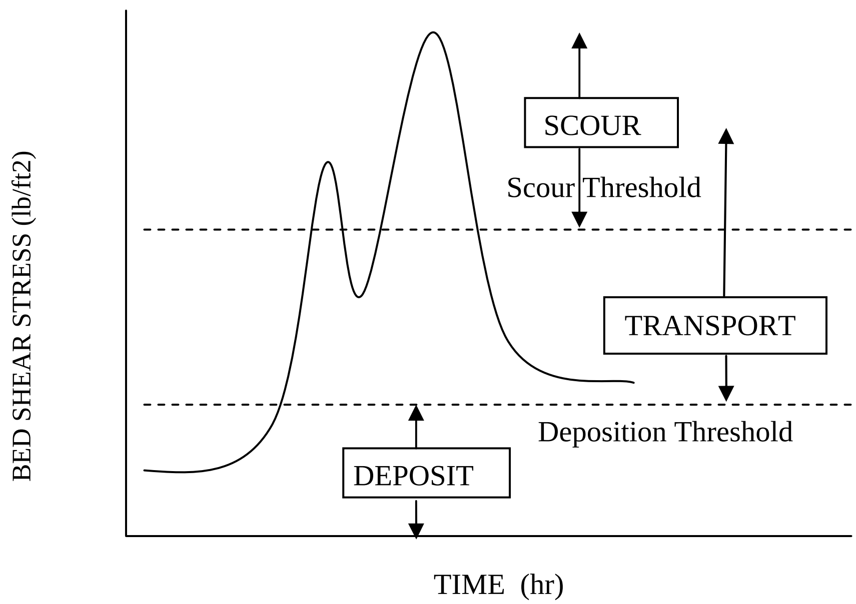

Figure 1. Shear Stress Algorithm for Silt and Clay Fractions in HSPF

The velocity (the driving function of the non-cohesives) is not represented in the model as directly related to shear stress (the driving function of the cohesives), and thus it is possible to have an unreasonable relationship between the two size fractions, and the corresponding flow rate. It is therefore advised to calculate the resulting shear stresses and velocities for each “portion” of the FTABLE using the equations presented in the HSPF User’s Manual. Even with reasonable FTABLES you will find that it is possible to have the cohesives settle out at low flows while maintaining non-negligible sand concentrations. These issues can be resolved by careful inspection and adjustment of the FTABLES. Since changes to the FTABLEs can impact the hydrologic calibration, the model flow results may need to be re-visited and checked if FTABLES are adjusted during the sediment calibration.

As part of the sediment parameterization, the model is run with the initial parameter estimates and shear stress values are output for each stream reach. For the silt and clay size particles, the critical shear stress parameters (one for scour and one for deposition) for each size are adjusted so that the model calculates scour during high flow events, deposition and settling during low flow periods, and transport with neither scour nor settling for moderate flow rates.

The shear stress values are then adjusted more carefully in calibration so that scour occurs during storm periods and deposition occurs at low flows. Once the timing of scour and deposition processes is correct, the rate of scour is adjusted in an attempt to match either expected behavior within each reach, and/or the observed concentrations. During high flow periods, the amount of scour is adjusted with an erodibility factor for each reach that controls the rate of scour whenever the actual shear stress is greater than the critical shear stress value for scour. During low flow periods the silt/clay fall velocity parameter can be adjusted slightly to improve the agreement. The Donigian and Love (2003) paper in the Appendix provides further discussion of the potential impact of FTABLEs on the shear stress calculations and resulting sediment concentrations. Note also: In HSPF the units of shear stress are lb-*force*/ft^2. Typically, shear stress values are expressed in the literature as Pascals (Pa) or Newtons/m^2 (N/m^2). The conversion is 1 Pa = 1 N/m^2 = 0.02088 lb/ft^2.

The calibration procedure generally involves comparison of model simulations (concentrations and loads) to available observed data. This is often limited to event mean concentrations of total suspended solids (TSS) for selected storm events and nonstorm (baseflow) periods, or pollutographs of TSS concentrations throughout a few events. However, other types of comparisons are also possible, such as load estimates and sediment rating curves; see the Appendix for examples of these types of comparisons.

Parameter Guidance

The parameter guidance below is listed in the order of the parameter tables required by each module section responsible for simulating sediment erosion and solids washoff from pervious and impervious surfaces, and instream sediment transport, deposition, and scour (i.e. SEDMNT, SOLIDS, and SEDTRN). The parameters are grouped as required in each UCI table.

<u>Pervious Land Accumulation and Removal of Sediment (SEDMNT) Parameters</u>

The SEDMNT section simulates the production and removal of sediment from a pervious land segment (PERLND).

SED-PARM1 Table:

CRV Flag to select constant (CRV=0) or monthly-variable (CFV=1) erosion-related cover, COVER. Monthly values are commonly used to reflect seasonal variability of the vegetation or other erosional cover, e.g., for agricultural areas to reflect the timing of cropping and tillage practices.

VSIV Flag to select a constant or monthly-variable rate of net vertical sediment input, NVSI. Constant annual values (VSIV=0) are commonly used since atmospheric sources are usually difficult to quantify and are a small fraction of surface storage for pervious land surfaces. However, monthly values (VSIV=1) can be used to reflect variability of NVSI as impacted by seasonal land surface activities, such as tillage, if data are available to estimate NVSI.

SDOP Flag to select the algorithm used to simulate removal of sediment from the land surface; choose either the method used in predecessor models (HSPX, ARM, and NPS) (SDOP=1), or an alternative method as described in the HSPF User Manual (SDOP=0). Recommendation: set SDOP to 1. This method, used in the predecessor models is more commonly used, and has been subjected to more widespread application.

SED-PARM2 Table:
This table includes parameters for estimating the production and reduction of detached sediment on the pervious land.

SMPF Supporting Management Practice Factor (unitless) (***measure/estimate***). SMPF is used to simulate the reduction in erosion achieved by use of erosion control practices. SMPF is analogous to the P factor in the Universal Soil Loss Equation (Wischmeier and Smith, 1978), and initial values should be set equal to the P value for practices such as contouring, terracing, strip-cropping, etc. Table 1 shows values of P for alternative practices and slope conditions. Model users should note that the practices listed in Table 1 also affect other HSPF parameters, such as NSUR, UZSN, LSUR, and SLSUR. The impact of different agricultural practices can only be evaluated with changes in all relevant parameters. Renard et al., (1997) provide detailed discussions on the physical basis and estimation of each of the USLE parameters, and as such it is also a valuable source of guidance for HSPF sediment parameters.

Use of BASINS Data/Tools:
In cases where GIS coverages are available for alternative management practices, BASINS GIS capabilities can be used to identify land areas with similar practices each of which may be represented as a separate PERLND with its own P value. Alternatively, the P values of different practices may be weighted by area fractions within a single PERLND.

KRER Coefficient in the soil detachment equation (complex) (***measure/estimate, then calibrate as needed to achieve target loading rates***). This parameter is related to the erodibility or detachability of the specific soil type and surface conditions. Experience indicates that KRER is directly related to the K factor in the USLE and can be initially estimated as KRER = K. K values can be obtained with techniques published in the literature or from soil scientists familiar with local soil conditions. Table 2 shows representative K values by soil texture and organic matter content. Renard et al (1997) provide extensive discussion on estimation of K from soil and land surface characteristics. Since adjustments to KRER will affect the amount of detached sediment that can be delivered to streams, users should review the detached sediment storage (DETS) to ensure that the accumulated sediment on the land surface is not continually increasing or decreasing throughout the simulation period.

Table 1. Values of Support-Practice Factor, P

Land Slope (%):	1.1–2.0	2.1–7.0	7.1–12.	12.1–18.	18.1–24.
Practice					
Contouring (P_C)	0.60	0.50	0.60	0.80	0.90
Contour Strip Cropping (P_{SC})					
R-R-M-M (1)	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.70
R-O	0.60	0.50	0.60	0.80	0.90
Contour Listing or Ridge Planting	0.30	0.25	0.30	0.40	0.45
Contour Terracing (P_t) (2,3)	$0.6/\sqrt{n}$	$0.6/\sqrt{n}$	$0.6/\sqrt{n}$	$0.6/\sqrt{n}$	$0.6/\sqrt{n}$
No Support Practice	1.0	1.0	1.0	1.0	1.0

(1) R = row crop, W = fall-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation, and are arranged on the field such that rowcrop strips are always separated by a meadow or winter-grain strip.
(2) These P_t values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, the P_t values are multiplied by 0.2
(3) n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

Source: Stewart, et al., 1975

Use of BASINS Data/Tools:

The State Soil (STATSGO) data layer contains data on '*kffac*t', defined as the soil erodibility factor that is fragment free for use in the USLE. Run the BASINS State Soil Characteristic Report and select mean estimate, area-weighted, surface layer, for '*kffact*'. The TMDL USLE Tool (Hummel et al., 2000; discussed in the Appendix) also provides guidance in selecting USLE parameters.

JRER Exponent in the soil detachment equation (complex) (***initialize with reported value, then calibrate as needed***). JRER approximates the relationship between rainfall intensity and incident energy to the land surface for the production of soil fines. Wischmeier and Smith (1978) proposed the following relationship for the kinetic energy produced by natural rainfall;

$$Y = 916 + 331 \log X$$

Where Y = kinetic energy, ft/ton/acre/in.
X = rainfall intensity, inches/hr

Table 2. Representative Values of the Soil Erodibility Factor, K

Organic Matter Content (%):	< 0.5	2.0	4.0
Texture Class			
Sand	0.05	0.03	0.02
Fine Sand	0.16	0.14	0.10
Very Fine Sand	0.42	0.36	0.28
Loamy Sand	0.12	0.10	0.08
Loamy Fine Sand	0.24	0.20	0.16
Loamy Very Fine Sand	0.44	0.38	0.30
Sandy Loam	0.27	0.24	0.19
Fine Sandy Loam	0.35	0.30	0.24
Loam	0.38	0.34	0.29
Silt Loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy Clay Loam	0.27	0.25	0.21
Clay Loam	0.28	0.25	0.21
Silty Clay Loam	0.37	0.32	0.26
Sandy Clay	0.14	0.13	0.12
Silty Clay	0.25	0.23	0.19
Clay		0.13–0.29	
These values are estimated averages of broad ranges of specific soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.			
Source: Stewart et al., 1975.			

Using this relationship, various investigations have also shown that soil splash is proportional to the square of the rainfall intensity (Meyer and Wischeimer 1969, David and Beer 1974). Thus, a value of about 2.0 for JRER is predicted from these studies. Most HSPF applications have used the default value of 2.0 for this exponent. Use the default value of 2.0, and adjust only if supported by local data and conditions.

AFFIX The fraction by which detached sediment storage decreases each day during non-storm periods (/day) (***estimate, then calibrate as needed***). AFFIX is a soil compaction factor that reduces the amount of detached soil particles available for transport. This parameter attempts to represent the natural aggregation and mutual attraction of soil particles and the compaction of the surface soil zone from which erosion occurs. These processes are a complex function of soil characteristics, meteorologic conditions, and tillage practices for which a detailed simulation is not possible. Values in the range of .001 to .1 are possible.

Typically, AFFIX is adjusted in combination with the KRER and NVSI parameters to ensure that the accumulated detached sediment on the land surface

(DETS) does not continually increase or decrease throughout the calibration period.

COVER The fraction of land surface which is shielded from rainfall (unitless) (***measure/ estimate, then calibrate as needed***), and is therefore not susceptible to soil fines detachment by raindrop impact. Seasonal/monthly values are often used. Overhead photographs at periodic intervals during the year are the most direct means of estimating the land cover fraction.

COVER values are sometimes estimated as one minus the monthly C factor in the USLE. For cropland, the C factors for the various stages of crop growth should be used in estimating COVER.

Tables 5.7 and 5.8 in the ARM User Manual (Donigian and Davis, 1978) pertain to the evaluation of C on undisturbed lands and have been reproduced from the paper by Wischmeier (1975). C factors for disturbed lands (croplands, agriculture, and construction areas) have been published in the USLE Report (Wischmeier and Smith 1965). The monthly COVER values estimated from C may need to be reduced since the C factor includes considerations other than crop canopy and raindrop interception since it represents a soil loss ratio, i.e. the ratio of soil loss for the current land surface conditions compared to clean-tilled continuous fallow conditions. Renard et al (1997) provide the most extensive recent guidance on estimation of the C factor. Users should avoid using COVER values of 0.98 to 1.0, even for dense forest or crop canopy conditions, since this will essentially eliminate any soil detachment and subsequent washoff of detached materials. In these cases, the lower COVER values allow for fringe and boundary areas of a PERLND that may contribute soil to the stream.

NVSI The rate at which sediment enters detached storage from the atmosphere (lb/ac/day), (***estimate, then calibrate as needed***). NVSI is often input with monthly variation. It represents any detached sediment accumulation processes not covered by rainfall impact or agricultural tillage operations that are generally specified using Special Actions. This can include the effects of wind-blown sediments, or land disturbance activities such as construction or landscaping. Note that NVSI can be negative, if the effects of the AFFIX parameter are not sufficient to represent all detached sediment reduction processes.

SED-PARM3 Table:

This table contains parameters for estimating the sediment removal from the pervious land by washoff and gully erosion processes.

KSER Coefficient in the soil washoff or transport equation (complex), (***estimate, then calibrate as needed***). It is an attempt to combine the effects of slope, overland flow length, sediment particle size, and surface roughness on the sediment transport capacity of overland flow into a single parameter. Consequently, calibration is the major method of evaluating KSER. Terracing, tillage practices, and other agricultural management techniques will have a significant effect on KSER. Experience to date has indicated a possible range of values of 0.01 to 5.0. However, variations from this can be expected.

JSER Exponent in the soil washoff equation (complex), (***initialize with reported value, then calibrate as needed***). JSER approximates the relationship between overland flow intensity and sediment transport capacity. The vast majority of HSPF applications have used the default value of 2.0 for this exponent. Use the default value of 2.0, and adjust only if supported by local data and conditions.

KGER Coefficient in the matrix soil equation, which simulates gully erosion (complex), (***estimate, then calibrate as needed***). Unless there is evidence of gully erosion occurring in the watershed, KGER should be set to 0.0.

JGER Exponent in the matrix soil equation, which simulates gully erosion (complex), (***estimate, then calibrate as needed***). The vast majority of HSPF applications have used the default value of 2.0 for this exponent, but few applications even include gully erosion. Use an initial value of 2.5, since JGER is expected to be greater than JSER, and adjust if supported by local data and conditions.

Monthly Input Parameter Tables:
In general, monthly variation in selected parameters, such as COVER and NVSI should be included with the initial parameter estimates. The monthly values represent the variable on the first day of each month; the values other days are then interpolated from the values for the current and following months. All monthly values can be adjusted to calibrate for seasonal variations.

MON-COVER Table:
Monthly values for the fraction of land surface which is shielded from rainfall. Monthly values are often used, since COVER is primarily a function of the seasonal and vegetation canopy changes.

MON-NVSI Table:
Monthly values for the rate at which sediment enters detached storage from the atmosphere.

Impervious Land Accumulation and Removal of Solids (SOLIDS) Parameters

The SOLIDS section simulates the accumulation and removal of solids from an impervious land segment (IMPLND).

SLD-PARM1 Table:

VASD Flag to select a constant (VASD=0) or monthly-variable (VASD=1) rate of solids accumulation, ACCSDP. Monthly values are commonly used to reflect variability of the accumulation as impacted by climate and seasonal land surface activities.

VRSD Flag to select a constant (VRSD=0) or monthly-variable (VRSD=1) rate of solids removal, REMSDP. Monthly values are commonly used to reflect variability of the removal rate as impacted by seasonal land surface activities.

SDOP Flag to select algorithm used to simulate removal of sediment from the impervious surface; choose either the method used in predecessor models (HSPX, ARM, and NPS), (SDOP=1), or the alternative method as described in the HSPF User Manual (SDOP=0). Recommendation: Set SDOP to 1; this method is more commonly used, and has been subjected to more widespread application.

SLD-PARM2 Table:

KEIM Coefficient in the solids washoff equation (complex), (***estimate, then calibrate as needed***). This parameter is an attempt to combine the effects of slope, overland flow length, sediment particle size, and surface roughness on the sediment transport capacity of overland flow into a single parameter. Consequently, calibration is the major method of evaluating KEIM. Experience to date has indicated a possible range of values of 0.01 to 5.0. However, variations from this can be expected.

JEIM Exponent in the solids washoff equation (complex), (***estimate, then calibrate as needed***). Values in the range of 1 to 2.5 are reasonable, with most models using a value of 1.6 to 2.0. Use an initial value of 1.8, and then adjust if supported by local data and conditions.

ACCSDP The rate solids accumulate on the impervious land surface (tons/ac/day), (***estimate, then calibrate as needed***). Data from street surfaces suggests values in the range of 0.0005 to 0.1, with most data in the range of 0.001 to 0.02. Note that ACCSDP is in units of ‘tons/ac/day’, whereas the corresponding rate for pervious surfaces (NVSI) is in lbs/ac/day.

REMSDP The fraction of solids storage which is removed each day when there is no runoff (per day) (***estimate, then calibrate as needed***). These removal processes include wind, air currents from traffic, aggregation to larger, less transportable particles, and street cleaning activities. Values should range from 0.001 to 0.1, with typical values in the range 0.001 to 0.07. The effects of street cleaning can be estimated as:

$$R = P*(E/D)$$

where R = sediment removal by street cleaning
P = fraction of impervious area where cleaning is performed
E = efficiency of cleaning
D = frequency of cleaning

For example, if cleaning is performed every seven days on 40% of the area with an efficiency of 80%, then

$$R = (.4)\ (.8)/(7) = 0.046$$

If wind removal is estimated as 0.02, then REMDSP would be approximately 0.066. Typically, removal rates are evaluated in conjunction with accumulation rates to establish a limit to the total sediment accumulation that can occur. This limit is given by ACCSDP/REMSDP. Consequently, joint calibration of accumulation and removal rates is recommended.

Monthly Input Parameter Tables:
In general, monthly variation in selected parameters, such as SACCUM and REMOV should be included with the initial parameter estimates. As noted above, the monthly values represent the variable on the first day of each month; the values for other days are then interpolated from the values for the current and following months. The monthly values can be adjusted to calibrate for seasonal variations.

MON-SACCUM Table:
Monthly values for the rate of solids accumulation on the land surface (**ACCSDP**).

MON-REMOV Table:
Monthly values for the fraction of solids storage which is removed each day when there is no runoff (**REMSDP).**

Instream Sediment Transport (SEDTRN) Parameters

The SEDTRN section simulates the transport, deposition, and scour of inorganic sediment from a free-flowing reach or mixed reservoir (RCHRES).

SANDFG Table:

SDFG Flag to select the method that will be used for sandload simulation.

1. **Toffaleti –** developed for wide rivers where hydraulic radius is approximately equal to depth; not often used due to lack of calibration parameters
2. **Colby –** developed for wide rivers where hydraulic radius is approximately equal to depth; not often used due to lack of calibration parameters
3. **User Specified Power Function** – most frequently used at the current time

SED-GENPARM Table:

BEDWID The effective width over which bed sediment is deposited; the BEDWID is constant regardless of stage, top width, etc. (ft), (***measure***, ***estimate***). BEDWID is used to calculate the depth of sediment in the bed in order to issue a warning whenever it exceeds BEDWRN (below). It may be estimated as the channel width at low flow.

Use of BASINS Data/Tools:

The RF1 coverage contains the mean stream width (Pwidth), but NHD does not. The BASINS delineation tools produce estimates of mean stream width as a function of upstream area using geomorphological relationships described in http://www.epa.gov/waterscience/basins/width_depth_FAQ.pdf. Digital orthophotos of the watershed are also a source of stream width data.

BEDWRN The depth of sediment in the bed, which, if exceeded (e.g., through sediment deposition) will cause a warning message to be printed in the echo/message file. (ft) (***adjust as needed***). These values will be dependent on the size of the water reach/body. For large rivers and lakes, these values will range from 2 to 15 ft, or even higher for large reservoirs. Smaller streams might range from 0.5 to 2 ft. Users should inspect the computed bed depth in the model output to verify that the results are reasonable, and that the temporal variation is consistent with expectations for each stream reach.

POR The porosity of sediment in the bed (volume of voids / total volume) (unitless) (***measure***, ***estimate***). POR is used to calculate the depth of sediment in the bed. For sand and/or gravel beds, porosities range between 0.35 and 0.5, with most values near 0.45. For beds with more cohesives, the values can be higher, with values up to 0.9 for newly deposited muds and peat. As consolidation occurs, particularly if the channel dries out for extended periods, the porosity would decrease to values closer to 0.4 – 0.5.

SED-HYDPARM Table:

This table is only required if section HYDR is not active. If HYDR is active, as it is in most simulations, these quantities are specified in the HYDR section.

LEN Length of the stream reach (miles), (***measure***). Length is used in the computation of auxiliary variables, including hydraulic radius, flow velocity, and shear stress, which are used to simulate sediment transport in SEDTRN.

Use of BASINS Data/Tools:

This is populated automatically by BASINS during model initialization.

DELTH Change in elevation from the upstream end of the stream reach to the downstream end (feet), ***(measure)*****.** DELTH is used to compute channel slope for (1) calculation of shear stress for cohesives (silt and clay), and (2) if sandload transport capacity is computed using either the Toffaleti or Colby method in the SEDTRN Block.

Use of BASINS Data/Tools:

This is populated automatically by BASINS, during model initialization, from the DEM by selecting the upstream and downstream elevations for the HSPF reach boundaries. Thus the accuracy of this slope calculation depends on the resolution and accuracy of the DEM.

DB50 Median diameter of the bed sediment (inches), ***(estimate/measure)*****.** DB50 is used to calculate: (1) the bed shear stress if the reach is a lake; and (2) the rate of sand transport if the Toffaleti or Colby method is used. Note: DB50 is not connected with the sand particle diameter (D) input in the SAND-PM table. Sediment diameter values can be obtained from texts on sedimentation/hydrology and from particle size analysis of the sediments in the watershed. Sand particles have diameters typically ranging from 0.05 – 2 mm (0.002 – 0.08 in). Table 3, reproduced from ASCE (1975) shows a sediment grade scale.

SAND-PM Table:

D The effective diameter of the sand particles (in), (***measure***, ***estimate***). Sediment diameter values can be obtained from texts on sedimentation/hydrology and from particle size analysis of the sediments in the watershed. Sand particles have diameters typically ranging from 0.05 – 2 mm (0.002 – 0.08 in); see Table 3 above. Note: D is not used in the calculations; it is included in this table for consistency with the cohesive sediment data inputs. The Colby and Toffaleti calculations for sand transport use the DB50 parameter, which is entered in the HYDR-PARM2 table. Therefore, enter a nominal value of 0.01 inches.

Table 3. Sediment Particle Diameters and Fall Velocities in Still Water

Class Name	Diameter[1] (mm)	Fall Velocity[2] (cm/sec)
Very coarse sand	2.0 - 1.0	20.
Coarse sand	1.0 - 0.5	12.
Medium sand	0.5 - 0.25	5.
Fine sand	0.25 - 0.125	2.2
Very fine sand	0.125 - 0.062	0.75
Coarse silt	0.062 - 0.031	0.16
Medium silt	0.031 - 0.016	0.04
Fine silt	0.016 - 0.008	0.01
Very fine silt	0.008 - 0.004	0.0027
Coarse clay	0.0040 - 0.0020	0.0006
Medium clay	0.0020 - 0.0010	0.00015
Fine clay	0.0010 - 0.0005	0.00004
Very fine clay	0.0005 - 0.00024	0.00001
Notes: 1. Source: ASCE, 1975		
2. Fall velocity in still water; for diameters < 0.125 mm, estimated based on Stokes Law; assumed: median diameter from column 1, temperature = 24 degC, and density = 2.65 g/cm^3. For larger particles, where Stokes Law does not apply, used estimated data for sand particles from Rouse (1937).		

W The fall velocity of the sand particles in still water (in/sec), (***measure***, ***obtain from literature, estimate***). Note: for sand transport, W is only used in the Toffaleti method; therefore, if the Colby method or power function method is being used, enter a nominal value of 0.4 in/sec.

Particle velocities in still water can be estimated using simple equations such as Stokes' Law for the terminal velocity of a spherical particle. See texts on sedimentation (e.g., SCS, (1983) and ASCE, (1975)) or screening procedure reference texts, for example Mills et al., (1985). Table 3 shows sediment settling velocities in cm/s. Sand settling velocities will typically be in the range of 0.1 to 4 in/sec.

RHO The density of the sand particles (g/cm^3), (***measure***, ***obtain from literature, estimate***). Sediment densities are used to calculate the bed depth along with the porosity (POR). Sediment density values can be obtained from texts on sedimentation/hydrology and from laboratory analysis of the sediments in the watershed. Typical values of RHO range from 1.5 to 2.8 g/cm^3. If local data are not available, use 2.6 g/cm^3.

KSAND The coefficient in the sandload power function, should be included if SDFG = 3. (complex) (***calibrate***). The sand transport power function is based on velocity. This equation will produce reasonable results if the computed velocites, which are determined from the volume and discharge columns in the FTABLE, are reasonable. This coefficient is a calibration parameter; start with a value of 0.1 and adjust, in concert with EXPSND, to improve the comparison between simulated and observed sand concentrations.

EXPSND The exponent in the sandload power function, should be included if SDFG = 3. (complex) (***calibrate***). See the discussion for KSAND above. Begin with a value of EXPSND of 2.0 and adjust slightly, in concert with KSAND.

SILT-CLAY-PM Table:
This table should be entered twice. The first occurrence provides parameters for silt; the second contains the clay parameters.

D The effective diameter of the silt or clay particles (in), (***measure***, ***estimate***). Sediment diameter values can be obtained from texts on sedimentation/hydrology and from particle size analysis of the sediments in the watershed. Table 3 contains a sediment grade scale. Silt particles have diameters typically ranging from 0.005 – 0.05 mm (0.0002 – 0.002 in). Clay particles range from 0.0002 to 0.004 mm (8.E-6 – 0.00015 in). In the absence of measured data, use 0.0006 inches for silt and 0.0001 inches for clay.

W The fall velocity of the silt or clay particles in still water. (in/sec) (***measure***, ***obtain from literature, estimate***). Particle velocities in still water can be estimated using simple equations such as Stokes' Law for the terminal velocity of a spherical particle, with adjustments for drag for non-spherical particles. See texts on sedimentation or screening procedure reference manuals, for example Mills et al., (1985). Table 3 contains estimated values of W (cm/s) as a function of particle diameter and density. In the absence of detailed data and calculations, use a value of 0.0005 in/sec for silt and 0.00005 in/sec for clay.

RHO The density of the silt or clay particles, (g/cm^3), (***measure***, ***obtain from literature, estimate***). Sediment densities are used to calculate the bed depth along with the porosity (POR). Sediment density values can be obtained from texts on sedimentation/hydrology and from laboratory analysis of the sediments in the watershed. Typical values of RHO range from 1.5 to 2.8 g/cm^3. If local data are not available, use 2.3 g/cm^3 for silt and 2.0 for clay.

TAUCD The critical bed shear stress for deposition (lb/ft^2), (***calibrate***). Initial values of TAUCD and TAUCS should be estimated on a reach-by-reach basis by examining graphs of the simulated shear stress timeseries (TAU) graphed at the timestep of the simulation. Assign values of TAUCS that are below the maximum of the curve, and TAUCD that are above the minimum of the curve. Calculated shear stress values should also be inspected to verify they are reasonable. The FTABLE volume and discharge columns determine the shear stress along with the simulated discharge, and unreasonable shear stress values should first be corrected by adjusting the FTABLE. Generally, TAUCS values will be greater than TAUCD, and the values of both parameters for silt will be greater than or equal to those for clay. Adjust TAUCD and W (particle fall velocity) to calibrate the timing and magnitude of silt and clay concentrations. Increasing TAUCD will result in increasing the occurrence and magnitude of deposition and vice versa.

TAUCS The critical bed shear stress for scour (lb/ft^2), (***calibrate***). See the discussion for TAUCD above to set initial values of TAUCS. Adjust TAUCS in concert with the erodibility coefficient (M) to calibrate the timing and magnitude of silt and clay concentrations. Increasing TAUCS will result in reductions in the occurrence and magnitude of scour and vice versa.

Procedures are available to calculate critical shear stress values from Shields' equation using bed and channel properties, as follows:

$$\tau_c = \theta\ (\gamma_s - \gamma)\ D$$

where θ is the dimensionless Shields parameter for entrainment of a sediment particle of size D, γ_s is the unit weight of bed sediment, and γ is the unit weight of water. Donigian and Love (2005) have used these procedures to estimate τ_c values and assess channel stability issues in urbanizing watersheds using HSPF. These same calculations can be used to develop initial TAUCS values which would subsequently be adjusted in calibration.

M The erodibility coefficient of the sediment ($lb/ft^2.d$), (***calibrate***). This coefficient is entirely a calibration parameter. Set it to 0.01 and then adjust it (in concert with TAUCS, and with consideration of the balance between land sediment loading and channel scour) to result in reasonable silt and clay concentrations during scour conditions in the reach.

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VALUE RANGES FOR HSPF SEDIMENT EROSION AND SOLIDS WASHOFF PARAMETERS

NAME	DEFINITION	UNITS	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	FUNCTION OF ...	COMMENT
PERLND								
SED - PARM2								
SMPF	Management Practice (P) factor from USLE	none	0.0	1.0	0.0	1.0	Land use, Ag practices	Use P factor from USLE
KRER	Coefficient in the soil detachment equation	complex	0.15	0.45	0.05	0.75	Soils	Estimate from soil erodibility factor (K) in USLE
JRER	Exponent in the soil detachment equation	none	1.5	2.5	1.0	3.0	Soils, climate	Usually start with value of 2.0
AFFIX	Daily reduction in detached sediment	per day	0.03	0.10	0.01	0.50	Soils, compaction, ag operations	Reduces fine sediments following tillage
COVER	Fraction land surface protected from rainfall	none	0.0	0.90	0.0	0.98	Vegetal cover, land use	Seasonal/monthly values often used
NVSI	Atmospheric additions to sediment storage	lb/ac-dy	0.0	5.0	0.0	20.0	Deposition, activities, etc.	Can be positive or negative
SED - PARM3								
KSER	Coefficient in the sediment washoff equation	complex	0.5	5.0	0.1	10.0	Soils, surface conditions	Primary sediment **Calibration** parameter
JSER	Exponent in the sediment washoff equation	none	1.5	2.5	1.0	3.0	Soils, surface conditions	Usually use value of about 2.0
KGER	Coefficient in soil matrix scour equation	complex	0.0	0.5	0.0	10.0	Soils, evidence of gullies	**Calibration**, only used if there is evidence of gullies
JGER	Exponent in soil matrix scour equation	none	1.0	3.0	1.0	5.0	Soils, evidence of gullies	Usually use value of about 2.5
IMPLND								
SLD – PARM2								
KEIM	Coefficient in the solids washoff equation	complex	0.5	5.0	0.1	10.0	Surface conditions, solids charac.	Primary solids **Calibration** parameter
JEIM	Exponent in the solids washoff equation	none	1.0	2.0	1.0	3.0	Surface conditions, solids charac.	Usually use value of about 1.8
ACCSDP	Solids accumulation rate on the land surface	lb/ac-dy	0.0	2.0	0.0	30.0	Land use, traffic, human activities	**Calibration**, primary source of solids from impervious areas
REMSDP	Fraction of solids removed per day	per day	0.03	0.2	0.01	1.0	Street sweeping, wind, traffic	Usually start with value of about 0.05, and calibrate

HSPF HYDRAULIC SEDIMENT PARAMETERS AND VALUE RANGES

NAME	DEFINITION	UNITS	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	FUNCTION OF ...	COMMENT
RCHRES								
SANDFG								
SDFG	Indicates Method Used for Sandload Simulation	none	1	3	1	3	Type of stream; user experience.	1 - Toffaleti, 2 - Colby, 3 - Power Function
SED-GENPARM								
BEDWID	Width of cross-section over which HSPF will assume bed sediment is deposited	ft	10	500	5	1000	Reach \ Waterbody morphology	Constant regardless of stage, top-width, etc
BEDWRN	Bed depth which, if exceeded (i.e., through deposition) will cause a warning message to be printed	ft	0.5	10	0.5	20	Reach \ Waterbody morphology, User Needs	Only affects when warning messages will be printed about high bed depth/deposition. Lakes/reservoirs will have higher values.
POR	Porosity of the bed (volume voids/total volume)	none	0.3	0.6	0.25	0.9	Reach \ Sediment Bed Characteristics	Only affects bed depth calculation. Can set to 0.5 if no data are available.
SED-HYDPARM								
LEN	Length of the RCHRES	miles	0.1	1.0	0.01	100	Topography, stream morphology	If very large lengths are calculated, reach should be subdivided.
DELTH	Drop in water elevation from upstream to downstream extremities of the RCHRES	ft	5	50	0.1	100	Topography, stream morphology	If large drops are calculated, the reach should be subdivided into multiple separate reaches.
DB50	Median diameter of bed sediment (assumed constant)	in	0.01	0.02	0.001	1.0	Channel bed properties	Only used for lake shear stress and Toffaleti/Colby methods
SAND-PM								
D	Effective diameter of the transported sand particles	in	.002	0.08	.0005	0.2	Sediment properties	Not used in calculations. Set to 0.01 in.
W	Fall velocity of transported sand particles in still water	in/sec	0.2	4.	0.1	10.	Particle diameter and density	Used for Toffaleti method.
RHO	Density of sand particles	g/cm^3	2.2	2.7	1.5	3.0	Sediment properties	Used for calculating bed depth.
KSAND	Coefficient in sandload power function formula	complex	0.01	0.5	0.001	10.	Sand properties and hydraulics	**Calibration**. Affects sand concentration.
EXPSND	Exponent in sandload power function formula	complex	1.5	3.5	1.0	6.0	Sand properties and hydraulics	**Calibration**. Affects sand scour. Usually start with 2.0
SILT-CLAY-PM								
D	Effective diameter of silt, or clay particles	in	.0002 .00001	.0025 .00015	.0001 .000005	.004 .00025	Sediment properties	Used for calculating bed depth.

W	Fall velocity of transported silt or clay particles in still water	in/sec	.0001	0.01	0.0	0.1	Particle diameter and density	Affects concentration during low flow.
RHO	Density of silt or clay particles	g/cm^3	1.8	2.7	1.5	3.0	Sediment properties	Used for calculating bed depth.
TAUCD*	Critical bed shear stress for deposition	lb/ft^2	0.01	0.3	0.001	1.0	Silt/clay properties and hydraulics	**Calibration**. Affects timing & magnitude of deposition. Initial values based on computed shear stress.
TAUCS*	Critical bed shear stress for scour	lb/ft^2	0.05	0.5	0.01	3.0	Silt/clay properties and hydraulics	**Calibration**. Affects timing & magnitude of scour. Initial values based on computed shear stress.
M*	Erodibility coefficient	$lb/ft^2.d$	0.01	2.	0.001	5.0	Silt/clay properties and hydraulics	**Calibration**. Affects magnitude of scour.

*** -** Minimum values for lakes and other waterbodies may be 2 to 3 orders of magnitude lower than the table ranges in order to represent reasonable sediment trapping efficiency.

APPENDIX

SEDIMENT CALIBRATION PROCEDURES AND GUIDELINES FOR WATERSHED MODELING

A. S. Donigian, Jr.
J. T. Love
AQUA TERRA Consultants
2685 Marine Way, Suite #1314
Mountain View, CA 94043

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ABSTRACT

Sediment is one of the most difficult water quality constituents to accurately represent in current watershed and stream models. Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes.

Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources, delivery, and transport behavior within the channel system. Rarely is there sufficient observed local data at sufficient spatial detail to accurately calibrate all parameters for all land uses and each stream and waterbody reach. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience.

This paper explores a 'weight of evidence' approach for sediment calibration as part of overall watershed model calibration, using both graphical and statistical measures, based on recent experience with the U. S. EPA Hydrological Simulation Program - FORTRAN (HSPF). Model parameterization and calibration procedures are described, using sample model results, to demonstrate recommended graphical and statistical procedures to assess model performance for sediment loadings, concentrations, and budgets within a watershed modeling framework. Although the results are specific to the EPA HSPF model, the approach and procedures for sediment calibration are applicable to other watershed models that represent sediment processes and behavior at the watershed scale.

KEYWORDS

HSPF, erosion, sediment delivery, GIS, sediment rating curves, shear stress, TMDL, USLE

INTRODUCTION

Sediment is a primary constituent of concern for many watershed assessments and Total Maximum Daily Load (TMDL) studies being performed across the country. In addition to issues related to sediment impacts on stream habitats, sediment is also a carrier of many other pollutants, including metals, phosphorus, organics, and bacteria. Unlike many other pollutants, eliminating all sediments from the stream is not a solution since that will ultimately lead to channel scour and/or bank failures, as the stream attempts to reach a stable, dynamic equilibrium.

Sediment is also one of the most difficult water quality constituents to accurately represent in current watershed and stream models. Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes.

A ‘weight-of-evidence’ approach is rapidly becoming the standard practice in watershed modeling. Model performance and calibration/validation are evaluated through qualitative and quantitative measures, involving both graphical comparisons and statistical tests. For flow simulations where continuous records are available, all these techniques are often employed, and the same comparisons are performed, during both the calibration and validation phases. For water quality constituents, including sediment, model performance is often based primarily on visual and graphical presentations as the frequency of observed data is often inadequate for accurate statistical measures beyond basic metrics (e.g., mean). However, consistency checks with expected value ranges for loading rates and stream morphology and behavior are critical when spatially distributed field data are limited.

This paper explores the ‘weight of evidence’ approach for sediment calibration as part of overall watershed model calibration based on recent experience with the U. S. EPA Hydrological Simulation Program - FORTRAN (HSPF) (Bicknell et al., 2001). Model parameterization and calibration procedures are described, using example applications and sample model results, to demonstrate recommended graphical and statistical procedures used to assess model performance for sediment loadings, concentrations, and budgets within a watershed modeling framework. Although the results are specific to the EPA HSPF model, the approach and procedures for sediment calibration are applicable to other watershed models that represent sediment processes and behavior at the watershed scale.

SEDIMENT CALIBRATION OVERVIEW

Sediment calibration follows the hydrologic calibration and must precede water quality calibration. Calibration of the parameters involved in simulation of watershed sediment erosion is more uncertain than hydrologic calibration due to less experience with sediment simulation in different regions of the country. The process is analogous; the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. However, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year.

Sediment calibration for watershed models involves numerous steps in estimating model parameters then determining appropriate adjustments needed to ensure a reasonable simulation of the sediment sources, delivery, and transport behavior within the channel system. These steps usually include:

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, land use, and management practices
2. Calibrating the model loading rates to the target rates
3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies
4. Analyzing sediment bed behavior (i.e. bed depths) and transport in each channel reach as compared to field observations
5. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network
6. Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available
7. Repeating steps 1 through 6 as needed to develop a reasonable overall representation of sediment sources, delivery, and transport throughout the watershed system

Rarely is there sufficient observed local data at sufficient spatial detail to accurately calibrate all parameters for all land uses and each stream and waterbody reach. In fact, for sediment modeling, users are often limited to observed data for monthly or storm periods at only selected sites within the watershed. Consequently, model users focus the calibration on those sites with observed data, and then must review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. This is especially critical for sediment modeling due to the extreme dynamic behavior of sediment erosion and transport processes.

Below we journey through each of the above steps to provide model users with general guidance and recommendations for modeling watershed-scale sediment processes in a logical and reasonable fashion. Although the specific parameter definitions and discussions and sample model results are based on the HSPF model, the overall procedures should prove useful to users of other watershed scale sediment model codes.

SEDIMENT EROSION CALIBRATION

Sediment loadings to the stream channel are estimated by land use category from literature data, local Extension Service sources, or procedures like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and then adjusted for delivery to the stream with estimated sediment delivery ratios (SDRs). This delivery adjustment is needed because HSPF, like most watershed-scale (lumped parameter) models, represents landscape loadings to the stream channel, which are less than the field-scale estimates from USLE. These estimated loading rates then become ***'calibration targets'*** for the watershed model.

Model parameters are then adjusted so that model-calculated loadings are consistent with these estimated ***'calibration targets'*** and loading ranges. The model-calculated loadings are further evaluated in conjunction with the instream sediment transport calibration (discussed below) that extend to a point in the watershed where sediment concentration and/or load data are available. The objective is to represent the overall sediment behavior of the watershed, with knowledge of the morphological characteristics of the stream (i.e. aggrading or degrading behavior), using sediment loading rates that are consistent with the ***calibration targets*** and modeled concentrations that provide a reasonable match with instream sediment data.

Step 1: Estimating Sediment Loadings from the Landscape

Sediment concentrations measured at a particular gage reflect the combined affects of nonpoint source contributions from multiple land uses, any point sources upstream from the gage, and instream processes (e.g., deposition, scour, bank erosion). Consequently, the ***calibration target*** sediment loading rates need to be developed to help guide the calibration effort and ensure that the simulated erosional rates from each land use category are reasonable, and thereby provide a sound basis for calibrating the instream processes.

Erosion is primarily a function of the amount of soil exposed directly to rainfall and surface runoff, which in turn is affected by rainfall, land cover, land slope, soil disturbance, and transport properties of the soil. The USLE is an empirical equation commonly used to estimate erosional rates as a function of these factors. The USLE formula is expressed as follows:

$$A = R * K * L * S * C * P$$

A = annual soil loss in tons per acre per year
R = rainfall erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope gradient factor
C = cover management factor
P = erosion control practice factor

The ***R factor*** *is* typically obtained from a national or regional isoerodent map, readily available in many soil engineering handbooks (e.g. Renard et al, 1997), and accounts for the amount and intensity of rainfall and runoff typical of a region.

The ***K factor*** is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting ***K***, but structure, organic matter and permeability also contribute. Determining ***K*** values can be performed either from handbook tables, or acquisition of accurate geo-spatial soils data from the U.S. Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) if a GIS approach is employed. The most common forms of these data are the STATSGO and SSURGO databases and/or GIS coverages.

The ***L factor*** is very closely associated with the ***S factor***, where ***S*** is the slope gradient factor and the ***L*** is the length of that slope. The USLE was created to predict soil erosion delivered to the base of a 22-meter agricultural plot with a uniform slope of 9 percent. The ***S*** and ***L factors*** are typically combined, defined as the topographic factor ***LS,*** to account for site specific conditions relative to the standard plot.

The ***C factor*** is the crop/vegetation and management factor. It is used to determine the relative effectiveness of soil and crop management system or vegetation in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land.

The ***P factor*** is the support practice factor and reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most commonly used supporting cropland practices are cross slope cultivation, contour farming, and strip cropping. In cases where the conservation practice factor is not relevant, it is set as 1.0 for all areas, which does not negatively or positively influence the output of the model.

As the USLE was developed at a field scale, depositional processes that occur in overland flow prior to reaching a stream channel are not included. Therefore, it is necessary to reduce the gross erosion by a fraction. This fraction or portion of sediment that is available for delivery is referred to as the Sediment Delivery Ratio (SDR). This ratio is then multiplied by the predicted or gross erosion rate to estimate the percent of eroded material to reach a specific point or location (e.g., outlet, waterbody, channel). There is no generally accepted procedure to estimate the SDR, which is affected by numerous factors including sediment source, texture, nearness to the stream, channel density, basin area, slope, land use/cover, and rainfall-runoff factors; however, several empirical formulas exist (e.g. see Greenfield et al., 2002).

Under EPA funding, AQUA TERRA Consultants developed a Visual Basic spreadsheet tool named **TMDL USLE** (Hummel et al., 2000) for use in sediment associated TMDL studies (http://www.epa.gov/ceampubl/swater/usle). This spreadsheet is useful for estimating the expected relative magnitude of land surface sediment loadings (tons per year) from different land use types within a watershed, and thereby can be used to develop sediment calibration targets for watershed models. Maps, recommended value tables for USLE factors, and other information useful in deriving appropriate values for the USLE and delivery ratios are provided, to the extent that it is practical, throughout the U.S. The tool includes an on-line tutorial and active links to Internet web sites containing supplemental information that can assist users in evaluating USLE factors.

Figure 1 shows the computation screen for the TMDL USLE program, with highlighted comment 'bubbles' identifying the source of values and information in each cell.

As an alternative to a spreadsheet based approach, using a GIS platform allows the USLE to be applied on a cell-by-cell basis, using watershed specific information, for a more spatially accurate use of the equation and model land use specific estimates of erosional rates. The USLE can be applied in a grid-based GIS environment where map algebra can be performed with the GIS layer values.

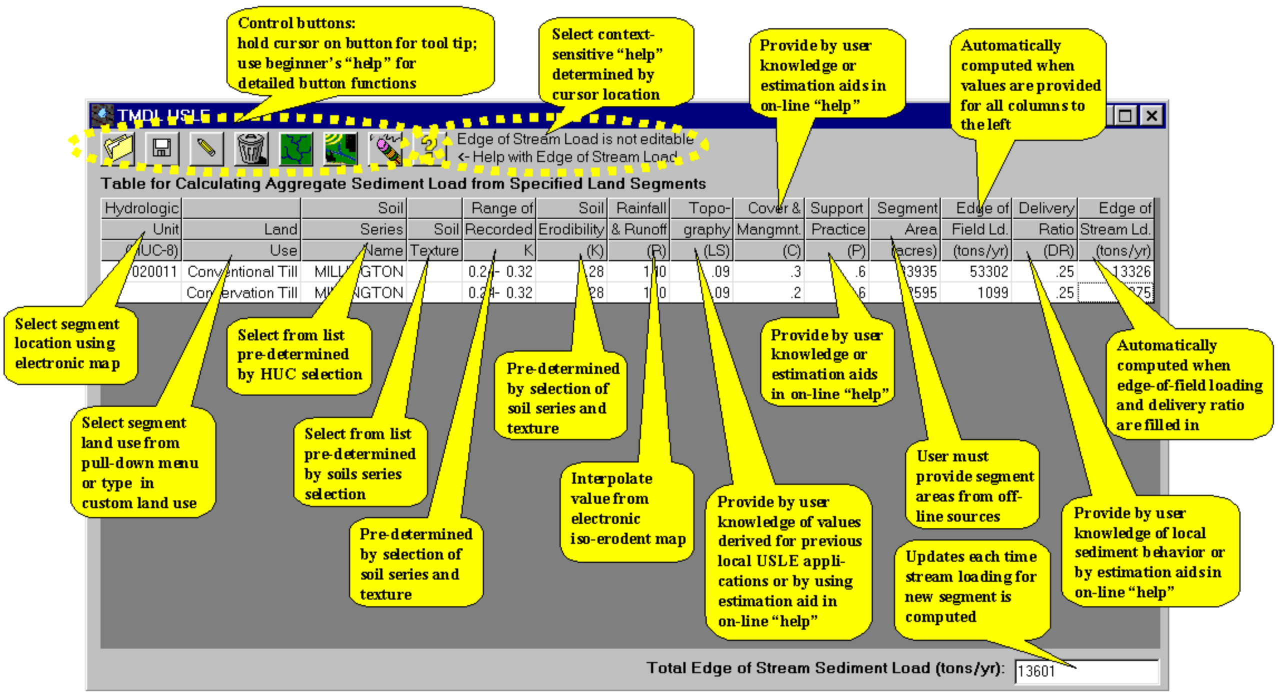

Figure 1 - TMDL USLE tool

Typically, in a GIS environment the ***S*** and ***L factors*** are combined together and defined as the topographic factor (***LS***) with the slope length normalized to a standard plot length of 22 meters and the slope normalized to 9 percent. Numerous empirical formulas exist such as the one below.

$$LS = [0.065 + 0.0456(slope) + 0.006541(slope)^2] * [resolution / normlength]^{n}$$

slope = slope steepness (%)
resolution = cell resolution (meters or feet)
normlength = 72.5 ft or 22.1 meters
n = function of slope (see table below)

slope	< 1	1 ≤ slope < 3	3 ≤ slope < 5	> 5
n	0.2	0.3	0.4	0.5

The ***K factor*** can be obtained from a descriptor or attribute, referred to as '*kffac*t' within the STATSGO or SSURGO databases. The attribute '*kffac*t' defines the soil erodibility factor that is fragment free for use in the USLE.

Within a GIS, the SDR can be calculated in a manner to try and account for all the aforementioned controlling factors, or in a simplified manner based on the drainage area of the channel segment as defined by the model setup. This simple approach is referred to as a watershed area-based method. The equation below was converted from a curve presented in the National Engineering Handbook produced by the Soil Conservation Service in 1983 (USDA-NRCS, 1983).

$$SDR = 0.417762 * A^{-0.134958} - 0.127097$$

A = drainage area (sq. miles)

Numerous additional empirical formulas exist, including formulas and tables provided within the TMDL USLE tool. Ultimately, once the gross erosional rates are adjusted by the SDR, it is possible to use the GIS to summarize the range of erosional rates on a model land use specific basis. Figure 2 graphically depicts the process of taking the input data (i.e., DEM, soils, land use/cover), calculating USLE factors, and developing estimates of the erosional rates.

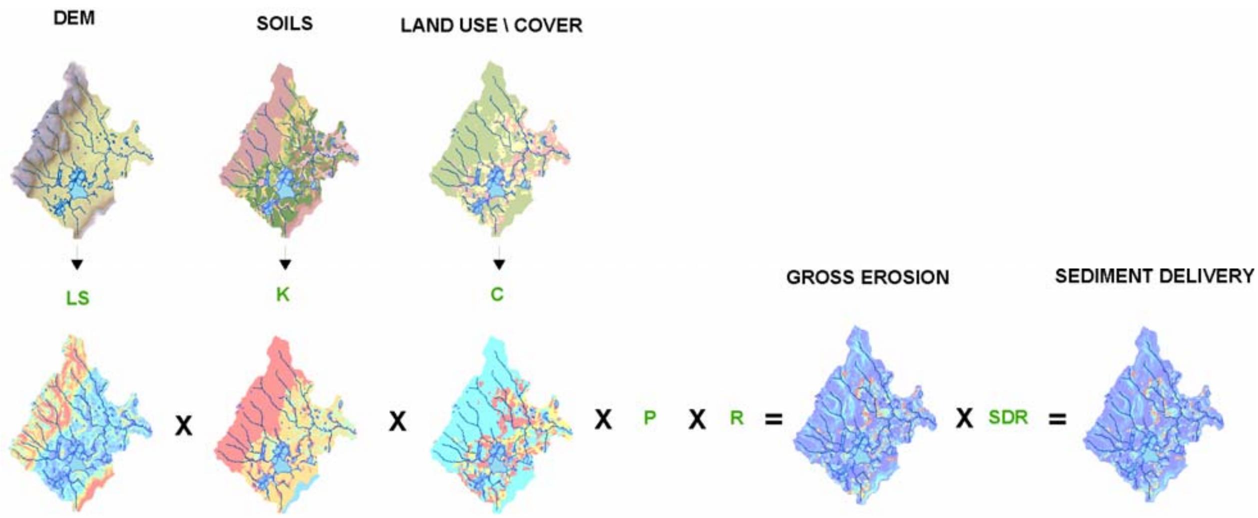

Figure 2 – GIS Framework for USLE

Calibration targets developed from the TMDL USLE spreadsheet, a GIS-based approach, or other procedures should be used only to define approximate ranges of loading rates to help guide the calibration for the watershed or region of concern. There will often be extreme variation in the calculated rates from year to year, and site to site, and users should only expect that the model rates will be ***consistent with*** the targets, not necessarily ***equal to*** them. Table 1 shows typical ranges of sediment loading rates for various land categories.

Table 1 - Typical Ranges of Expected Erosion Rates

	Tons/ac	**Tonnes/ha**
Forest	0.05 - 0.4	0.1 - 0.9
Pasture	0.3 - 1.5	0.7 - 3.4
Conventional Tillage	1.0 - 7.0	2.2 - 15.7 (crop dependent)
Conservation Tillage	0.5 - 4.0	1.1 - 9.0 (crop dependent)
Hay	0.3 - 1.8	0.7 - 4.0
Urban	0.2 - 1.0	0.4 - 2.2
Highly Erodible Land	> ~ 15.0	> ~ 33.6

Step 2: Sediment Erosion Calibration

Each of the calibration steps identified in the overall procedures involve first a parameterization component followed by the actual calibration, or parameter adjustment, component to improve agreement between model values and various field observations. Clearly, the specific parameters to adjust for soil erosion calibration will depend on the specific model being used. In HSPF, the erosion process on pervious land areas is represented as the net result of detachment of soil particles by raindrop impact on the land surface, and then subsequent transport of these fine particles by overland flow. On impervious surfaces (e.g. parking lots, driveways), soil splash by raindrop impact is neglected and solids washoff is often controlled by the rate of accumulation of solid materials. The primary sediment erosion solids parameters are as follows:

KRER	-	Coefficient in soil detachment equation (pervious areas)
KSER	-	Coefficient in sediment washoff equation (pervious areas)
KEIM	-	Coefficient in impervious area solids washoff equation
ACCSDP	-	Accumulation rate of solids on impervious surfaces

Although a number of additional parameters are involved in sediment erosion and solids calibration, such as those related to vegetal cover, agricultural practices, rainfall and overland flow intensity, etc., KRER and KSER are the primary ones controlling sediment loading rates. KRER is usually estimated as equal to the erodibility factor, K, in the USLE (noted above), and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience. For impervious surfaces, the rate of washoff is controlled by the KEIM parameter, but the net washoff is most often limited by the accumulation rate, ACCSDP. Table 2 lists the sediment and solids washoff parameters in HSPF, along with typical and possible minimum and maximum ranges based on application experience over the past 20 years. In addition, the HSPFParm database (U. S. EPA, 1999) provides calibrated parameter values for numerous watersheds across the US.

In general, sediment calibration involves the development of an approximate equilibrium or balance between the accumulation and generation of sediment particles on one hand and the washoff or transport of sediment on the other hand. Thus, the accumulated sediment on the land surface should not be continually increasing or decreasing throughout the calibration period. Extended dry periods will produce increases in surface sediment accumulations, and extended wet periods will produce decreases. However, the overall trend should be relatively stable from year to year. This equilibrium must be developed on both pervious and impervious surfaces, and must exist in conjunction with the accurate simulation of monthly and storm event sediment loss, depending on the data available for calibration. Additional guidance in sediment erosion calibration is provided in the HSPF Application Guide (Donigian et al., 1984).

Table 2 - Value Ranges for HSPF Sediment Erosion and Solids Washoff Parameters

NAME	DEFINITION	UNITS	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	FUNCTION OF ...	COMMENT
SED - PARM2								
SMPF	Management Practice (P) factor from USLE	none	0.0	1.0	0.0	1.0	Land use, Ag practices	Use P factor from USLE
KRER	Coefficient in the soil detachment equation	complex	0.15	0.45	0.05	0.75	Soils	Estimate from soil erodibility factor (K) in USLE
JRER	Exponent in the soil detachment equation	none	1.5	2.5	1.0	3.0	Soils, climate	Usually start with value of 2.0
AFFIX	Daily reduction in detached sediment	per day	0.03	0.10	0.01	0.50	Soils, compaction, ag operations	Reduces fine sediments following tillage
COVER	Fraction land surface protected from rainfall	none	0.0	0.90	0.0	0.98	Vegetal cover, land use	Seasonal/monthly values often used
NVSI	Atmospheric additions to sediment storage	lb/ac-dy	0.0	5.0	0.0	20.0	Deposition, activities, etc.	Can be positive or negative
SED - PARM3								
KSER	Coefficient in the sediment washoff equation	complex	0.5	5.0	0.1	10.0	Soils, surface conditions	Primary sediment **Calibration** parameter
JSER	Exponent in the sediment washoff equation	none	1.5	2.5	1.0	3.0	Soils, surface conditions	Usually use value of about 2.0
KGER	Coefficient in soil matrix scour equation	complex	0.0	0.5	0.0	10.0	Soils, evidence of gullies	**Calibration**, only used if there is evidence of gullies
JGER	Exponent in soil matrix scour equation	none	1.0	3.0	1.0	5.0	Soils, evidence of gullies	Usually use value of about 2.5
SLD – PARM2								
KEIM	Coefficient in the solids washoff equation	complex	0.5	5.0	0.1	10.0	Surface conditions, solids charac.	Primary solids **Calibration** parameter
JEIM	Exponent in the solids washoff equation	none	1.0	2.0	1.0	3.0	Surface conditions, solids charac.	Usually use value of about 1.8
ACCSDP	Solids accumulation rate on the land surface	lb/ac-dy	0.0	2.0	0.0	30.0	Land use, traffic, human activities	**Calibration**, primary source of solids from impervious areas
REMSDP	Fraction of solids removed per day	per day	0.03	0.2	0.01	1.0	Street sweeping, wind, traffic	Usually start with value of about 0.05, and calibrate

INSTREAM SEDIMENT TRANSPORT CALIBRATION

Parameterization of Instream Sediment Transport Processes

Once the sediment loading rates are calibrated to provide the expected input to the stream channel, the sediment calibration then focuses on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations to be compared with observations. In practice, instream calibration involves steps 3, 4 and 5 as listed and discussed above; these steps involve both initial parameterization, to establish initial parameter values, and a subsequent adjustment process. For HSPF, the initial parameterization includes the following:

- Divide input sediment loads into appropriate size fractions
- Estimate initial parameter values and storages for all reaches
- Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values

Since the sediment load from the land surface is calculated in HSPF as a total input, it must be divided into sand, silt, and clay fractions for simulation of instream processes. Each sediment size fraction is simulated separately, and storages of each size are maintained for both the water column (i.e. suspended sediment) and the bed.

Fractionating the Eroded Material

The eroded material is fractionated into sand, silt, and clay prior to entering a model reach using available soils information; typically, a single fractionation scheme is used for all reaches. However, if the resolution of the data and spatial diversity of the soils warrant alternate schemes, it is possible for each reach to use separate fractions. The fractions should reflect the relative percent of the surface material (i.e., sand, silt, clay) available for erosion in the surrounding watershed, but also should include an enrichment factor of silt and clay to represent the likelihood of these finer materials reaching the channel. Thus, the sand particles are more likely to be deposited in the overland flow plane, in swales, ditches, depressions, etc. and therefore the sand would be somewhat transport limited, compared to the silt and clay. For example, if surface soils demonstrate a 40/50/10 distribution for sand/silt/clay, the fractionation for input to the reach might be 15/55/30. Investigation of the bed material composition will also help to provide insight into appropriate fractionation values.

Estimate Initial Parameter Values And Storages For All Reaches

For HSPF, initial sediment parameters, such as particle diameter, particle density, settling velocity, bed depth and composition, and beginning calibration parameter values can be evaluated from local/regional data, past experience, handbook values, etc., and then adjusted based on available site specific data and calibration. Bed composition data are especially important so that the model results can be adjusted to reflect localized aggredation (deposition) or degradation (scour) conditions within the stream system.

In HSPF, the value of bed depth represents the amount of material (calculated from input values for bed width and porosity) that can be scoured from the stream reach; in effect it provides a limit so that the model will inform the user, through a warning message, when the channel has been completely scoured so that the user can make appropriate parameter changes if needed. We often set initial bed depths to 2.0 to 5.0 feet for the natural (i.e. non-channelized) stream segments, and 0.5 to .05 feet for the channelized segments to allow a reasonable amount of scour in the upstream natural channel and limit the scour to scattered localized deposits in channelized sections.

Setting Initial Critical Scour and Depositional Shear Stresses

In HSPF, the transport of the **sand (non-cohesive) fraction** is commonly calculated as a power function of the average velocity in the channel reach in each timestep. This transport capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in suspension within the channel reach. For the **silt and clay (cohesive) fractions**, shear stress calculations are performed by the hydraulics (HYDR) module and are compared to user-defined critical, or threshold, values for deposition and scour for each size. When the shear stress for a timestep is greater than the critical value for scour, the bed is scoured at a user-defined erodibility rate; when the shear stress is less than the critical deposition value, the silt or clay fraction deposits at a settling rate input by the user for each size. If the calculated shear stress falls between the critical scour and deposition values, the suspended material is transported through the reach. After all scour and/or deposition fluxes have been determined, the bed and water column storages are updated and outflow concentrations and fluxes are calculated for each timestep. These simulations are performed by the SEDTRN module in HSPF, complete details of which are provided in the HSPF User Manual (Bicknell et al., 2001).

In HSPF, if the model reach being simulated is a stream or river, the bed shear stress is determined as a function of the slope and hydraulic radius of the reach, as follows:

TAU = SLOPE*GAM*HRAD

where:

TAU	= stream bed shear stress (lb/ft2 or kg/m2)
SLOPE	= slope of the RCHRES (-)
GAM	= unit weight, or density, of water (62.4 lb/ft3 or 1000 kg/m3)
HRAD	= hydraulic radius (ft or m)

The hydraulic radius is calculated as a function of average water depth (AVDEP) and mean top width (TWID):

HRAD = (AVDEP*TWID)/(2.*AVDEP + TWID)

Average depth is computed as: AVDEP = VOL/SAREA

The mean top width is found using: TWID = SAREA/LEN

where:

LEN = length of the RCHRES, supplied by the user

If the stream reach is a lake, alternative methods are used for the shear calculations (see Users Manual for details).

In HSPF, the hydraulic characteristics of a stream reach are represented by a function table (FTABLE) that includes the relationships between stage, storage (volume), surface area, and discharge. From the equations shown above, it is clear that the accuracy of the FTABLE for a specific reach will be a **critical factor** in adequately representing the hydraulic radius and subsequent shear values, as a function of the stage, or depth of flow. This is especially evident for simulations of flood flows that exceed bankfull discharges; improper extension of the FTABLES can lead to erroneous shear and scour conditions during high flow events, and have major impacts on the model simulations for those events.

As part of the sediment parameterization, the model is run with the initial parameter estimates and shear stress values are output for each stream reach. For the silt and clay size particles, the critical shear stress parameters (one for scour and one for deposition) for each size are adjusted so that the model calculates scour during high flow events, deposition and settling during low flow periods, and transport with neither scour nor settling for moderate flow rates; this is shown schematically in Figure 3. In general, the values are set so that scour of clay occurs at lower shear values than for silt (i.e. clay scours before silt), and deposition of silt occurs at higher shear values than clay (i.e. silt deposits before clay).

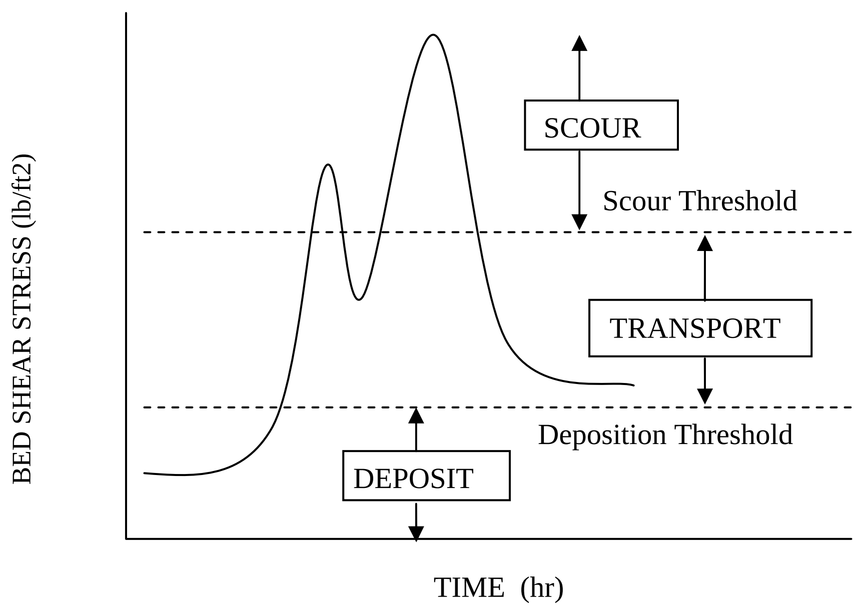

Figure 3 – Shear Stress Calculations in HSPF

Figure 4 shows an example of setting the critical shear values based on both flow and shear stress simulations for a small eastern US watershed; the top plot show the flow simulation corresponding to the shear simulations on the bottom curve. We've also included, on the right-hand scale of the shear curve, the percent exceedance values to help quantify how often scour and deposition conditions occur at different shear values.

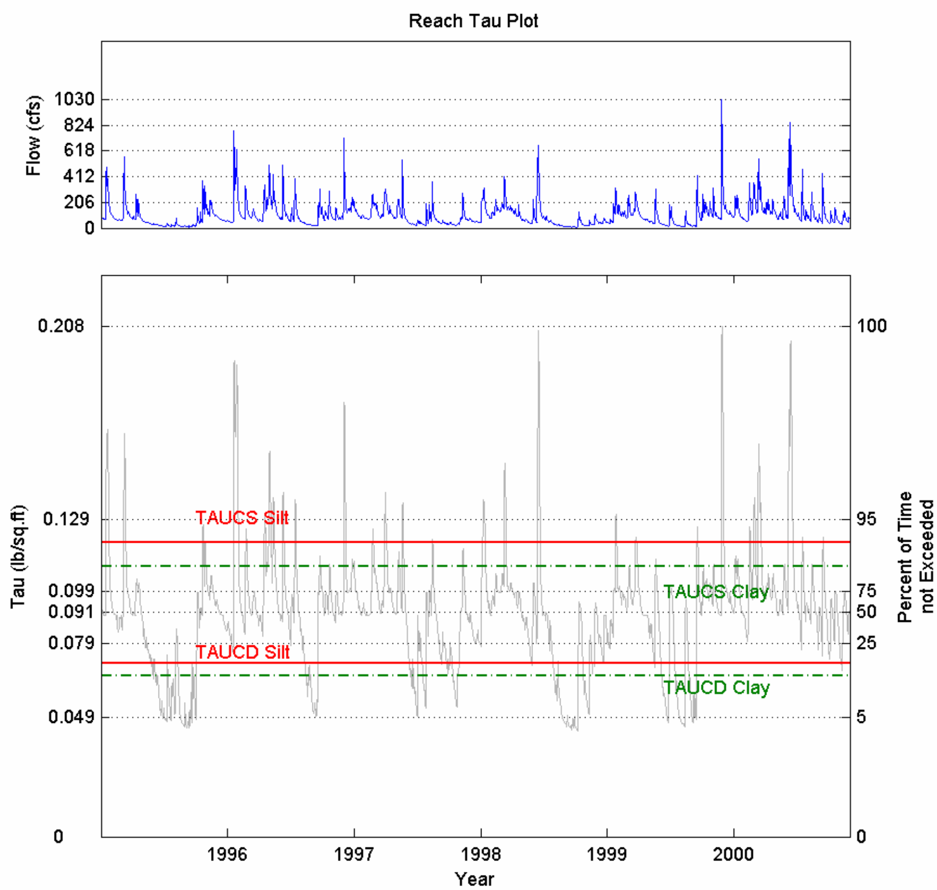

Figure 4 - Example calculations for setting critical shear values for HSPF

Step 3: Adjust Instream Scour, Deposition, and Transport parameters

Step 4: Analyze Bed Behavior and Transport Fluxes

Step 5: Analyze Overall Sediment Budgets and Stream Behavior

These 3 steps are listed together as they normally are performed while reviewing the same tabulations of model results; bed behavior and sediment budgets need to be reviewed to establish the basis for parameter adjustments on a reach-by-reach basis. Table 3 shows an example tabulation of reach-by-reach model results for a small eastern US watershed. The watershed includes 2 tributary reaches and 6 mainstem reaches, and the tabulations include sediment erosion (nonpoint) loads, point loads, upstream and total inflow loads, total outflow loads, and both cumulative and reach trapping efficiencies. For example, note that the tributaries demonstrate net scour behavior (deposition/scour column values are negative), while the mainstem is depositional throughout. This information can be compared with historical accounts or field observations to identify the 'expected' behavior for those stream segments. If this information is contrary to the model representation, i.e., the model simulates deposition when the reach is primarily being scoured, reach parameters and/or inflows need to be adjusted to correct the simulated behavior.

Table 3 – Example Tabulation of Stream Sediment Fluxes and Behavior

Reach Segment	Nonpoint (tons)	Point Source (tons)	Upstream In (tons)	Total Inflow (tons)	Outflow (tons)	Deposit (+) Scour (-) (tons)	Cumulative Point/NonPt (tons)	Cumulative Trapping Efficiency (%)	Reach Trapping Efficiency (%)
Mainstem 1	212.5	107.4	6,453.7	6,785.3	6,186.3	599.7	10,566.9	41.5	8.8
Mainstem 2	68.8	0.0	6,186.3	6,255.0	5,384.8	870.6	10,635.7	49.4	13.9
Tributary 1	102.4	0.0	0.0	102.2	125.0	-22.7	102.2	-22.0	-22.0
Mainstem 3	5.8	0.0	5,509.8	5,515.6	4,916.3	599.9	10,744.0	54.2	10.9
Tributary 2	281.1	0.0	0.0	280.5	352.6	-72.1	280.5	-25.5	-25.5
Mainstem 4	215.4	0.0	5,268.9	5,483.9	4,269.8	1,215.1	11,240.4	62.0	22.1
Mainstem 5	54.1	0.0	4,269.8	4,323.8	3,507.1	826.2	11,294.5	68.9	18.9
Mainstem 6	93.9	0.0	3,507.1	3,600.8	2,190.8	1,421.3	11,388.4	80.8	39.2

Table 4 shows the corresponding detailed behavior of bed depth and sediment fractions in selected reaches within the watershed (Tributary 1 and Mainstem reaches 2 and 3). The tabulations in Table 4 include, annual inflow loads, outflow loads, and deposition/scour in the reach, along with the composition of these loads and the bed behavior and composition throughout the simulation period. Field observations of bed depth changes, expected deposition rates, bed sediment composition fractions, etc. can be used to assess the validity of the model results and identify needed changes.

These results demonstrate the types of analyses performed as part of the sediment calibration effort. In this example, sand comprises a small fraction of the total sediment concentration and discharge, and thus the sand parameters are set to values to reflect this small contribution. In other watersheds, the non-cohesive (sand) fractions may be more critical and thus require greater focus and calibration effort.

The primary focus of this example calibration is the silt and clay parameters. As noted above, the shear stress values are adjusted so that scour occurs during storm periods and deposition occurs at low flows. Once the timing of scour and deposition processes is correct, the rate of scour (i.e. erodibility factor in the model) is adjusted in an attempt to match either the expected behavior within each reach, from review of the type of information shown in Tables 3 and 4, and/or the observed concentrations (discussed below in the next step). During high flow periods, the amount of scour is adjusted with an erodibility factor for each reach that controls the rate of scour whenever the actual shear stress is greater than the critical shear stress value for scour.

The need to analyze the model simulations on a reach-by-reach basis is mandated by the extreme variability in sediment processes. If upstream reaches are depositing more than expected, then inflows to downstream reaches will be less than what really occurs, requiring parameter adjustments that may not be reasonable for the downstream reaches. The opposite would occur if upstream reaches are eroding much more than expected; inflows to downstream reaches will be too large, resulting in more deposition than would be expected. If the reach parameters are set so that deposition does not occur, then the upstream eroded load will be transported and will subsequently impact other downstream reaches. Thus, an upstream to downstream analysis, on a reach-by-reach basis, is required to adequately assess model simulations.

Table 4 - Example Bed and Stream Reach Sediment Simulations

Mainstem 2								Final	Average	Arithmetic
	Init Val	1995	1996	1997	1998	1999	2000	Fraction	Fraction	Average
Bed Depth (ft)	2.00	2.10	2.10	2.10	2.20	2.20	2.30			2.20
Bed Storage (tons)										
Sand	0.79	34,684.7	34,775.7	34,795.8	34,805.4	34,828.3	34,840.5	0.70	0.73	34,788.4
Silt	0.15	7,623.7	8,780.0	9,310.2	9,867.1	10,581.5	11,573.3	0.23	0.20	9,622.6
Clay	0.07	3,112.9	3,165.8	3,181.9	3,201.7	3,222.9	3,255.5	0.07	0.07	3,190.1
Total		45,421.3	46,721.6	47,287.9	47,874.2	48,632.8	49,669.2			47,601.2
Inflow (tons)										
Sand		152.6	273.5	115.0	133.0	130.6	219.8	0.03	0.03	170.7
Silt		4,705.1	5,024.8	2,503.7	2,571.7	3,357.7	4,437.0	0.61	0.60	3,766.7
Clay		3,152.5	3,270.2	1,354.6	1,528.3	1,939.2	2,638.8	0.36	0.37	2,313.9
Total		8,010.2	8,568.5	3,973.3	4,232.9	5,427.4	7,295.6			6,251.3
Dep(+)/Scour(-) (tons)										
Sand		4.7	-0.4	22.9	12.1	25.6	14.9			13.3
Silt		1,038.4	1,135.4	530.0	556.7	714.9	991.9			827.9
Clay		39.8	44.4	16.0	19.8	21.3	32.5			29.0
Total		1,082.8	1,179.4	568.9	588.5	761.8	1,039.4			870.1
Outflow (tons)										
Sand		148.0	273.8	92.2	120.9	104.9	204.9	0.03	0.03	157.5
Silt		3,668.1	3,889.2	1,974.0	2,015.0	2,642.8	3,445.1	0.55	0.55	2,939.0
Clay		3,113.9	3,225.5	1,339.0	1,508.6	1,917.8	2,606.2	0.42	0.43	2,285.2
Total		6,929.9	7,388.5	3,405.2	3,644.4	4,665.6	6,256.2			5,381.6
Tributary 1								Final	Average	Arithmetic
	Init Val	1995	1996	1997	1998	1999	2000	Fraction	Fraction	Average
Bed Depth (ft)	2.00	2.00	2.00	2.00	2.00	2.00	2.00			2.00
Bed Storage (tons)										
Sand	0.9	28,369.1	28,440.4	28,434.4	28,415.9	28,407.7	28,417.6	0.90	0.90	28,414.2
Silt	0.05	1,569.4	1,563.8	1,561.0	1,559.1	1,554.2	1,544.3	0.05	0.05	1,558.6
Clay	0.05	1,563.0	1,549.4	1,544.4	1,538.6	1,529.9	1,513.4	0.05	0.05	1,539.8
Total		31,501.5	31,553.6	31,539.8	31,513.6	31,491.9	31,475.4			31,512.6
Inflow (tons)										
Sand		32.1	49.3	24.3	14.9	29.2	64.6	0.35	0.35	35.8
Silt		45.9	70.5	34.8	21.4	41.8	92.3	0.50	0.50	51.1
Clay		13.8	21.2	10.4	6.4	12.5	27.7	0.15	0.15	15.3
Total		91.8	141.0	69.5	42.7	83.6	184.6			102.2
Dep(+)/Scour(-) (tons)										
Sand		-0.7	-6.8	-7.3	-19.3	-8.7	9.4			-5.6
Silt		-6.6	-10.0	-2.8	-2.0	-4.8	-9.9			-6.0
Clay		-13.1	-17.8	-5.0	-5.7	-8.7	-16.5			-11.2
Total		-20.4	-34.6	-15.1	-27.0	-22.2	-17.0			-22.7
Outflow (tons)										
Sand		32.8	56.1	31.6	34.3	37.9	55.2	0.27	0.33	41.3
Silt		52.6	80.5	37.5	23.3	46.6	102.2	0.51	0.46	57.1
Clay		27.0	39.0	15.5	12.2	21.2	44.2	0.22	0.21	26.5
Total		112.4	175.6	84.6	69.7	105.7	201.6			124.9
Mainstem 3								Final	Average	Arithmetic
	Init Val	1995	1996	1997	1998	1999	2000	Fraction	Fraction	Average
Bed Depth (ft)	2.00	2.10	2.10	2.10	2.20	2.20	2.20			2.10
Bed Storage (tons)										
Sand	0.79	27,713.8	28,089.4	28,204.8	28,346.9	28,480.0	28,720.2	0.74	0.75	28,259.2
Silt	0.15	5,710.9	6,354.4	6,552.4	6,789.1	7,078.2	7,578.0	0.19	0.18	6,677.2
Clay	0.07	2,481.1	2,537.1	2,547.4	2,564.5	2,582.8	2,617.0	0.07	0.07	2,555.0
Total		35,905.8	36,981.0	37,304.6	37,700.6	38,141.1	38,915.2			37,491.4
Inflow (tons)										
Sand		182.5	332.6	125.4	156.1	144.5	263.5	0.04	0.04	200.8
Silt		3,723.3	3,973.5	2,013.7	2,039.7	2,691.8	3,552.2	0.55	0.54	2,999.0
Clay		3,141.7	3,265.6	1,355.1	1,521.2	1,939.8	2,651.9	0.41	0.42	2,312.6
Total		7,047.5	7,571.7	3,494.2	3,716.9	4,776.1	6,467.7			5,512.3
Dep(+)/Scour(-) (tons)										
Sand		164.8	300.0	116.0	142.4	133.3	240.1			182.8
Silt		480.4	627.7	198.1	236.6	289.1	499.6			388.6
Clay		40.0	49.2	10.2	17.3	18.3	34.2			28.2
Total		685.2	976.9	324.4	396.3	440.7	773.9			599.6
Outflow (tons)										
Sand		17.7	32.6	9.3	13.7	11.2	23.4	0.00	0.00	18.0
Silt		3,244.6	3,345.3	1,816.1	1,803.0	2,402.7	3,052.6	0.54	0.53	2,610.7
Clay		3,103.1	3,215.9	1,345.6	1,503.9	1,921.4	2,617.7	0.46	0.47	2,284.6
Total		6,365.4	6,593.8	3,171.1	3,320.6	4,335.3	5,693.8			4,913.3

Step 6: Compare Results with Available Data

The remaining step in the calibration procedure is to compare model simulations of concentrations and loads to available observed data. In many cases, this may be limited to event mean concentrations of total suspended solids (TSS) for selected storm events and nonstorm (baseflow) periods, or pollutographs of TSS concentrations throughout a few events. However, other types of comparisons are also possible, such as load estimates and sediment rating curves; each of these is discussed below.

Figure 5 shows an example of the conventional storm event comparison for TSS for the same small eastern US watershed. Clearly, such comparisons need to be made for as many storm events as there are available data. Figure 5 shows a very good simulation for both flow and TSS concentrations; most simulations will not be this good, and will show large variations from storm to storm. Even with this storm, there are inconsistencies demonstrated; the simulated flow peak is higher than the observed and precedes it, identifying a possible time lag in the peak that is not well represented in the model. In addition, the flow peak is about 25% higher than observed, whereas the TSS peak is only about 10% higher. Both of these differences may be entirely acceptable, considering the uncertainty in the observations and needed accuracy of the model, but model results need to be viewed with a critical eye toward demanding consistent behavior, i.e. if flows are over-simulated, TSS should be over-simulated, and vise-versa.

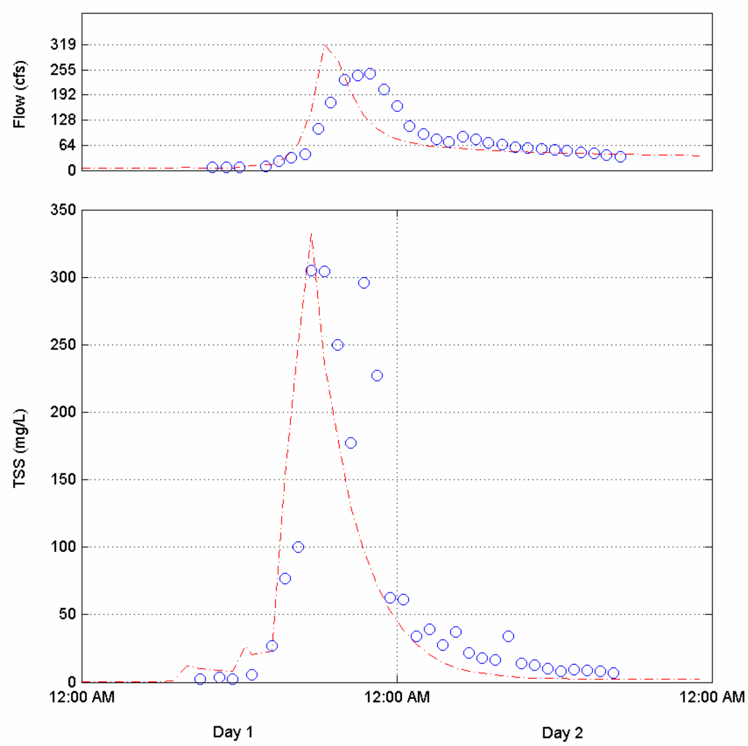

Figure 5 - Example comparison of simulated and observed storm flow and TSS concentrations

Figure 6 shows an annual plot of simulated and estimated sediment loads for the watershed outlet. In this case the 'Load Estimates' were extrapolations from available TSS data, and were **not** the results of continuous, or even daily sampling. So this comparison is really between two models: a simulation model (HSPF) and a regression model. However, even this type of comparison is useful, recognizing that differences do not necessarily detract from the validity or utility of the simulation model. This is simply one additional type of comparison that can be included in the weight-of-evidence approach to sediment calibration. The average annual values in Figure 6 indicate a very good simulation even though there are significant differences year to year. For sediment modeling these types of differences are to be expected, since, as noted earlier, sediment is one of the most difficult water quality constituents to model accurately.

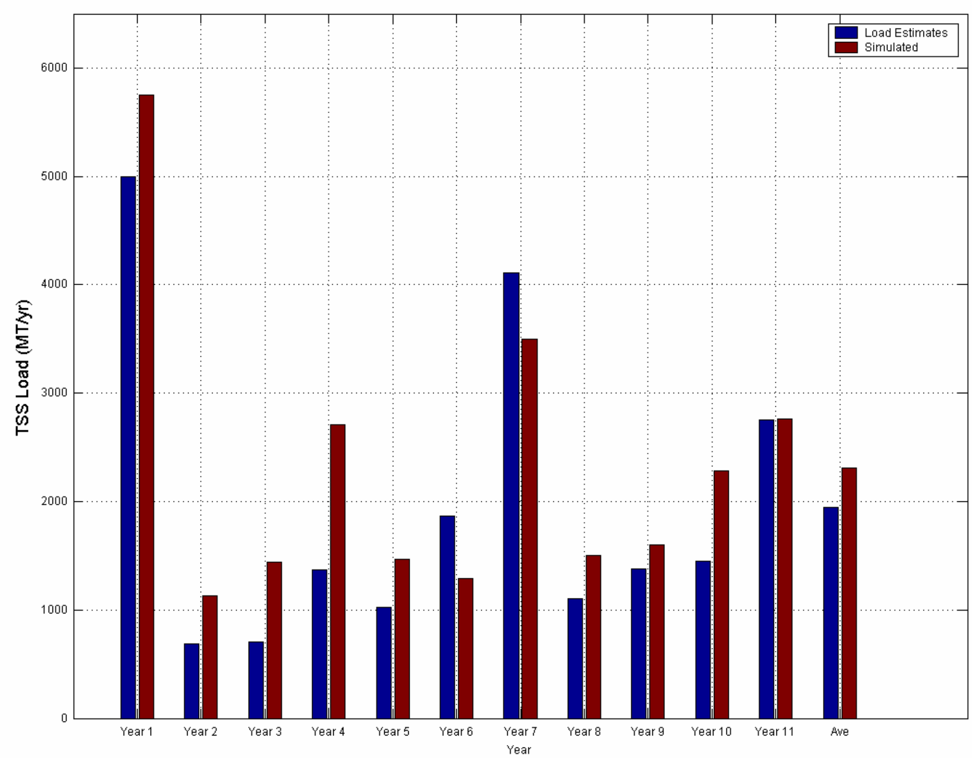

Figure 6 – Example comparison of simulated and estimated annual TSS loads

Figure 7 shows an example of comparing sediment rating curves, simulated and observed, for a single site at the watershed outlet. These curves essentially demonstrate the relationship between flow rate and sediment concentrations, and the concept in this comparison is to evaluate whether the model and the data demonstrate similar relationships. The top curve shows the flow versus load relationship, corresponding to the bottom curve of sediment concentration versus flow. Regression lines have been fitted to both the data and model results, and are shown on the curves. The log scale is used, as is typical for, and usually required for sediment rating analyses.

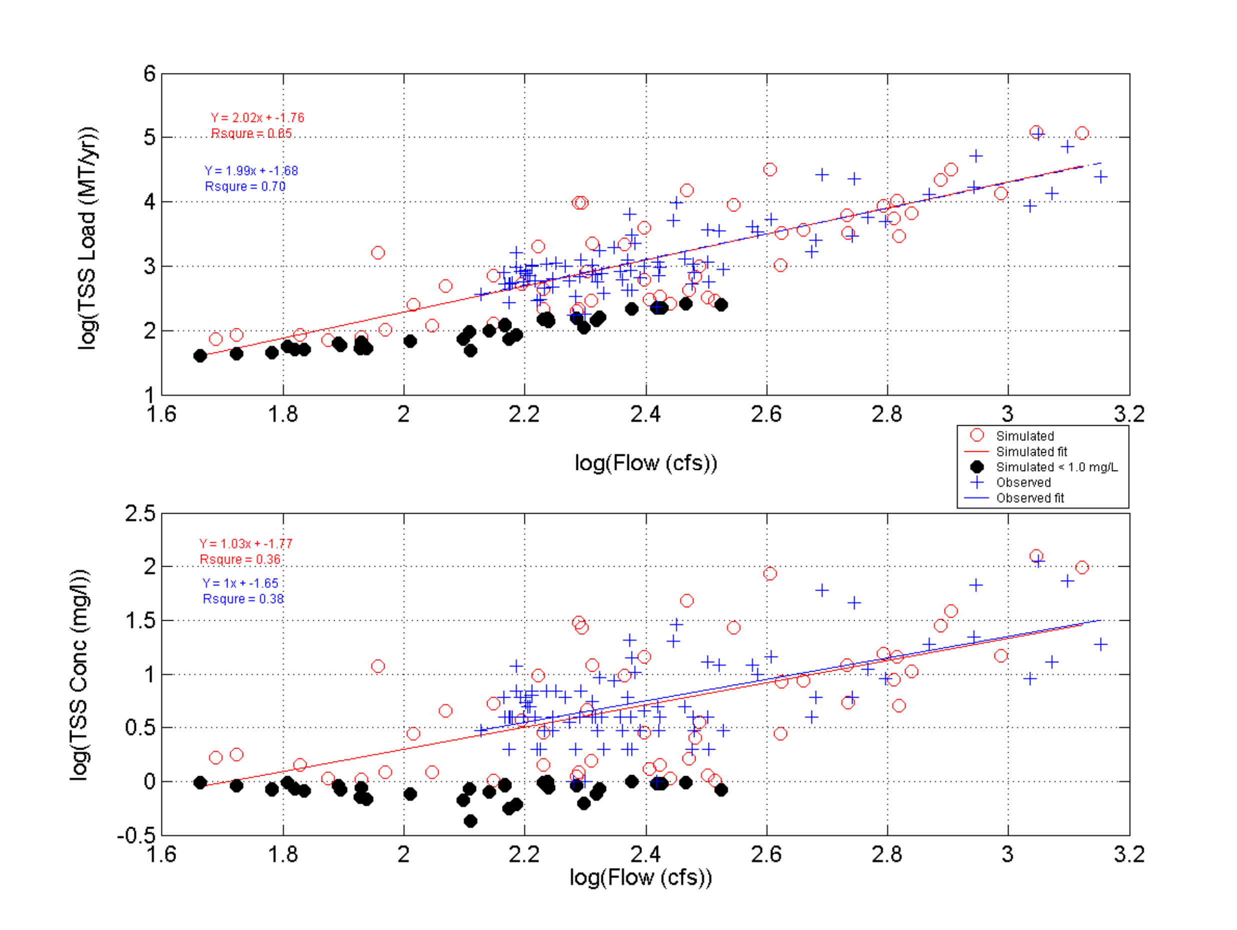

Figure 7 – Example of observed and simulated sediment rating curves

It should be noted that the regression curves are fitted to a subset of the observed and simulated values; the **solid dots were excluded from the analyses**, corresponding to TSS concentration values less than 1.0 mg/l. The rationale for this was as follows:

- The observations were performed primarily at moderate to high flow conditions, so very low concentrations would not be well represented.
- The HSPF model employs a relatively gross channel representation, with long reach lengths, that tends to eliminate localized turbulence and scour conditions that would likely contribute to under-simulating the low concentrations.
- The extremely low concentrations contribute to a small fraction of the total annual sediment load, approximately less than 3 to 5 percent of the annual load in this watershed.

The overall results in Figure 7 show a relatively good simulation of the flow-sediment relationship demonstrated in the sediment rating curves. Both the range of concentration and flow values, and the slopes of the regression lines, demonstrate consistency between the model and the observed data. If large consistent differences existed, it would justify continued calibration efforts to minimize such differences.

Step 7: Repeat Calibration Steps, as Needed, To Improve Sediment Representation

Modeling tends to be a circular, or iterative, process. For sediment calibration, Steps 3 through 6 often need to be repeated until all the components of the calibration exercise are in reasonable balance. In some cases, the process may need to reconsider the target loading rates developed in Step 1, and then re-calibrate the model rates. This might occur if the surface loadings appear to dominate unrealistically the overall watershed simulation results.

The iteration process doesn't require that every comparison be brought to the same level of agreement, but only that the entire process be repeated until the entire 'weight-of-evidence' from the simulations indicates either that the model is 'as good as it can be' or that it can not meet the specific needs of the watershed assessment. This should produce sufficient evidence that the model is either acceptable for the intended purpose, a recommendation that the model or data input improvements may be needed, or that a different model should be considered.

CLOSURE

This paper explores the 'weight of evidence' approach for sediment calibration as part of overall watershed model calibration based on recent experience with the U. S. EPA HSPF. The steps in the overall sediment calibration process are identified and discussed, along with specific issues related to model parameterization and calibration procedures. Using example applications and sample model results, we demonstrate recommended graphical and statistical procedures used to assess model performance for sediment loadings, concentrations, and budgets within a watershed modeling framework. Although the results are specific to the EPA HSPF model, the approach and procedures for sediment calibration are applicable to other watershed models that represent sediment processes and behavior at the watershed scale. Although sediment calibration remains one of the most difficult components of watershed-scale water quality assessments, it is hoped that the procedures outlined herein will provide some guidance and assistance to model users who attempt this often daunting task.

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