SECTION 9. SEDIMENT SIMULATION

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9.1 Introduction to the Sediment Simulation

Sediment is a concern in the Chesapeake Bay watershed because of its detrimental effects on water clarity and its impact on riverine habitats, impaired drinking water quality, reduced reservoir storage, and impairments to flood control measures. An accurate simulation of sediment processes and behavior contributes to development of sound sediment load reduction strategies and providing a basis for sediment transport of phosphorus and other sediment-bound constituents.

The HSPF model code simulates sediment transport as separate processes on the land and in the river. Corresponding to the model structure, the Phase 5.3 Model sediment simulation is described here in three parts: (1) land calibration of the edge-of-field (EoF) loads, (2) calculation of the transport of sediment from the EoF to the edge-of-river, and (3) river calibration to monitoring stations (Figure 9.1). Factors adjust the EoF load for land area and any best management practices (BMPs) applied to the land. Combined, the three components simulate sediment sources, delivery, and transport in the watershed (Figure 9.1).

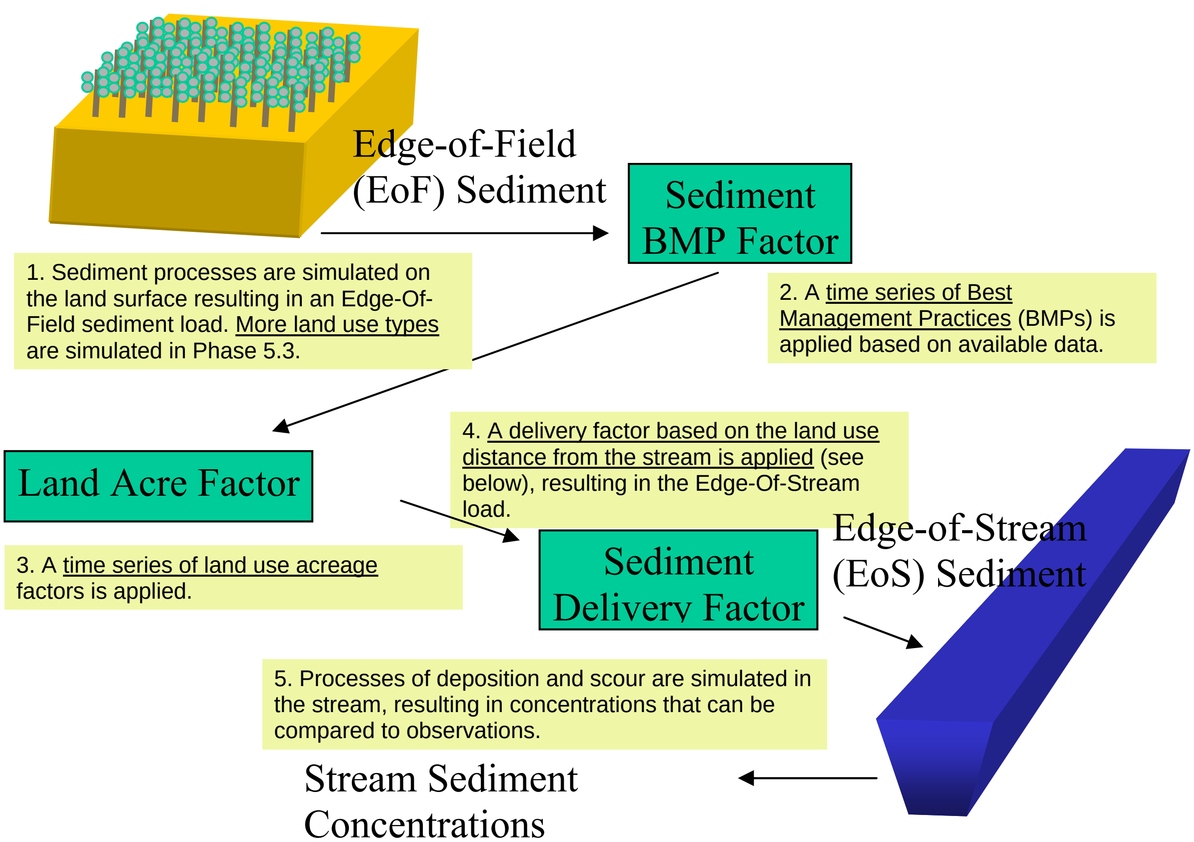


Figure 9-1. Phase 5.3 Model sediment simulation components.

9.1.1 Overview of Edge-of-Field Erosion

The Phase 5.3 Watershed Model simulates erosion from the land surface and the transport of sediment in river reaches. It is important to distinguish the different phases of erosion and sediment transport and the calibration methods associated with them. Precipitation and surface runoff cause sediment to erode from the land surface. The sediment loss from a field is the edge-of-field (EoF) load.

The EoF expected annual erosion rate estimates, also called *target loads*, are based on assessments such as the National Resources Inventory (NRI) database, Natural Resource Conservation Service's (NRCS's) Universal Soil Loss Equation (USLE) or the more recent Revised Universal Soil Loss Equation (RUSLE), observed data, or literature values. Calibration of sediment starts with matching the simulated EoF sediment loads with the target loads. The target loads are represented in units of tons/acre-year (ton/ac-yr).

9.1.2 Overview of Edge-of-Field to Edge-of-Stream Transport

A portion of EoF sediment load is delivered to the stream or river. The remaining eroded sediment is stored on fields downslope, at the foot of hillsides, or in smaller rivers or streams that are unrepresented in the model. The ratio of the sediment load at the EoS to the EoF load generated in the watershed is the sediment delivery ratio or sediment delivery factor (SDF). The edge-of-stream (EoS) load is the load delivered to the represented river or stream from the land segments. The EoS sediment load can, therefore, be represented as the product of the EoF load and the SDF. The SDF for each land use in a river segment is determined by the average distance that land use is away from the main river simulated in the river reach.

9.1.3 Overview of Riverine Transport

Additional processes come into play in the Phase 5.3 simulated river reaches. Sediment can be deposited in a reach, or additional sediment can be scoured from the bed, banks, or other sources of stored sediment throughout the watershed segment. The load delivered at the reach outlet can be represented by the following components:

Equation 1. $$\text{Load at Reach Outlet} = EoF \times SDF + (Scour - Deposition)$$

where

EoF = edge-of-field load (lbs/ac-yr)
SDF = edge-of-field load to edge-of-stream load sediment delivery factor
Scour = scour of sediment throughout the watershed segment because of high flow
Deposition = deposition sediment in the watershed segment because of low flow

In Equation 1, the *EoF* load is the end result of the land processes simulation using HSPF's PERLND and IMPLND modules. The second term, the *SDF*, is a function of the distance the average land use is from the river reach simulated, and the net scour or net deposition terms are simulated in the stream network with the RCHRES module.

The calibration procedure described in *Sediment Parameter and Calibration Guidance for HSPF* (USEPA 2006) is used in Phase 5.3 Model. The simulation of erosion and sediment transport is calibrated as follows:

1. Sediment loads for each land use in the form of estimated EoF load targets are determined on the basis of National Resources Inventory (NRI) estimates or by literature survey.
2. All land uses in each land-segment are calibrated to the estimated EoF load targets.
3. SDFs are calculated for each land use by their average distance from the simulated reach to adjust the EoF sediment load to the EoS sediment load.
4. The influence of BMPs in reducing EoS loads is calculated.
5. Reach processes are calibrated against monitoring data using user defined parameters of scour, deposition and erodibility.

The steps are explained below in detail.

9.2 Sediment Loads by Land Use

The first step in the sediment calibration for each land use is to calibrate the simulated loads to the expected annual average EoF erosion rates. The expected annual average EoF sediment load rates are provided for crop, pasture, hay, and forest by the NRI (Nusser and Goebel 1997; NRI 2007), which are EoF annual average erosion rates estimated from USLE or the RUSLE, as described below. Urban loads are estimated from a regression on the basis of sediment export studies. Other land uses use literature values of expected EoF sediment load rates.

Table 9-1 lists the different land uses and estimated EoF sediment loads. The estimated loads in that table are base loads and are reduced by the application of state reported levels of BMPs as described in Section 6.

Table 9-1. Overall estimated sediment erosion rate targets for different land uses

Land use	EoF sediment loading rate (ton/ac-yr)	Source
Conventional Tillage Crop	*5.8*	adjusted NRI average (1982-1987)
Conservation Tillage Crop	*3.9*	adjusted NRI average (1982-1987)
Hay	1.5	adjusted NRI average (1982-1987)
Pasture	1.6	NRI average (1982-1987)
Degraded Riparian Pasture	14.4	NRI pasture average (1982-1987) × 9
Developed – Pervious (0%)	NA	NA
Developed – Impervious (100%)	NA	NA
Industrial (90%I)	4.7	regression
Commercial (80%I)	4.3	regression
Highway (50%I)	3.0	regression
High Density Res. (35%I)	2.3	regression
Med Density Res. (25%I)	1.8	regression
Low Density Res. (15%I)	1.4	regression
Park/Recreational Area (2%I)	0.8	regression
Bare-Construction (no BMP)	24.0	literature values
Bare-Construction (with E&S)	12.0	literature values

Forest-Woodlots-Wooded areas	0.3	NRI (1987)
Harvested Forest	3.0	literature values
Natural Grass	1.5	NRI average (1982-1997)
Extractive (uncontrolled)	10.0	literature values/best professional judgment
Extractive (controlled)	0.2	calculated from active mine effluent limits
Water	0.005	literature values

9.2.1 Crop Land—Conventional Tillage, Conventional Tillage with Manure Application, and Conservation Tillage with Manure Applications

The Phase 5.3 simulation has two cropland tillage types—conventional and conservation tillage—which are used to represent a wide range of tillage practices. Cropland erosion, or EoF sediment loading rates, are estimated by using the average NRI county estimates for the years of 1982 and 1987 (Nusser and Goebel 1997; NRI 2007.

Crop EoF sediment loading rates vary over the available NRI sampling periods of 1982, 1987, 1992, and 1997 and trend toward lower estimated erosion rates in more recent sampling periods. That could be because of an increased rate of BMP application, newer, more efficient BMP approaches such as integrated farm plans, other agricultural factors such as changing management practices or crop type, or it could simply be sampling differences. The downward trend is also seen nationally in other river basins and is attributed to improved conservation measures (Figure 9.2.1). For the Phase 5.3 EoF erosion target for crops, the average of the NRI estimated erosion rates for cropland for the NRI assessment years of 1982 and 1987 are used.

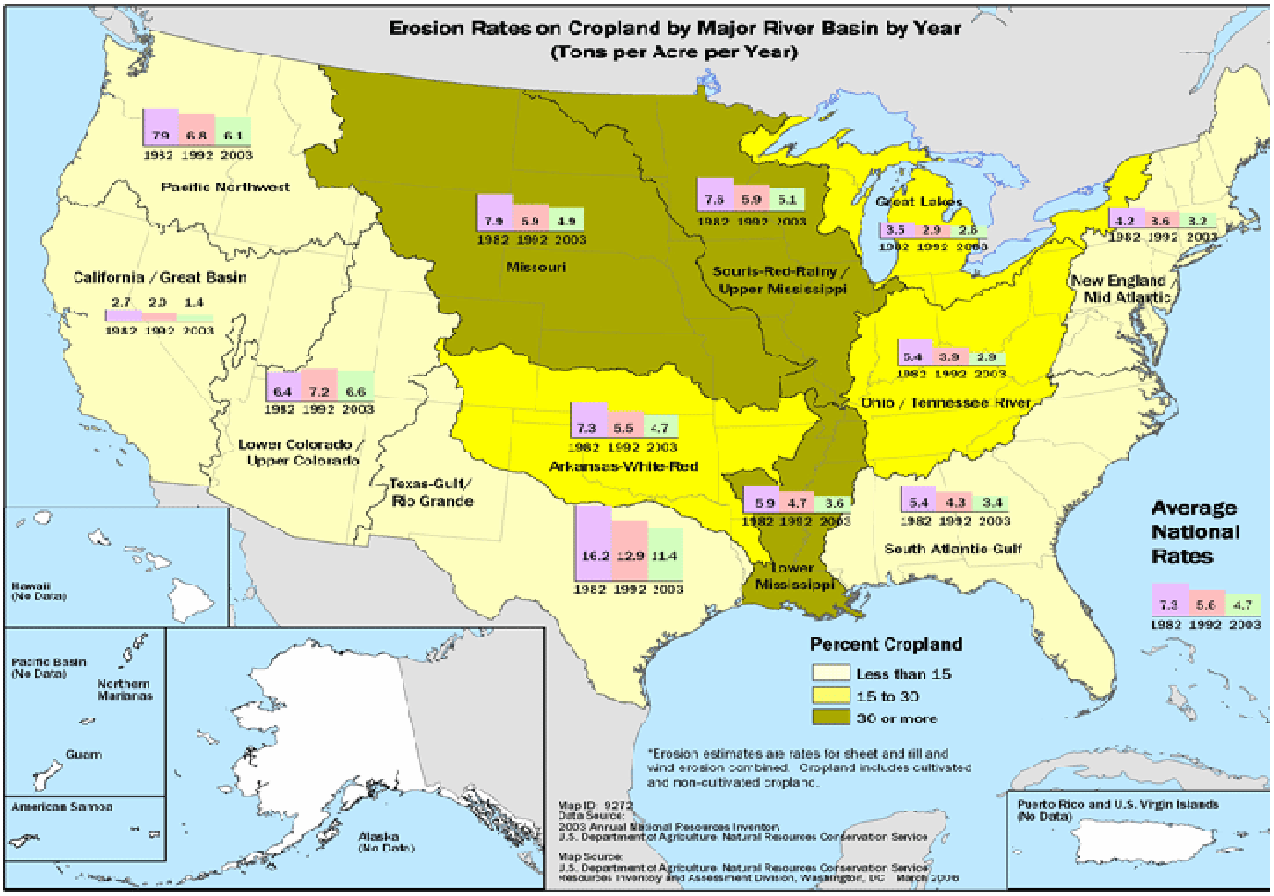


Figure 9-2. National trends in erosion rates.

The downward trend in the NRI data of estimated erosion rates from 1982, 1987, 1992, and 1997 is assumed to be because of general improvements in management practices, a trend that would cause double-counting if the reduction is represented first by the full 1982–1997 average of the NRI data and then by applying load reductions by sediment BMPs. To avoid potential double-counting of BMP reductions in sediment loads, and for operational simplicity, a 2-year (1982-1987) NRI estimate was used for each crop land use. Overall, the 2-year average was thought to best represent the Phase 5.3 simulation approach of using a base rate of sediment EoF loading rates and subsequently modifying the loading rates by applying BMPs as reported in state BMP implementation databases.

Differences between tillage practices are unavailable from the NRI database. Consequently, the overall crop EoF sediment load estimates from NRI are adjusted for conventional tillage practices, conservation tillage practices, and hay land. Conservation tillage is broadly defined as cropland management practices that provide for 30 percent land surface cover at the time of planting. Tillage practices that provide at least 30 percent cover at the time of planting vary widely (Angle et al. 1984; Angle 1985; Camacho 1990; Langdale et al. 1985; SCS 1988; Staver et al. 1988). Some conservation tillage practices that result in minimum soil disturbance and leave high crop residue cover, such as no-till practices, have high sediment reduction efficiencies on the order or 80 to 90 percent. Other conservation tillage practices disturb soils to a greater extent and leave less crop residue cover, resulting in lower efficiencies of around 40 percent. The CBP conservatively assumes that sediment erosion reduction efficiencies of conventional tillage compared with conservation tillage of whatever means that leaves 30 percent crop residue cover at the time of planting, provides a sediment reduction efficiency of 50 percent compared to conventional tillage practices. Other sediment BMPs, applied with conservation tillage would reduce sediment loads further.

The NRI crop EoF sediment load estimates represent an aggregate of all tillage practices. Because CBP is using the average of the 1982 and 1987 NRI data, and conservation tillage practices are about half of total cropland tillage practices during the period, and CBP is assuming a difference between conventional and conservation sediment EoF load rates of about 50 percent, the EoF sediment loading rates for conventional cropland are set at 125 percent of the NRI crop estimates, and rates for conservation cropland are set at 75 percent of the NRI estimates.

Plow Actions, Field Operations, and Detached Sediment (DETS)

Plow dates for each crop were set at the 15th of the month before the first month of the year in which canopy cover is greater than zero. The total amount of detached sediment (DETS) added per year for each crop was taken from the previous Phase 4.3 model application. All conventional tilled crops received a total of 5.5 ton/ac-yr of DETS and conservation tilled crops received a total of 2 ton/ac-yr DETS. Because composite crops are made up of many crops that are plowed at different times of the year, the total DETS in each composite crop were distributed proportionally to the percent composition of each constituent crop and assigned the plow date of that crop. Tables 9-2 and 9-3 show the DETS from conventional tilled crops and DETS from conservation tilled crops, respectively.

Table 9-2. High till without manure DETS

Land-segment	15-Feb	15-Mar	15-Apr
A10001	0.0	0.8	4.7
A10003	0.0	2.9	2.6
A10005	0.0	0.0	5.5
A11001	0.0	0.0	0.0
A24001	0.0	5.5	0.0
A24003	0.2	4.5	0.9
A24005	0.1	5.4	0.0
A24009	0.7	3.2	1.6
A24011	0.3	5.2	0.0
A24013	0.0	5.5	0.0
A24015	2.8	2.4	0.4
A24017	0.2	3.2	2.1
A24019	0.9	4.6	0.0
A24021	0.6	4.9	0.0
A24023	0.0	5.5	0.0
A24025	0.1	5.4	0.0
A24027	0.2	5.3	0.0
A24029	0.6	4.9	0.0

A24031	0.0	5.5	0.0
A24033	0.1	4.9	0.4
A24035	0.0	5.5	0.0
A24037	0.1	2.5	2.9
A24039	0.0	5.5	0.0
A24041	0.0	5.5	0.0
A24043	0.1	5.4	0.0
A24045	0.1	5.4	0.0
A24047	4.6	0.8	0.1
A24510	0.0	0.0	0.0

Table 9-3. Low till with manure DETS

Land-segment	15-Mar	15-Apr	15-Aug
A10001	1.6	0.0	0.4
A10003	1.6	0.0	0.4
A10005	1.7	0.0	0.3
A11001	0.0	0.0	0.0
A24001	1.6	0.0	0.4
A24003	1.7	0.0	0.3
A24005	0.0	1.8	0.2
A24009	1.6	0.0	0.4
A24011	1.5	0.0	0.5
A24013	0.0	1.7	0.3
A24015	0.0	1.6	0.4
A24017	1.6	0.0	0.4
A24019	1.6	0.0	0.4
A24021	0.0	1.6	0.4
A24023	1.6	0.0	0.4
A24025	0.0	1.8	0.2
A24027	0.0	1.6	0.4
A24029	1.6	0.0	0.4
A24031	0.0	1.7	0.3
A24033	1.7	0.0	0.3
A24035	1.6	0.0	0.4
A24037	1.6	0.0	0.4
A24039	1.7	0.0	0.3
A24041	1.6	0.0	0.4
A24043	1.6	0.0	0.4
A24045	1.8	0.0	0.2
A24047	1.8	0.0	0.2
A24510	0.0	0.0	0.0

Cover

Cover is an important parameter in the Phase 5.3 sediment simulation. Cover represents both the living vegetative canopy and all ground covers such as leaf litter. The presence of cover, expressed as a percent of ground covered, prevents the initial soil erosion from rain drop detachment of soil particles from the soil matrix. The rain detached soil particles would then contribute to the pool of detached soil material available for washoff (DETS). Because DETS is decremented by a small portion at each time step as soil particles are reattached to the simulated soil matrix, a land use with 100 percent cover would erode little, if at all. In HSPF, the cover is set monthly but interpolated between user-defined monthly rates for each simulation day.

Monthly cover in Phase 5.3 is assumed to be the sum of monthly canopy cover from the Revised Universal Soil Loss Equation 2 (RUSLE2) (NRCS 2007) and the monthly residue cover. Table 9-4 lists the agricultural land use crop types and what crop is used from RUSLE2 to determine the monthly canopy cover. If a crop is not listed, it is because RUSLE2 has no equivalent crop, or because that crop is not applicable in this circumstance. Because the land use crop types often had many different breakouts in RUSLE2, the breakout that was closest to the Bay was chosen.

Table 9-4. Relationships among the Agricultural Census crop types and the RUSLE crop types

Agricultural land use crop type	RUSLE2's equivalent
Corn for Grain	corn, grain
Corn for Silage	corn, silage
Soybeans	soybean, southern 15–20 in rows
Small Grain	winter wheat S.E.
Cotton	cotton southern upland or cotton delta
Tobacco	flue-cured
Potatoes	Irish potatoes

Many different vegetables are included in the vegetables crop type; therefore, the largest vegetable by acre was used to decide what vegetable to pull from the RUSLE2 database for monthly canopy cover. Monthly canopy cover for sweet potatoes, sorghum, and dry edible beans were not available. For those crops, sweet potatoes were included with potatoes, sorghum with corn, and dry edible beans with soybeans. Monthly cover was unavailable for counties in Tennessee or North Carolina. For those counties, the percent cover from the Virginia region closest to each county was used.

To calculate the true monthly cover, because RUSLE2 provides only the *canopy* cover, the crop residue cover was calculated and added to the RUSLE2 canopy cover numbers. To simulate variation found in actual agricultural settings, the estimated residue amounts varied by crop, tillage and climatic region. Baseline residue levels at planting and harvest were estimated for each crop and climatic region (Mark Dubin, University of Maryland, personal communication March 6, 2007). Residue decay rates were then used to interpolate changes in residue amounts between harvest and planting. In general, decay rates are assumed to be governed by temperature, therefore they are somewhat lower in colder regions. During January and February, the decay rate remains at a relatively steady value. The residue cover was added to the RUSLE2 monthly *canopy* cover to determine the total monthly percent cover. Table 9.5 lists the monthly cover used for different land uses in one land segment. Full cover data is in the Phase 5.3 Data Library at http://ches.communitymodeling.org/models/CBPhase5/datalibrary/model-input.php.

Table 9-5. Phase 5.3 Model estimates of crop cover used in the calibration for land segment A10001

	Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
A10001	trp	0.41	0.41	0.45	0.58	0.67	0.77	0.71	0.74	0.75	0.56	0.64	0.55
A10001	nhy	0.35	0.35	0.38	0.49	0.57	0.71	0.71	0.73	0.65	0.39	0.49	0.41
A10001	hwm	0.47	0.47	0.46	0.32	0.24	0.60	0.92	0.99	0.80	0.57	0.51	0.46
A10001	nal	0.21	0.20	0.18	0.26	0.41	0.67	0.56	0.59	0.67	0.29	0.26	0.24
A10001	puh	0.34	0.34	0.39	0.51	0.59	0.72	0.65	0.68	0.68	0.44	0.53	0.42
A10001	hom	0.19	0.18	0.17	0.16	0.26	0.50	0.48	0.44	0.32	0.25	0.22	0.20
A10001	pas	0.41	0.41	0.45	0.58	0.67	0.77	0.71	0.74	0.75	0.56	0.64	0.55
A10001	hyw	0.35	0.35	0.38	0.49	0.57	0.71	0.71	0.73	0.65	0.39	0.49	0.41
A10001	pul	0.34	0.34	0.39	0.51	0.59	0.72	0.65	0.68	0.68	0.44	0.53	0.42
A10001	urs	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
A10001	alf	0.21	0.20	0.18	0.26	0.41	0.67	0.56	0.59	0.67	0.29	0.26	0.24
A10001	nhi	0.47	0.47	0.46	0.32	0.24	0.60	0.92	0.99	0.80	0.57	0.51	0.46
A10001	nho	0.19	0.18	0.17	0.16	0.26	0.50	0.48	0.44	0.32	0.25	0.22	0.20
A10001	hyo	0.35	0.35	0.39	0.48	0.56	0.70	0.67	0.70	0.67	0.44	0.53	0.42
A10001	lwm	0.61	0.60	0.58	0.57	0.53	0.67	0.97	1.04	0.90	0.71	0.65	0.62
A10001	npa	0.41	0.41	0.45	0.58	0.67	0.77	0.71	0.74	0.75	0.56	0.64	0.55
A10001	nlo	0.61	0.60	0.58	0.57	0.53	0.67	0.97	1.04	0.90	0.71	0.65	0.62

Note: trp = degraded riparian pasture, nhy = nutrient management hay, hwm = high till with manure, nal = nutrient management alfalfa, puh = high intensity developed pervious, hom = high till without manure, pas = pasture, hyw = hay with nutrients, pul = low intensity developed pervious, urs = nursery, alf = alfalfa, nhi = nutrient management high till with manure, nho = nutrient management high till without manure, hyo = hay without nutrients, lwm = low till with manure, npa = nutrient management pasture, nlo = nutrient management low till.

Phase 5.3 land uses include composite crops. For those crops, the percent cover for each month is calculated as an area-weighted average of the percent cover for each of the individual constituent crops. Similarly, the residue is an area-weighted residue cover for each crop. The following formula was used to create this acreage-weighting (where *n* = the number of crops on a given land use, *r* = residue fraction of crop *i*, *c* = canopy fraction of crop *i*, and *a* = the area of crop *i*):

$$C = \frac{\sum_{i=1}^{n} (r^i + c^i) \cdot a^i}{\sum_{i=1}^{n} a^i}$$

For the years 1990 and 2000, percent cover was calculated as a linear interpolation of 1982, 1987, 1992, and 1997. Tables 9-6, 9-7, and 9-8 show the average percent cover in each state for crop land uses. Full percent cover data are at ftp://ftp.chesapeakebay.net/Modeling/phase5/Phase%205.3%20Calibration/Model%20Input/.

Through consultation with the Nutrient Subcommittee, the monthly cover for berries was determined. Because berries usually have either an artificial or hay ground cover, the monthly cover was assumed to be 95 percent for each month. Berries are part of the *conventional tillage without manure* composite crop, and the cover for this land use is adjusted by area weighting of the different crop types.

Table 9-6. Average percent cover for conventional tillage without manure

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
DE	0.18	0.18	0.17	0.18	0.28	0.47	0.44	0.40	0.29	0.23	0.21	0.19
MD	0.44	0.44	0.30	0.22	0.28	0.47	0.63	0.64	0.60	0.53	0.51	0.47
NY	0.37	0.38	0.35	0.29	0.25	0.40	0.58	0.54	0.52	0.43	0.39	0.38
PA	0.40	0.39	0.35	0.30	0.33	0.44	0.63	0.67	0.62	0.52	0.48	0.43
VA	0.43	0.42	0.30	0.24	0.32	0.49	0.67	0.68	0.61	0.56	0.55	0.47
WV	0.42	0.41	0.38	0.36	0.42	0.48	0.64	0.73	0.66	0.58	0.54	0.46

Table 9-7. Average percent cover for conventional tillage receiving manure

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
DE	0.49	0.49	0.48	0.29	0.20	0.59	0.91	0.98	0.81	0.59	0.53	0.48
MD	0.54	0.54	0.53	0.28	0.15	0.54	0.90	0.95	0.82	0.62	0.57	0.53
NY	0.47	0.48	0.48	0.38	0.07	0.21	0.71	0.92	0.72	0.51	0.48	0.47
PA	0.53	0.53	0.53	0.31	0.11	0.40	0.82	0.91	0.77	0.57	0.54	0.52
VA	0.54	0.51	0.46	0.16	0.20	0.54	0.87	0.85	0.70	0.59	0.55	0.51
WV	0.46	0.46	0.46	0.18	0.10	0.45	0.87	0.92	0.74	0.49	0.47	0.45

Table 9-8. Average percent cover for conservation tillage receiving manure

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
DE	0.61	0.60	0.58	0.57	0.52	0.64	0.95	1.03	0.89	0.70	0.65	0.62
MD	0.64	0.63	0.62	0.61	0.58	0.63	0.92	0.99	0.88	0.71	0.67	0.65
NY	0.56	0.56	0.55	0.55	0.53	0.49	0.64	0.92	0.77	0.59	0.57	0.56
PA	0.62	0.62	0.61	0.61	0.60	0.59	0.79	0.93	0.82	0.66	0.63	0.62
VA	0.63	0.64	0.64	0.64	0.58	0.57	0.80	0.95	0.77	0.68	0.65	0.64
WV	0.54	0.54	0.53	0.53	0.51	0.54	0.85	0.95	0.79	0.58	0.55	0.54

9.2.2 Hay Land—Alfalfa, Hay-Fertilized, and Hay-Unfertilized

Hay lands are generally in constant cover and vegetation and are not plowed from year to year. Hay lands do have some soil exposure and disturbance from what is often several mowing and harvesting operations during the year, as well as periodic planting. Hay land is undifferentiated from other crops in the NRI database. Tables 9-9 and 9-10 list the cover by state and month for alfalfa. Hay lands include *hay with nutrients, hay without nutrients, nutrient management hay, alfalfa, and nutrient management alfalfa*.

Table 9-9. Average percent cover for alfalfa

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
DE	0.21	0.20	0.18	0.26	0.41	0.67	0.56	0.59	0.67	0.29	0.26	0.24
MD	0.24	0.23	0.21	0.27	0.41	0.67	0.56	0.59	0.67	0.31	0.28	0.27
NY	0.41	0.40	0.39	0.39	0.62	0.49	0.48	0.50	0.55	0.31	0.36	0.39
PA	0.33	0.32	0.31	0.32	0.49	0.60	0.53	0.56	0.63	0.32	0.33	0.34
VA	0.22	0.21	0.20	0.44	0.55	0.64	0.57	0.56	0.56	0.31	0.28	0.25
WV	0.26	0.25	0.24	0.27	0.41	0.67	0.57	0.60	0.68	0.33	0.31	0.29

Table 9-10. Average percent cover for hay without nutrients

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
DE	0.35	0.35	0.38	0.47	0.54	0.69	0.68	0.71	0.66	0.44	0.52	0.41
MD	0.41	0.42	0.48	0.52	0.56	0.75	0.70	0.76	0.68	0.53	0.57	0.49
NY	0.51	0.51	0.55	0.61	0.77	0.56	0.57	0.59	0.61	0.58	0.77	0.60
PA	0.47	0.46	0.48	0.50	0.59	0.65	0.63	0.66	0.65	0.53	0.67	0.53
VA	0.55	0.58	0.70	0.76	0.79	0.96	0.89	0.99	0.78	0.75	0.62	0.61
WV	0.45	0.44	0.44	0.44	0.49	0.71	0.67	0.70	0.69	0.51	0.61	0.51

9.2.3 *Pasture*

For the *pasture* land use, the estimated NRI erosion rates by county are applied as tabulated in the *pasture* column of Table 9-14. Erosion rates are considered to be a function of stocking rates, pasture management, soils, geography, and other factors unique for each county. The EoF erosion target for *pasture* in each county segment is based on the average of the NRI estimated erosion rates for pasture for the NRI assessment years of 1982 and 1987. State average pasture cover by month is in Table 9-11.

Table 9-11. Average percent cover for pasture

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
DE	0.43	0.42	0.46	0.59	0.68	0.78	0.72	0.75	0.76	0.58	0.66	0.58
MD	0.47	0.47	0.53	0.60	0.65	0.77	0.70	0.73	0.71	0.58	0.64	0.55
NY	0.46	0.48	0.52	0.61	0.75	0.59	0.56	0.49	0.51	0.47	0.60	0.45
PA	0.45	0.46	0.49	0.54	0.64	0.66	0.61	0.58	0.60	0.48	0.59	0.46
VA	0.60	0.61	0.72	0.79	0.80	0.90	0.78	0.84	0.72	0.75	0.66	0.63
WV	0.35	0.35	0.38	0.51	0.54	0.65	0.58	0.60	0.63	0.46	0.54	0.42

9.2.4 *Degraded Riparian Pasture*

The *degraded riparian pasture* land use represents an unfenced riparian pasture area and stream that is degraded by livestock. The land use has high sediment loads and is treated by riparian buffer BMPs, primarily fencing. The sediment load target is set at 12 times the *pasture* target rate for each county segment because of larger areas of bare ground caused by beef and dairy livestock spending more time in riparian areas than in non-riparian pasture areas. Also, the higher sediment load target reflects in part the stream bank damage associated with livestock.

9.2.5 *Nutrient Management Pasture*

Nutrient management pasture is pasture that is part of a farm plan where crop nutrient management is practiced. Nutrient management pasture is pasture that receives manures that are excess on a farm after all crop nutrient needs are satisfied. *Nutrient management pasture* has the same sediment target rates as *pasture*.

9.2.6 Developed—Pervious and Impervious

The watershed model is constrained in the number of land uses it can represent. Two general land uses—pervious developed and impervious developed—are used to simulate all the developed land uses of residential, commercial, institutional, industrial, and others. The CBP uses the pervious and impervious land uses to represent the two classes of Phase 5.3 developed land, the *high-intensity developed** and the *low-intensity developed* land uses as described in Section 10.2.1.15.

The simulation is spatially refined by the use of imperviousness estimated on every land-river segment as described in Section 4. A percent imperviousness is determined for both the *high-intensity developed* and *low-intensity developed* land use at the land-river segment scale. The percent imperviousness provides an estimate of the mix of pervious and impervious area to be simulated on each Phase 5.3 land-river segment for both the *high-intensity developed* and *low-intensity developed* land uses.

For example, if a river-segment was estimated to have 100 acres of *low-intensity developed* land and the percent imperviousness was 10 percent, the 10 acres of impervious *low-intensity developed* land and 90 acres of *pervious low-intensity developed* land would be simulated. The same would be done for *high-intensity developed* land though typically with estimates of higher imperviousness.

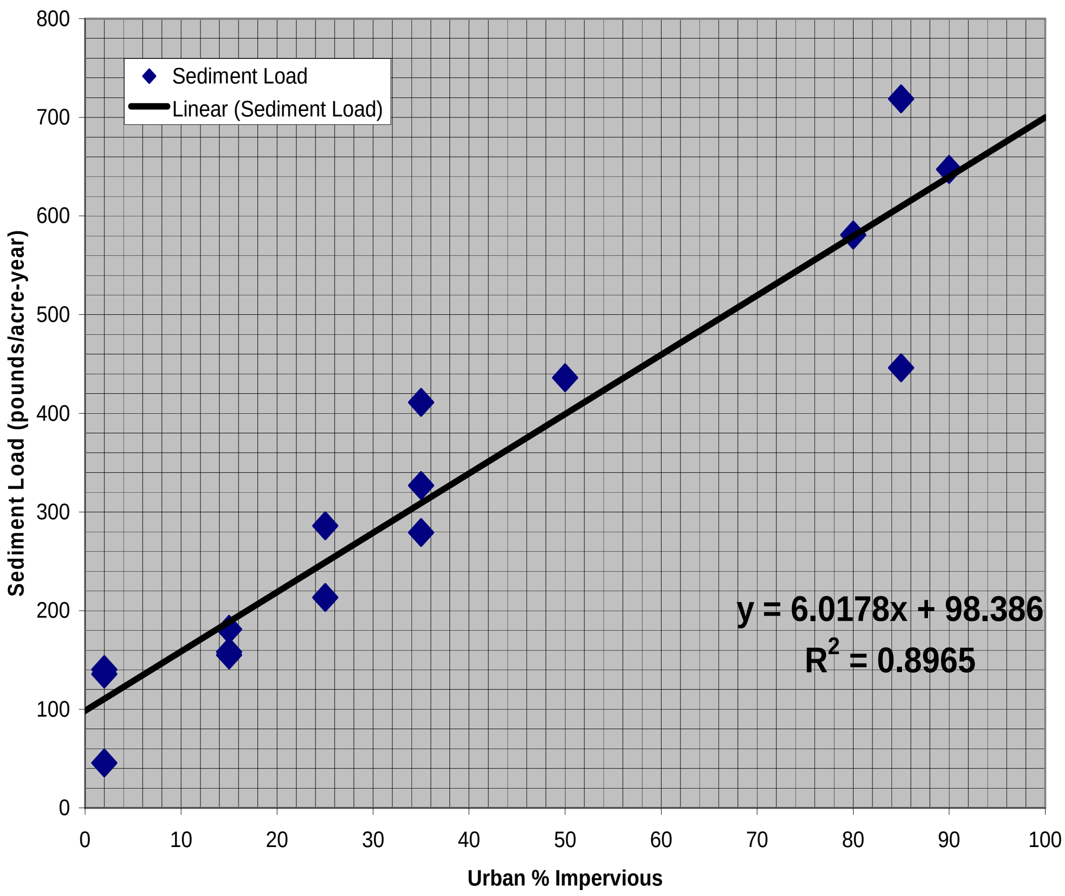
Using the pervious and impervious developed land uses, which are assumed to be at levels of zero percent and 100 percent impervious, respectively, the full range of sediment responses to the level of developed imperviousness is simulated and is reported as Phase 5.3 outputs of *low-intensity developed* and *high-intensity developed* land uses.

Erosion rates for developed lands are highly variable and, of all land uses, most likely to be augmented by sediment loads scoured from developed land waterways because of increased concentrated flow. Recent estimates of developed land erosion rates provide insight into the extent of imperviousness and the yield of sediment from developed areas (Langland and Cronin 2003; Shaver et al. 2007; Trimble 1997). At a watershed scale of measurement, Dreher and Price (1995) estimated post-development developed sediment loads for different land use categories. Also at a watershed scale, Langland and Cronin (2003) provided SWMM Model estimated sediment loads for different developed categories. Langland and Cronin (2003) point out that "for the watershed as a whole, approximately two-thirds of the sediment load was the result of channel erosion" because of the concentrated flow from impervious areas.

Combining that information and assigning a percent imperviousness to each of the developed land uses in the three studies (industrial = 90 percent, commercial = 80 percent, low-density residential = 15, medium-density residential = 25 percent, high-density residential = 35 percent, highway/arterial road = 50 percent, open land/developed park = 2 percent) one forms a relationship between the degree of imperviousness and an associated sediment load (Figure 9.2.6.1). Using that relationship one calibrates developed pervious and impervious land to the

* Note: Land uses that are simulated in Phase 5.3 are always in italics in this document.

values calculated at a level of 0 percent and 100 percent impervious respectively. Then, the estimated imperviousness of each land-river-segment is matched in area with appropriate combinations of pervious and impervious areas to calculate a unique sediment load for the level of imperviousness in each land-river-segment. The land use database has estimated imperviousness for each 30 m by 30 m pixel for the years 1990 and 2000. Interpolation and extrapolation of the two years provides a unique developed area with associated imperviousness for each year in the simulation.



Source: Langland and Cronin 2003

Figure 9-3. Relationship of sediment loads to degree of developed imperviousness.

There remains the question of scale. Phase 5.3 operates on the assumption that all sediment loads are EoF, and that transport and associated losses in overland flow and in low-order streams decrement the sediment load to an EoS input. To be consistent among all the land uses, the watershed scale of the Langland and Cronin (2003) estimates of sediment loads by different developed land uses must be placed in the same order of EoF scale as the other Phase 5.3 land uses. To do that, the estimated forest sediment loads provided in both studies are used. The average forest load estimates of these studies is 46 lbs/ac-yr, which represent the watershed scale delivered sediment load to an in-stream gaging station. That is compared to the NRI average Phase 5.3 forest load of 680 lbs/ac-yr at the EoF. To scale the watershed estimates to EoF estimates, a factor of 14.8 was used.

9.2.7 *Bare-Construction*

Bare-construction is considered to be a transitional land use as forest or agricultural land uses are converted to developed land. Land area estimates of the *bare-construction* land use are based on the assumption that the *bare-construction* area is equivalent to 2.5 times the annual change in imperviousness (as described in Section 4).

Guy and Furguson (1962) reported annual sediment yields of 39 to 78 ton/ac-yr from construction sites. The CBP estimates erosion rates to be between 7.2 to 500 ton/ac-yr on the basis of a number of sites (USEPA 2002). Included in the CBP assessment are Metropolitan Washington Council of Governments estimates of erosion rates of 35 to 45 tons/acre (MWCOG 1987). The CBP is inclined toward the middle values of the two studies reported in the Chesapeake watershed (Guy and Furguson 1962; MWCOG 1987) to represent the erosion rate for *bare-construction* areas, and use a rate of 40 ton/ac-yr specifically for the several-month period of mass grading, a period of construction where most of the construction site is bare disturbed soil.

The CBP assumes that five phases of construction are sequenced on this land use over the project duration. The sequence of construction phases include (1) clearing and grubbing for erosion and sediment (E&S) controls; (2) clearing and grubbing the remainder of the site; (3) mass grading with completion of construction of buildings, roads, and other impervious structures; (4) partial site stabilization and building; and (5) final grade and stabilization.

On the basis of information from Trickett (Trickett, R., Water Management Administration. 2006, March 24. Personal communication between Rick Trickett and Lee Curry (Maryland Department of Environment) as described in email from Lee Curry), it is assumed that the clearing and grubbing for E&S controls will be approximately 5 percent of the total project duration with 10 percent of the site exposed. Clearing and grubbing the remainder of the site will last approximately 5 percent of the project duration with 75 percent of the site exposed at any given time. The mass grading phase is assumed to be 25 percent of the project duration with 75 percent of the site exposed at any time. With most of the site as disturbed, there will be a higher sediment yield during the last two phases (2 and 3). From partial stabilization to project completion, there will be a decreasing amount of exposed area because of construction completion in various areas. It is assumed that partial stabilization will occur over 50 percent of the project duration with an average exposed area of 66 percent (two-thirds of the total site). The remaining 15 percent of the project duration will have an average exposed area of 34 percent (one-third of the total site).

During each of the construction phases, only a portion of the site is exposed and thus has the maximum erosion potential of 40 ton/ac-yr. To estimate an annual average construction site sediment yield, it is assumed the project duration is one year, and then the 40 ton/ac-yr is adjusted according to the portion of the site that is exposed or disturbed from grading at a specific time. The final calculation adds the sediment yield for each phase of site development, over the project duration, to approximate the average annual construction site yield. Combining the estimated portion of the ground disturbed and the estimated time of the disturbance gives us a rate of 24.4 ton/ac-yr for construction areas before implementation of E&S controls (Table 9-12).

Table 9-12. Table of estimated exposed areas, duration of construction phase activity, and estimated sediment EoF annual load for the bare-construction land use

Construction Phase	(A) Portion of Area Exposed	(B) Portion of Year for Phase	(C) Lit. Value tons/ac-yr	(D)=A*B*C Yield for Phase tons/ac-yr
Clearing & grubbing for E&S controls	10%	5%	40	0.2
Clearing & grubbing for remainder of site	75%	5%	40	1.5
Grade site to rough grade, inistall sewer, water, roads, etc	75%	25%	40	7.5
Partial stabilization	66%	50%	40	13.2
Project completion, final grade and stabilization	34%	15%	40	2.0
Total Annual Sediment Load				**24.4**

As described in Section 6, E&S control regulations, which were applied in different states at different times, have the effect of reducing the *bare-construction* erosion rate by an estimated 50 percent (Palace et al. 1998) after the erosion and stormwater regulations are fully adopted and implemented. Such a level of reduction by E&S controls is further supported by Schueler (2007) who reports that the median turbidity from construction sites in Maryland drops from about 450 nephelometric turbidity units (NTUs) (range 4 to 8,200) and to a little more than 200 NTUs when effective E&S controls are applied.

The language of the Stormwater Phase II Rule directs states to “develop, implement, and enforce a program to reduce pollutants in any storm water runoff to from construction activities that result in a land disturbance of greater than or equal to one acre.” E&S control legislation for construction activities were adopted by the states in the Phase 5.3 domain at different times between the early 1970s to the 1990s as described in Table 9-13. Estimated levels of effectiveness of the E&S controls as described in Table 9-13 for the different states are applied over the Phase 5.3 simulation period of 1985 to 2005.

Table 9-13. Dates of E&S control legislation in the states of the Phase 5 Model domain and estimates of relative effectiveness over time.

State	E & S law enacted	Regs adopted	Program Implementation	Recommended model decision rules for E&S BMP
DE	1973	Early 1970s and 1990 and various others	Although there were laws and regulations on the books from the early 1970s on, E&S plan review and enforcement were weak and scattered until 1991. In 1991 a functional, statewide program started. Personal communications with Randy Greer, Div of Soil and Water, DNREC (302) 739-4411, March 2005.	1973–6/91: 25% sediment reduction From 7/91 on: 50% sediment reduction
MD	1970	Early 1970s, early 1980s, mid-1990	Small, statewide enforcement of E&S from 1970 on. Beginning in 1985, E&S statewide program became fully functional. Personal communications with Jack Bowen, MDE (410) 537-3145, March 2005.	1970–3/84: 25% sediment reduction From 4/84: 50% sediment reduction
PA	1937 (Clean Streams Law)	1972, 1998, 2002	1972 regulations promulgated for all earth disturbances (ag, mining, construction, timber harvest, etc.). Beginning in 1984 program became stronger and more effective. Personal communications with Ken Murin, PA DEP (717) 772-5975, March 2005.	1972–1983: 25% sediment reduction From 1984: 50% sediment reduction
DC	1977	Various	Small, district-wide program until significant improvement in 1994. In 1998 the program drastically improved again. Personal communications with Colin Burrell, DC DOH (202) 535-2240, March 2005.	1977–1994: 25% sediment reduction From 1994: 50% sediment reduction
VA	1973	1977 and various	Small, less-effective program until delegated E&S to counties in 1980. Personal communications with Lee Hill VaDCR (804) 786-3998, March 2005.	1973–6/80: 25% sediment reduction From 7/80 on: 50% sediment reduction
WV	1991	1991	Late 1970s state agencies addressed sediment control through a non-point source program which operated on a complaint basis only. Phase I 1991, Phase II 2002. (Stated still operates mostly on a complaint basis.) Bill Brannon 304-926-0499 ext. 1003, contacted 3/14/05	1978–1991: 15% sediment reduction From 1991 on: 35% sediment reduction
NY	Early 1970s	Early 1970s, early/mid-1990	Before Phase I, E&S was more *reactive than proactive*. NPDES Phase 1 Permit issued August 1, 1993. Phase 2 Permit issued January 8, 2003. Peter Freehafer, (518) 402 –8272, contacted 3/14/05	1973–1993: 25% sediment reduction From 1993 on: 50% sediment reduction
KY	1990	1991	No E&S control program before NPDES Phase I for construction sites, though industrial sites with other permits (KPDES) had their stormwater examined…Phase I 1991, MS4 1992, Phase II 2003, Contact Jory Becker (502) 564-2225, ext 477, contacted 3/18/05.	From 1991 on: 50% sediment reduction

9.2.8 *Forest, Woodlots, and Wooded Areas*

The Phase 5.3 forest land use covers woodland, woodlots, which are usually any wooded area of 30 m by 30 m which were remotely sensed by spectral analysis. The *forest, woodlots, and wooded* land use is the predominate land use in the Chesapeake watershed.

Forest estimates of EoF erosion rates from the USLE were provided by NRI in 1990 for model segments of a previous version (Phase 2) of the Watershed Model (USEPA 1990) but were unavailable for the more recent Phase 5.3 model development. Consequently, the previous NRI forest EoF estimates of forest were used, transferring the values of the Phase 2 Model segments to the Phase 5.3 land segments with values as tabulated in the last column of Table 9-14. The average forest EoF sediment load for the entire Phase 5.3 domain is 0.3 tons/acre, a value consistent with average literature values of EoF sediment loads.

Because the Phase 2 Watershed Model had a domain of only the Chesapeake watershed, the Phase 5.3 expanded land areas in Virginia have no Phase 2 forest EoF erosion rates. For those areas, standard techniques for applying USLE in forest lands were applied and the USLE edge-of-field results were scaled to appropriately match the range of edge-of stream results estimated in Phase 5.3 in the rest of the Chesapeake Bay watershed.

Table 9-14. Conventional till, conservation till, pasture, hay, and forest EoF sediment loading rates derived from NRI estimates.

State	County	FIPS	Conventional Tillage Crop (tons/ac)	Conservation Tillage Crop (tons/ac)	Pasture (tons/ac)	Hay (tons/ac)	Forest (tons/ac)
Delaware	DE Kent	10001	3.27	1.96	0.20	0.84	0.14
	DE New Castle	10003	4.51	2.71	0.80	1.16	0.17
	DE Sussex	10005	1.26	0.75	0.03	0.32	0.13
Maryland	MD Allegany	24001	4.08	2.45	0.23	1.04	0.13
	MD Anne Arundel	24003	10.06	6.04	0.47	2.58	0.29
	MD Baltimore	24005	12.42	7.45	1.29	3.18	0.46
	MD Calvert	24009	22.15	13.29	1.15	5.67	0.30
	MD Caroline	24011	2.58	1.55	0.04	0.66	0.13
	MD Carroll	24013	4.09	2.45	0.85	1.05	0.34
	MD Cecil	24015	6.82	4.09	0.49	1.75	0.16
	MD Charles	24017	14.41	8.65	0.36	3.69	0.33
	MD Dorchester	24019	2.49	1.49	0.08	0.64	0.13
	MD Frederick	24021	9.59	5.76	1.48	2.46	0.21
	MD Garrett	24023	4.34	2.60	0.57	1.11	0.13
	MD Harford	24025	6.87	4.12	0.38	1.76	0.34
	MD Howard	24027	7.89	4.73	3.20	2.02	0.50
	MD Kent	24029	5.58	3.35	1.27	1.43	0.17
	MD Montgomery	24031	10.96	6.57	1.23	2.80	0.36
	MD Prince Georges	24033	22.28	13.37	2.99	5.70	0.34
	MD Queen Annes	24035	4.33	2.60	0.16	1.11	0.17
	MD St Marys	24037	7.83	4.70	0.28	2.00	0.33
	MD Somerset	24039	2.09	1.26	0.03	0.54	0.13
	MD Talbot	24041	2.17	1.30	0.03	0.56	0.13
	MD Washington	24043	6.24	3.74	1.28	1.60	0.31
	MD Wicomico	24045	2.80	1.68	0.16	0.72	0.13
	MD Worcester	24047	3.14	1.89	0.27	0.80	0.13

New York	NY Allegany	36003	2.63	1.58	0.98	0.67	0.27
	NY Broome	36007	2.56	1.54	0.17	0.66	0.27
	NY Chemung	36015	4.11	2.46	0.57	1.05	0.27
	NY Chenango	36017	4.46	2.68	0.38	1.14	0.27
	NY Cortland	36023	3.14	1.88	0.18	0.80	0.27
	NY Delaware	36025	3.44	2.06	0.41	0.88	0.27
	NY Herkimer	36043	5.62	3.37	0.31	1.44	0.27
	NY Livingston	36051	4.96	2.97	0.55	1.27	0.27
	NY Madison	36053	4.38	2.63	0.17	1.12	0.27
	NY Oneida	36065	4.01	2.40	0.22	1.03	0.27
	NY Onondaga	36067	3.54	2.13	0.08	0.91	0.27
	NY Ontario	36069	3.26	1.95	1.00	0.83	0.27
	NY Otsego	36077	4.05	2.43	2.32	1.04	0.27
	NY Schoharie	36095	3.90	2.34	0.35	1.00	0.27
	NY Schuyler	36097	1.97	1.18	0.42	0.50	0.27
	NY Steuben	36101	3.82	2.29	0.29	0.98	0.27
	NY Tioga	36107	1.99	1.20	0.55	0.51	0.27
	NY Tompkins	36109	2.18	1.31	0.11	0.56	0.27
	NY Yates	36123	4.02	2.41	0.46	1.03	0.27
North Carolina	NC Alamance	37001	18.66	11.19	0.17	4.78	0.19
	NC Alleghany	37005	8.71	5.23	0.85	2.23	0.38
	NC Ashe	37009	6.55	3.93	3.00	1.68	0.47
	NC Caswell	37033	9.09	5.45	0.18	2.33	0.20
	NC Forsyth	37067	17.71	10.63	1.80	4.53	0.20
	NC Granville	37077	12.88	7.73	1.67	3.30	0.16
	NC Guilford	37081	7.81	4.69	0.14	2.00	0.21
	NC Northampton	37131	5.14	3.08	0.07	1.32	0.14
	NC Orange	37135	7.94	4.76	0.24	2.03	0.21
	NC Person	37145	12.10	7.26	0.30	3.10	0.19
	NC Rockingham	37157	10.25	6.15	2.82	2.62	0.20
	NC Stokes	37169	24.47	14.68	0.33	6.27	0.23
	NC Surry	37171	13.91	8.34	0.39	3.56	0.27
	NC Vance	37181	11.54	6.92	0.57	2.95	0.18
	NC Warren	37185	14.89	8.93	1.68	3.81	0.22
	NC Watauga	37189	17.66	10.59	3.22	4.52	0.44
Pennsylvania	PA Adams	42001	5.61	3.36	0.17	1.44	0.27
	PA Bedford	42009	5.73	3.44	1.08	1.47	0.27
	PA Berks	42011	8.39	5.03	0.74	2.15	0.33
	PA Blair	42013	4.33	2.60	0.21	1.11	0.33
	PA Bradford	42015	5.76	3.46	0.23	1.48	0.31
	PA Cambria	42021	3.90	2.34	0.22	1.00	0.33
	PA Cameron	42023	3.90	2.34	0.29	1.00	0.33
	PA Carbon	42025	4.62	2.77	0.54	1.18	0.33
	PA Centre	42027	7.47	4.48	1.41	1.91	0.33
	PA Chester	42029	9.25	5.55	0.49	2.37	0.18
	PA Clearfield	42033	1.04	0.62	4.53	0.27	0.33
	PA Clinton	42035	3.50	2.10	0.65	0.90	0.33
	PA Columbia	42037	5.74	3.44	0.40	1.47	0.33
	PA Cumberland	42041	7.51	4.51	1.22	1.92	0.33
	PA Dauphin	42043	5.27	3.16	0.31	1.35	0.33
	PA Elk	42047	1.00	0.60	0.22	0.26	0.33
	PA Franklin	42055	7.82	4.69	0.74	2.00	0.33
	PA Fulton	42057	3.40	2.04	1.77	0.87	0.32

	PA Huntingdon	42061	7.19	4.32	0.55	1.84	0.33
	PA Indiana	42063	2.51	1.51	1.30	0.64	0.33
	PA Jefferson	42065	4.18	2.51	1.00	1.07	0.33
	PA Juniata	42067	6.17	3.07	0.36	1.58	0.33
	PA Lackawanna	42069	2.13	1.28	0.53	0.55	0.33
	PA Lancaster	42071	10.03	6.02	1.65	2.57	0.30
	PA Lebanon	42075	8.44	5.07	0.46	2.16	0.33
	PA Luzerne	42079	3.43	2.06	0.15	0.88	0.33
	PA Lycoming	42081	7.08	4.25	0.26	1.81	0.33
	PA McKean	42083	0.54	0.32	0.03	0.14	0.33
	PA Mifflin	42087	6.49	3.89	0.27	1.66	0.33
	PA Montour	42093	11.28	6.77	0.20	2.89	0.33
	PA Northumberland	42097	10.03	6.02	0.81	2.57	0.33
	PA Perry	42099	5.40	3.24	1.36	1.38	0.33
	PA Potter	42105	3.17	1.90	0.49	0.81	0.33
	PA Schuylkill	42107	6.91	4.14	0.54	1.77	0.33
	PA Snyder	42109	7.15	4.29	10.08	1.83	0.33
	PA Somerset	42111	3.72	2.23	1.21	0.95	0.17
	PA Sullivan	42113	1.65	0.99	0.91	0.42	0.33
	PA Susquehanna	42115	1.02	0.61	0.16	0.26	0.31
	PA Tioga	42117	4.29	2.58	0.60	1.10	0.30
	PA Union	42119	5.58	3.35	0.08	1.43	0.33
	PA Wayne	42127	0.66	0.40	0.12	0.17	0.30
	PA Wyoming	42131	5.25	3.15	0.18	1.34	0.33
	PA York	42133	11.29	6.78	0.31	2.89	0.30
	TN Johnson	47091	2.48	1.49	0.40	0.63	0.46
	TN Sullivan	47163	12.29	7.37	1.28	3.15	0.60
Virginia	VA Accomack	51001	2.22	1.33	0.04	0.57	0.13
	VA Albemarle	51003	1.04	0.63	2.85	0.27	0.25
	VA Alleghany	51005	0.09	0.06	1.54	0.02	0.35
	VA Amelia	51007	12.26	7.36	0.90	3.14	0.18
	VA Amherst	51009	3.12	1.87	3.45	0.80	0.26
	VA Appomattox	51011	5.03	3.02	1.83	1.29	0.25
	VA Augusta	51015	12.53	7.52	3.74	3.21	0.21
	VA Bath	51017	0.75	0.45	1.51	0.19	0.38
	A Bedford	51019	3.46	2.08	4.54	0.89	0.38
	VA Bland	51021	2.17	1.30	8.36	0.56	0.36
	A Botetourt	51023	8.46	5.08	6.85	2.17	0.33
	A Brunswick	51025	10.09	6.05	1.83	2.58	0.19
	VA Buchanan	51027	2.11	1.27	3.40	0.54	0.48
	A Buckingham	51029	3.78	2.27	1.97	0.97	0.22
	VA Campbell	51031	3.88	2.33	1.08	0.99	0.22
	VA Caroline	51033	4.92	2.95	0.09	1.26	0.17
	VA Carroll	51035	10.52	6.31	3.52	2.69	0.26
	VA Charles City	51036	4.39	2.63	0.19	1.12	0.15
	VA Charlotte	51037	5.35	3.21	1.33	1.37	0.20
	VA Chesterfield	51041	5.90	3.54	0.28	1.51	0.16
	VA Clarke	51043	2.15	1.29	0.67	0.55	0.23
	VA Craig	51045	3.80	2.28	1.95	0.97	0.32
	VA Culpeper	51047	8.95	5.37	1.71	2.29	0.20
	VA Cumberland	51049	3.58	2.15	1.03	0.92	0.18
	VA Dickenson	51051	8.67	5.20	3.85	2.22	0.40
	VA Dinwiddie	51053	12.57	7.54	1.29	3.22	0.16
	VA Essex	51057	6.23	3.74	0.22	1.59	0.18

	VA Fairfax	51059	5.28	3.17	1.32	1.35	0.20
	VA Fauquier	51061	4.78	2.87	0.73	1.22	0.21
	VA Floyd	51063	2.04	1.22	1.50	0.52	0.25
	VA Fluvanna	51065	2.54	1.52	0.66	0.65	0.21
	VA Franklin	51067	7.87	4.72	2.77	2.01	0.23
	VA Frederick	51069	4.20	2.52	0.88	1.07	0.24
	VA Giles	51071	0.11	0.07	0.48	0.03	0.36
	VA Gloucester	51073	4.61	2.77	0.18	1.18	0.18
	VA Goochland	51075	1.76	1.06	0.50	0.45	0.19
	VA Grayson	51077	3.67	2.20	3.22	0.94	0.26
	VA Greene	51079	4.77	2.86	1.24	1.22	0.21
	VA Greensville	51081	7.27	4.36	0.08	1.86	0.15
	VA Halifax	51083	8.84	5.30	1.62	2.26	0.20
	VA Hanover	51085	7.07	4.24	3.58	1.81	0.16
	VA Henrico	51087	6.40	3.84	0.24	1.64	0.14
	VA Henry	51089	9.57	5.74	2.04	2.45	0.25
	VA Highland	51091	0.42	0.25	5.50	0.11	0.34
	VA Isle of Wight	51093	6.07	3.64	0.05	1.55	0.14
	VA James City	51095	5.92	3.55	0.64	1.51	0.17
	VA King and Queen	51097	4.07	2.44	10.85	1.04	0.16
	VA King George	51099	2.45	1.47	1.68	0.63	0.18
	VA King William	51101	5.27	3.16	0.39	1.35	0.19
	VA Lancaster	51103	0.80	0.48	0.16	0.20	0.20
	VA Lee	51105	8.32	4.99	7.96	2.13	0.39
	VA Loudoun	51107	5.19	3.12	0.66	1.33	0.19
	VA Louisa	51109	4.49	2.70	0.27	1.15	0.18
	VA Lunenburg	51111	13.38	8.03	1.32	3.42	0.19
	VA Madison	51113	10.75	6.45	1.54	2.75	0.23
	VA Mathews	51115	2.03	1.22	0.07	0.52	0.14
	VA Mecklenburg	51117	13.33	8.00	1.23	3.41	0.2
	VA Middlesex	51119	6.14	3.68	0.09	1.57	0.18
	VA Montgomery	51121	8.46	5.07	7.07	2.16	0.34
	VA Nelson	51125	7.86	4.72	2.34	2.01	0.3
	VA New Kent	51127	5.11	3.07	2.34	1.31	0.19
	VA Northampton	51131	2.25	1.35	2.34	0.58	0.13
	VA Northumberland	51133	4.33	2.60	1.26	1.11	0.20
	VA Nottoway	51135	9.02	5.41	0.76	2.31	0.19
	VA Orange	51137	7.26	4.35	1.66	1.86	0.20
	VA Page	51139	7.61	4.57	0.89	1.95	0.30
	VA Patrick	51141	9.03	5.42	3.75	2.31	0.26
	VA Pittsylvania	51143	11.25	6.75	1.62	2.88	0.19
	VA Powhatan	51145	3.09	1.86	0.32	0.79	0.19
	VA Prince Edward	51147	4.53	2.72	0.97	1.16	0.19
	VA Prince George	51149	8.79	5.27	0.64	2.25	0.15
	VA Prince William	51153	3.58	2.15	0.34	0.92	0.18
	VA Pulaski	51155	2.83	1.70	2.14	0.73	0.35
	VA Rappahannock	51157	14.88	8.93	0.83	3.81	0.25
	VA Richmond	51159	0.92	0.55	3.73	0.24	0.16
	VA Roanoke	51161	7.06	4.24	3.13	1.81	0.60
	VA Rockbridge	51163	7.24	4.34	9.90	1.85	0.34
	VA Rockingham	51165	11.06	6.64	3.56	2.83	0.24
	VA Russell	51167	5.41	3.24	8.93	1.38	0.50
	VA Scott	51169	3.61	2.16	11.5	0.92	0.46

	VA Shenandoah	51171	8.19	4.91	3.20	2.10	0.27
	VA Smyth	51173	2.96	1.78	4.85	0.76	0.39
	VA Southampton	51175	5.40	3.24	0.38	1.38	0.14
	VA Spotsylvania	51177	5.52	3.31	0.89	1.41	0.17
	VA Stafford	51179	12.52	7.51	1.48	3.20	0.19
	VA Surry	51181	7.28	4.37	0.26	1.86	0.16
	VA Sussex	51183	7.31	4.39	0.09	1.87	0.14
	VA Tazewell	51185	5.58	3.35	10.24	1.43	0.45
	VA Warren	51187	7.52	4.51	1.31	1.92	0.47
	VA Washington	51191	8.18	4.91	8.09	2.09	0.44
	VA Westmoreland	51193	1.19	0.71	2.01	0.30	0.16
	VA Wise	51195	0.52	0.31	4.84	0.13	0.39
	VA Wythe	51197	3.37	2.02	2.38	0.86	0.34
	VA York	51199	3.73	2.24	2.38	0.95	0.15
	VA Chesapeake City	51550	2.57	1.54	0.02	0.66	0.13
	VA Falls Church City	51610	2.57	1.54	0.02	0.66	0.33
	VA Lynchburg City	51680	2.57	1.54	0.02	0.66	0.24
	VA Norfolk City	51710	2.57	1.54	0.02	0.66	0.14
	VA Portsmouth City	51740	2.57	1.54	0.02	0.66	0.14
	VA Richmond City	51760	2.57	1.54	0.02	0.66	0.16
	VA Suffolk City	51800	3.72	2.23	0.06	0.95	0.13
	VA Virginia Beach City	51810	2.34	1.40	0.09	0.60	0.13
West Virginia	WV Berkeley	54003	2.45	1.47	0.33	0.63	0.33
	WV Grant	54023	0.85	0.51	2.82	0.22	0.13
	WV Hampshire	54027	1.45	0.87	1.74	0.37	0.13
	WV Hardy	54031	1.86	1.12	1.87	0.48	0.15
	WV Jefferson	54037	2.21	1.33	0.28	0.57	0.40
	WV Mineral	54057	0.68	0.41	1.87	0.18	0.13
	WV Monroe	54063	8.44	5.06	6.44	2.16	0.60
	WV Morgan	54065	10.5	6.30	1.36	2.69	0.24
	WV Pendleton	54071	1.41	0.85	1.55	0.36	0.13
	WV Preston	54077	7.95	4.77	1.60	2.04	0.13
	WV Tucker	54093	0.14	0.08	2.25	0.03	0.13
Average			5.92	3.55	1.53	1.52	0.26
Standard Deviation			4.19	2.51	2.12	1.07	0.10
Maximum			24.47	14.68	11.50	6.27	0.60
Minimum			0.09	0.06	0.02	0.02	0.13

Sediment erosion EoF targets derived from NRI estimates.

9.2.9 *Harvested Forest*

Harvested forests have higher erosion rates because of silviculture activities such as road building and movement of heavy equipment on forest soils (Arthur et al. 1998; Riekerk et al. 1998; Wilson et al. 1999; Grace 2004; Hewlett, et al. 1979; Keppeler et al. 2003). In addition, harvesting decreases interception storage and evapotranspiration, which also increases runoff. As Riekerk et al. (1988) relate, “Logging entails the cutting and skidding of trees. Cutting is done with power saws or by mechanical shearing with a feller-buncher. The later operation exposes and compacts soil, allowing more overland flow with its attendant erosion. Tree removal with rubber-tired or tracked skidders is most common and tends to disturb the soil most."

Bare ground erosion rates of forest soils are typically estimated to be 3 to 4 orders of magnitude greater than that of base forest erosion rates. Current silviculture practice in the mid-Atlantic does not reduce forest soils to bare ground, but forest roads and harvest machinery bare some portion of harvested forest soils. The literature typically reports harvested forest erosion rates as being about an order of magnitude greater than undisturbed forest (Arthur et al. 1998; Riekerk et al. 1998; Perry 1998). Accordingly, the Phase 5.3 *harvested forest* EoS erosion target is set at 3 tons/acre-year.

9.2.10 *Extractive*—Active and Abandoned Mines

The *extractive* land use is composed of mines, gravel pits, and the like. Federal and state laws in the early 1980s regulated active working mines and applied effluent limits of about 70 milligrams per liter (mg/l) total suspended solids (TSS) to discharges from mines. Abandoned mines have, of course, no effluent limits. Consistent with the level of information available, extractive land south of the confluence of the West Branch and Susquehanna rivers is considered to be active mines with an effluent limit applied (Don Fiesta, personal communication, August 9, 2004). Assuming precipitation of 40 inches/year, annual evaporation and other losses of 50 percent, and effluent limits of 70 mg/l, the sediment loading rate for regulated active mines is estimated to be 0.16 ton/ac-yr.

Areas of *extractive* land use north of the confluence of the West Branch and Susquehanna are assumed to be largely waste piles and abandoned mine areas (Don Fiesta, personal communication, August 9, 2004). Those areas of mines and waste piles are characterized as largely unvegetated, with relatively little groundwater, and in fractured ground. That is particularly true for waste and product piles. The hydrology of such areas after a rainfall event is described as an initial slight loss from evaporation from surface storage and roughness, followed by the majority of the water acting like interflow with the flow slowing and ending after a number of days. In that sense, the waste and product piles act as a slightly porous sponge with water percolating though the pile slowly over a period of days. For such areas, the estimated EoF erosion rates for the *extractive* land use are arbitrarily set (in the absence of available literature values) at 10 tons/acre-yr, a value one-quarter that of bare-construction land use sediment load estimates.

9.2.11 Nurseries—Container Nurseries

As discussed in Section 4 the *nursery* land use is composed of field nurseries and container nurseries. The Agricultural Census is the source of area estimates for the two nursery types. Field nurseries have characteristics similar to *conventional tillage without manure* and are included in that land use. Container nurseries are simulated separately and are simulated as primarily a source of nutrients but not of sediment. Therefore, the estimated sediment loads from *container nurseries* is set to be equal to that of natural grass.

9.2.12 *Open Water*—Rivers, Reservoirs, and Other Water Surfaces

Aeolian, or atmospheric deposition, sources of sediment are slight, yet make a small contribution to the overall mass balance. Aeolian sediment is from fine material blown off land surfaces onto *open water* land use areas. While land surfaces also have an aeolian input of sediment, there is also an aeolian reduction. The overall net aeolian input to land surfaces is assumed to be zero. For water surfaces, Langland and Cronin (2003) estimate atmospheric deposition to be 1.15 grams/m^2 yr, or 5.13 x 10^{-3} ton/ac-yr. That is simulated as a constant daily input to water surfaces.

9.3 Edge-of-Field Sediment Calibration Rules

HSPF simulates erosion from the land surface by simulating three processes: (1) detachment of soil by rainfall, wind, or human activities; (2) removal of detached soil by runoff; and (3) reattachment of detached soil to the soil matrix. Table 9-15 shows the parameters that control the simulation of those processes.

Table 9-15. Key parameters in sediment calibration on land segments

Parameter	Description
NVSI	Rate at which sediment is added to detached soil from atmosphere; Negative values can simulate removal of sediment by wind or human activities.
KRER	Coefficient which determines how much sediment is detaches from the soil matrix as a function of rainfall.
COVER	Fraction of soil surface in vegetative cover and unavailable for erosion; COVER varies monthly by land use.
AFFIX	Rate at which detached sediment is re-attached to soil matrix.
KSER	Coefficient which determines how much detached sediment is eroded as a function of rainfall.

An iterative calibration program was developed to calibrate each land use type to the target values. Developing an automated calibration procedure is necessary given the large number of EoF target loads. The number of Phase 5.3 EoF sediment loads to be calibrated is 7,700 from the 25 land uses and 308 land-segments. Because there are four parameters (COVER derived from data) but only one calibration target for each land use/segment pair, three calibration rules were set up to regulate the four parameters to reduce the number of parameters to be calibrated so that an iterative calibration procedure is operationally feasible.

The automated calibration starts from the parameter set from manual calibration and adjusts parameters on the basis of model output according to the following three calibration rules:

1. *Ninety percent of detached sediment is reattached to the soil in 30 days.* Detached sediment decreases each day as a result of soil compaction on days without rainfall. Detached sediment storage tends to gradually reach its maximum value and stay at a stable status over time (Figure 9-4). This rule is used in an attempt to reflect this natural property of sediment dynamic by regulating the behavior of AFFIX. This constraint is met by setting the first-order reattachment rate, AFFIX, to 0.07675/day for all land uses/all segments.

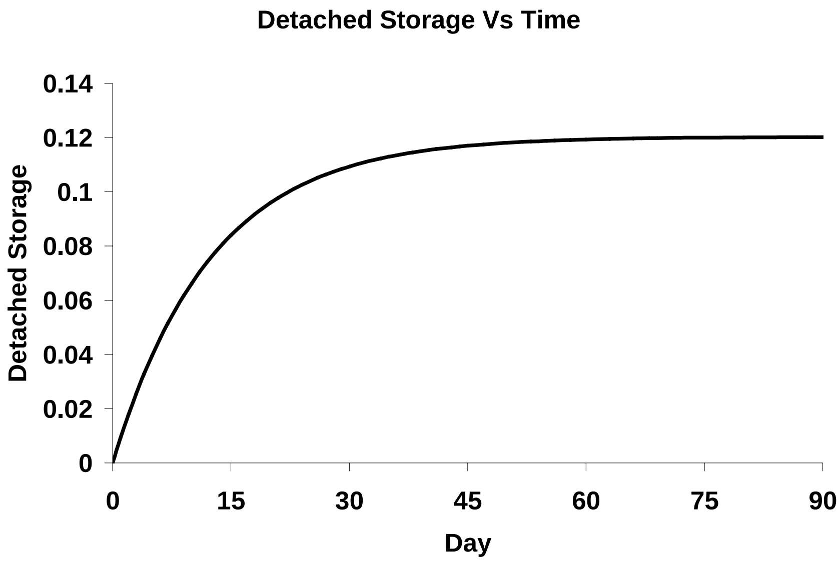


Figure 9-4. The dynamic of detached storage over time.

2. *NSVI should be set high enough that sediment concentrations during storms are larger on the rising limb of the hydrograph than the falling limb (the hysteresis effect).* It has been observed that sediment concentrations during storms are larger as water is rising than when water levels are falling. This is attributed to the fact that as water rises, previously detached sediment is removed until storage is depleted (Dinehart, 1997)

   To mimic the hysteresis effect, NVSI is used in the Phase 5.3 Model to increase the detached sediment storage, so there is a sufficient supply before each storm event. Within that context, NVSI represents any net additions or removal of detached sediment by human activities or wind daily, other than standard HSPF definition. Mathematically, the rule can be expressed as follows:

   $$NVSI \times 365 = a \times \text{Target loads}$$

   where a is the significant fraction that related *NVSI* to total target loads, and it was determined together with the specification of *KSER*/*KRER* ratio, as discussed below.

3. *There should be no detached sediment in storage after large storms.* Generally, large storms should flush watersheds of detached sediment three or four times a year. Sediment storage is typically depleted during storm events and on a seasonal time scale (Van Sickle and Beschta 1983). The qualitative effects of changing sediment supplies are reflected in the decreasing sediment concentrations at a specific discharge level with time during a single storm event, as well as on a seasonal time scale as the runoff season progresses and sediment are flushed from the watershed. The phenomena of seasonal decline and storm hysteresis are apparent in streams of all sizes.

   From a long-term perspective, the accumulated sediment on the land surface should not be continually increasing or decreasing (Allen Gellis, personal communication, 2004).

This rule is developed to reproduce the sediment dynamics of storm hysteresis and of seasonal decline. The rule has important management implications, particularly for agriculture. Cropland is generally plowed two or three times a year during planting season in spring and harvesting season in fall. During those periods, the soil is loosened from land and added to detached storage available for washoff. As a result, sediment loadings from agriculture land typically increase at these times because of increased sediment supply, consistent with numerous field observations. To capture the impact of plowing on sediment loading and the effects of stormwater management strategies for erosion control, the simulated sediment storage needs to go down to zero so that sediment supply will become storage limited.

This rule is enforced by adjusting *KRER* and *KSER* within their minimum and maximum values. To further reduce the parameter set, a proportional relationship between *KSER* and *KRER* was assumed:

$$KSER = b \times KRER$$

A strategy was developed to optimize the ratio *a* and *b* together. In light of numerous possible combinations that these two ratios could formulate, best engineering judgment was exercised to formulate a set of 20 combinations that are physically meaningful and operationally feasible. The feasibility of each scenario was tested, first with land simulation and then river simulation. Among them, the scenario with the significant fraction *a* of 1.5 and the ratio of KSER:KRER of 5 gives the slight better correlations, and produces relative low average detached storage, and was therefore chosen as the final solution. NVSI can then be determined for each land use within each county on the basis of their NRI targets, and KSER values are kept as 5 times of KRER values.

Once the ratio *a* and *b* is specified, the iterative calibration process was carried out to adjust KSER on the basis of model outputs to ensure that simulated EOF loads reach to the target loads, as well as appropriate hysteresis in washoff and appropriate response to high rainfall events.

9.4 Sediment Transport to Edge-of-Stream

EoS loads are defined as the loads that enter the river reaches represented in the model. They represent not only the erosion from the land but all the intervening processes of deposition on hillsides and sediment transport through smaller rivers and streams that are not represented in the Phase 5.3 Model. The influence of the sum of the processes is contained in the estimated sediment delivery ratio, which represents the ratio between sediment transported at a watershed outlet and erosion generated in the watershed. The EoS load for a reach is, therefore, the integration of sediment load scour, transport, storage, and fate from all smaller watersheds and streams unrepresented in the model.

Delivery of sediment to the EoS is in the portions of sand, silt, and clay is based on the STATSGO county level assessment of the percent sand silt and clay in the soils. The portion of sand is discounted by an order of magnitude because of the greater portion of delivery of fines relative to the sand and gravels from the EoF to the EoS. That has the effect of an average portion of sand delivered to the EoS from the EoF to be about 4 percent, which is consistent with Phase 4.3 sand delivery to EoS.

As EoF loads are transported sequentially through model segments, loss occurs because of depositional processes that occur in overland flow before reaching a stream channel as well as in low-order streams. The low-order streams are not explicitly simulated in the Phase 5.3 simulation. Therefore, it is necessary to use an SDF to reduce the EoF erosion rates if they are to be used to represent EoS erosion rates. The fraction of sediment that is available for delivery to the EoS is referred to as the SDF. That factor is multiplied by the predicted EoF erosion rate to estimate the eroded sediments actually delivered to a specific reach. Several approaches are available for calculating a SDF translating EoF sediment loads to EoS (Benedict and Klik 2006; Sun and Mcnulty 1998; Yagow et al. 1988; USDA-NRCS 1983; Swift 2000)

The base formula for calculating sediment delivery ratios in the Phase 5.3 Model is

$$SDF = 0.417762 \times A^{-0.134958} - 0.127097$$

Where *SDF* is the sediment delivery ratio and *A* is drainage area in square miles. The use of that formula was standard practice for the NRCS (USDA-NRCS 1983) and it was also used in earlier versions of the Watershed Model. In the Phase 5.3 Model, the sediment delivery ratio was calculated by land use and river segment to take into account the fact that land uses can differ in how they are situated with respect to river reaches. In the Ridge and Valley region, for example, the bottom of the valleys is more likely to be cultivated, while because of steep slopes, hillsides are forested or used for pasture. To take that into account, land use-specific sediment delivery ratios were calculated for each river segment, using the following procedure: (1) In GIS, the mean distance between the parcels of a river segment in a land use and the river reach was calculated; (2) the sediment delivery ratio for that land used was calculated by assuming that the area in the SDF formula is equal to a circle with radius equal to the mean distance between the land use and the river reach.

A single factor for each land use in each segment was calculated using SCS method. The factor is related to watershed size and unique for each land use. The drainage area in the equation was estimated by assuming the area is a circle and the mean distance from land to river is the radius. The mean distance from a land use to a river was calculated using GIS tools. To derive a unique SDF for each land use in each segment, the average distance to stream for a given land use in a segment is conceived as the radius of a circle, giving a sense of the heuristic nature of the actual, but unknown distance to low-order streams and overall efficiency of sediment transport. The area of that circle is used to calculate the SDF for that land use using the equation above.

Using the above sediment target loads and SDFs the EoS loads were generated and used in the riverine calibration of sediment to observed values at monitoring stations. Because scour and deposition are calibrated in the river reaches, there is a check on these EoS sediment loads in all provinces except for the province of the coastal plain.

The Coastal Plain physiographic region simulated in Phase 5.3 has few monitoring stations and the calibration of the EoS sediment loads as is done in the other physiographic regions is unachievable in the coastal plain except for a few river reaches. For this region, a separate analysis was done relating the EoF sediment loads to the load estimates at the monitoring stations using the Estimator regression model (Curry, L., Maryland Department of Environment. 2006. An analysis of sediment EoF to EoS transport factors in Chesapeake physiographic regions. Personal communication). The analysis found that the EoF to EoS transport factors in the coastal plain was about one-quarter that of the Appalachian Highland and Ridge and Valley physiographic regions. That could be related to the *competency* of rivers to transport of sediment loads and the low gradients of the Coastal Plain region (Figure 9-5), and it is consistent with current understanding of sediment behavior in watersheds (Walling 1983; Trimble 1999; Trimble and Crosson 2000; Walter et al. 2007; Walter and Merritts 2008). The low gradient of the coastal plain delivers relatively less sediment loads than the higher gradient physiographic regions. On the basis of that analysis the SDFs in the Coastal Plain were multiplied by a factor of 0.25. The other physiographic regions were unadjusted because the sediment monitoring stations allowed a calibration of the EoS sediment loads. That is true even in the case of the Piedmont province where the application of a methodology to discern estimates of legacy sediment loads from erosion form the land is applied as described in Section 9.5.

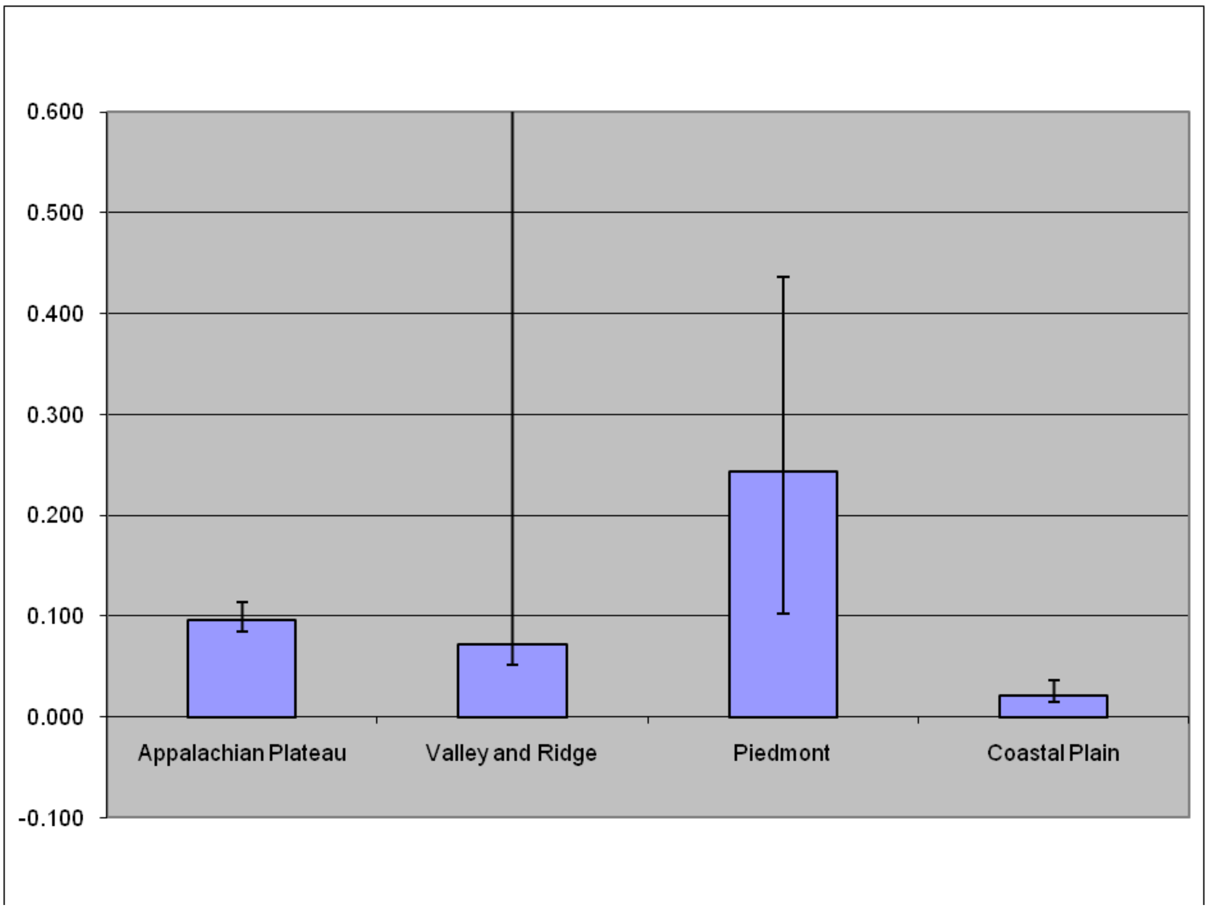


Figure 9-5. The median, 25th percentile, and 75th percentile estimates of the sediment delivery ratio for major physiographic regions of the Chesapeake.

In Phase 5.3 only a single sediment size fraction is simulated at the EoF, but when loading sediment to the EoS, a sand, silt, and clay fraction is required. To best represent sediment loads CBP assumed the EoF load is best represented in each land-segment by the STATSGO assessment of percent sand in the land-segment soils (Schwarz and Alexander 1995). The STATSGO percent sand, silt, and clay is what is assumed to be eroded at the EoF and the EoS percent sand is assumed to be an order of magnitude less than this. That varies from land-segment to land-segment but on average is about 4 percent sand. The EoS silt and clay are adjusted proportionately.

9.5 Riverine Transport Processes

The HSPF simulation of Phase 5.3 is a relatively simple simulation system for sediment transport. HSPF simulates a reach as a completely mixed reactor at each time step of an hour. The flow for each hour is estimated by a stage-discharge relationship that in HSPF is called an FTABLE. If the flow is below some user specified level, then deposition will occur. At a higher flow, no deposition occurs, and when higher still, scour occurs. Levels of critical flow (critical shear stress) are set for both scour and deposition of silt and clay, with each set independently. Sand scour is handled slightly differently and occurs only at high flows. Settling rates for sand, silt, and clay are also set separately. Each of the user-defined parameters is set to be as consistent as possible to observed data, but some data are very sparse, such as observed sand, silt, and clay partitions. Finally, the simulation is for an entire Phase 5.3 watershed segment, and scour is best conceptualized as representing *all* the processes that set sediment in motion throughout the simulated segment during high flows. That conceptualization of scour in the segment includes sediment stored in reverse slopes of hillsides and in other areas like low-order streams not explicitly simulated but implicitly included in the Phase 5.3 sediment load estimates as Phase 5.3 is calibrated to observations at monitoring stations that include all the scoured sources.

In summary, simulated deposition can happen at low flows, and scour can occur at high flows, and neither deposition nor scour can happen at intermediate flows depending on what is needed to calibrate to a monitoring station's observations. Deposition, scour, or neither occur in each simulated hour time step depending on the simulated flow and the user-defined shear stress for scour and deposition in each segment. Another constraint on sediment calibration is the Phase 5.3 decision rule that riverine sediment deposition and scour rates are oriented toward a steady-state condition, for an overall river bed net change of zero, meaning that over the two-decade simulation period, the river bed is neither consistently aggrading or scouring.

Phase 5.3 simulates the fate and transport of three grain sizes: sand, silt, and clay. Deposition can reduce the load of each of the three grain sizes transported through a reach, while scour from the bed can increase it.

The deposition or scour of cohesive sediments is controlled by bed shear stress, τ, which is calculated by the following formula:

$$\tau = \gamma \times R \times S$$

where γ is the weight of water, S is the reach slope, and R is the hydraulic radius, which is calculated internally as a function of the simulation of the hydraulic routing in the reach. Scour occurs when the bed shear stress is above a specified critical shear stress, and the amount of scour is proportional to the user-defined erodibility of the segment (Figure 9-6). Deposition occurs, on the other hand, when bed shear stress is below a specified critical shear stress. The amount of deposition is a function of fall velocity and the average water depth.

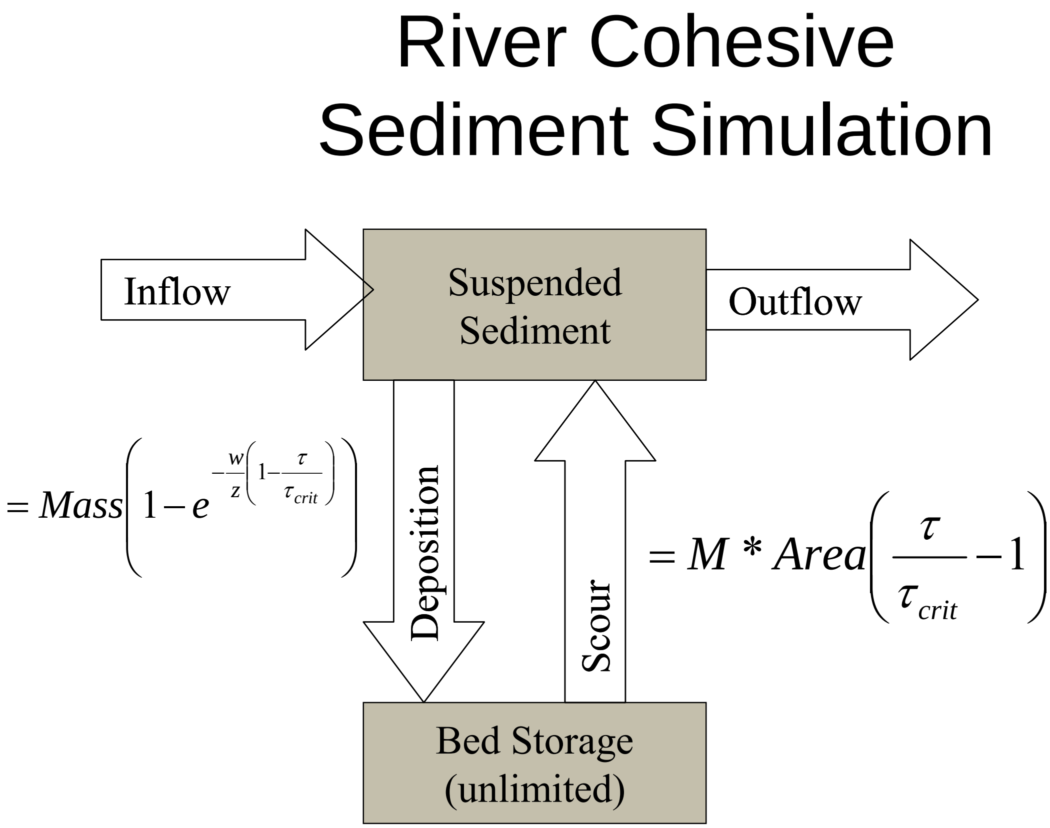


Figure 9-6. Schematic of the silt and clay cohesive sediment simulation.

Sand is simulated differently from cohesive sediments. The amount of sand transported in a reach is determined by the transport capacity of the flow, which is a power function of the average velocity in the reach. Deposition of sand occurs if the concentration of sand in the reach exceeds its transport capacity of the flow, and sand is scoured from the bed if the concentration of sand is below the transport capacity (Figure 9.7). Table 9-16 summarizes the HSPF parameters used in the sediment calibration in the reaches.

Table 9-16. Key parameters for sediment transport calibration

Parameter	Description
TAUCD	Critical bed shear stress for deposition

TAUCS	Critical bed shear stress for scour
W	Fall velocity in still water
M	Erodibility coefficient
KSAND	Coefficient of sand load power function
EXPSND	Exponent of sand load power function

9.5.1 Calibration of Sediment Concentrations and Loads in River Reaches

There are 164 sediment calibration points with varying numbers of observations. All ungaged river segments upstream of a calibration point have identical parameters of depositional and scour shear stress for silt and clay as shown in Figure 9.8.

$$[sand] = k * \{velocity\}^{J}$$

Adjustments are then made to the bed depth

Figure 9-7. Equation governing simulation of riverine sand transport.

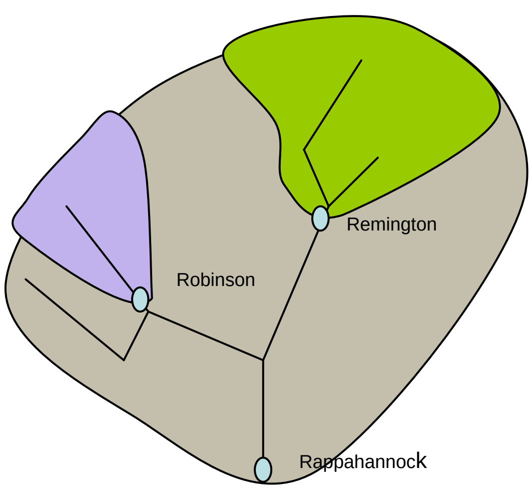


Figure 9-8. All rivers segments upstream of a calibration point have identical parameters as shown in this figure of three sediment monitoring stations with three separate calibrations.

Sediment calibration can be confounded because of inaccuracies in the flow simulation. If peak flow is missed by one day, the sediment concentration might not match observed values at that point. However, it should match it at the point when the peak was simulated. To take that into account, the simulation was checked 24 hours before and after an observation point, and the simulation value for that observation was set to the point closest to the observed value to better represent the in the daily calibration occasions when the sediment peak was correctly simulated, but the timing was missed by > 24 hours.

The calibration rules were applied by an automated calibration system called AIM for Automated Iterative Method. The AIM is described in Section 13 for calibrating both EoF and riverine transported sediment. Many larger stations have more data available and are often easier to calibrate than smaller stations. Further, larger stations could be more important overall because they are a composite of many smaller upstream reaches that are more affected by local phenomena.

A key goal of the calibration was to match observed and simulated concentrations and loads at high flows. High flows are considered to be the highest 30 percent percentile of the flow. High flows encompass storm flows that transport sediment eroded from the land. Below the 30 percent percentile of flow, most of the observed total suspended solid are organic solids. These were calibrated to match the observed data.

9.6 Assessment of the Sediment Calibration

There are several points of calibration in the sediment simulation. The first point of calibration is the simulation of the individual land uses in each segment to the EoF sediment targets. The next points of calibration are to the observed sediment concentrations in the rivers. This a key area of calibration and sediment loads in major rivers are often calibrated at several stations. More than 100 sediment monitoring stations were used to calibrate the Phase 5.3 Model.

9.6.1 Quality of the Land Use Calibration to Literature Targets

The calibration of Phase 5.3 Model sediment loads to the EoF sediment targets was done by adjusting the erodibility variable in the initial rainfall detachment equation in HSPF (Bicknell et al. 2001). By adjusting that variable, all EoF sediment targets were calibrated within a few percentage points, plus or minus, of the target load.

9.6.2 Quality of the Riverine Calibration to Observed Data at Monitoring Stations

Many different measures were used to assess the agreement between observed and simulated sediment concentrations and loads. Those include

- Summary statistics such as minimum, mean, maximum, and median values
- Time series plots
- Scatter plots of concentration or log concentration

- Cumulative distribution of paired observed and simulated concentrations or log concentrations
- Statistical measures of correlation such as model efficiency or coefficients of determination

Plots of simulated and observed instantaneous concentrations and loads are available on the calibration website: ftp://ftp.chesapeakebay.net/Modeling/phase5/Phase%205.3%20Calibration/Calibration_pdf/all_validation.pdf.

Rating curves, representing the relation between flow and sediment concentration, were also compared. A special set of plots and statistical measures were developed to take into account the following three problems in comparing sediment simulations to observed values:

1. Sediment concentrations vary widely over a storm, but most available sediment observations consist of grab samples taken at a moment in time.
2. Simulated storms can lead or lag the real events, so simulated concentrations or loads can be in essential agreement with their observed counterparts but lead or lag them in time.
3. Over a wide range of low flows, suspended sediment concentrations are low, contribute little to sediment loads, and are made up mostly of organic solids.

To take those problems into account, CBP adopted *windowed* plots and statistical measures. In a windowed plot, observed data are compared to a one-day window of simulated values, before and after the observation. If the observation falls within the range of simulated values, the simulated value is set equal to the observed value. If the range of simulated values is above or below the observed value, the simulated value is set equal to the minimum or maximum simulated value, respectively. Such a procedure was used for both concentrations and loads. Figure 9-9 shows an example of windowed concentration plots for the Potomac River at Chain Bridge; Figure 9-10 shows the windowed load plots for the Potomac River at Chain Bridge.

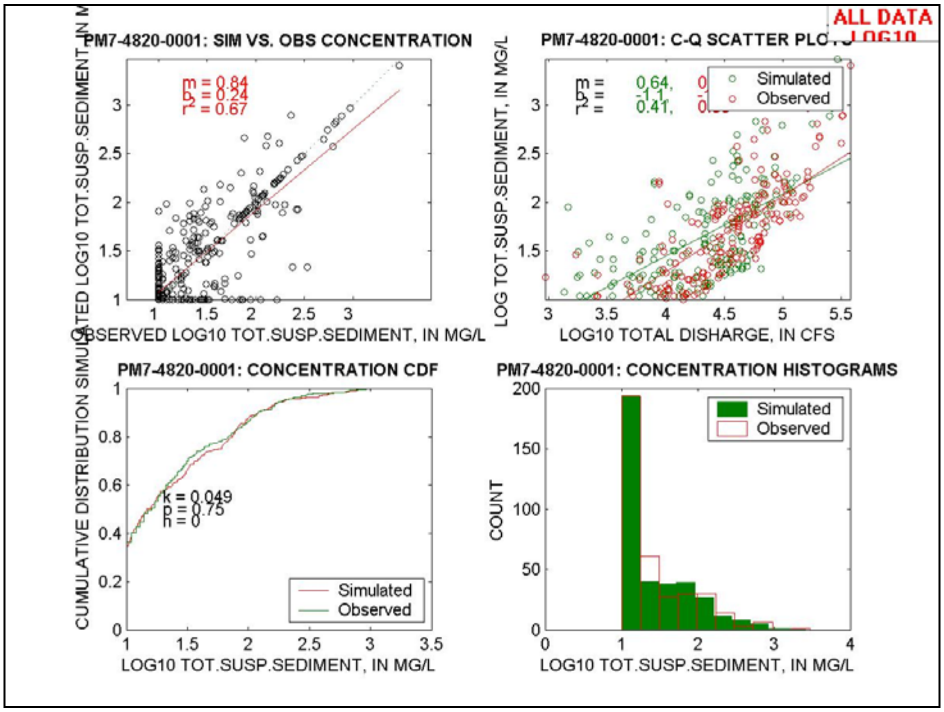


Figure 9-9. Windowed concentration plots, Potomac River at Chain Bridge.

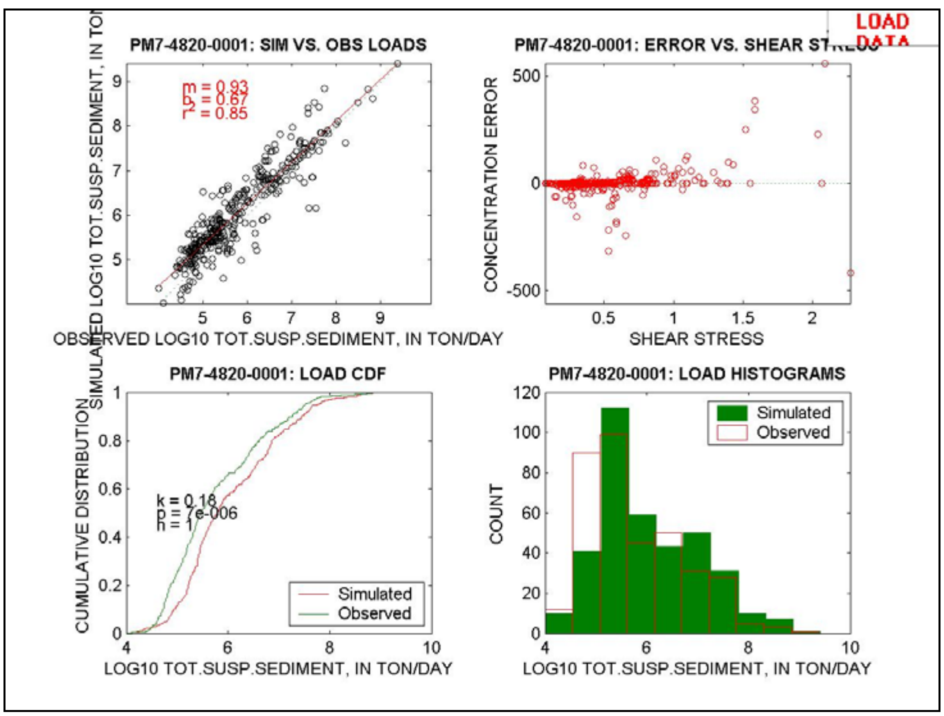


Figure 9-10. Windowed load plots, Potomac River at Chain Bridge.

Another assessment of the quality of the sediment calibration is to compare it with the monthly load estimates from the USGS's River Input Monitoring (RIM) program, which evaluates nutrient and sediment loads entering Chesapeake Bay and its tidal tributaries at the fall line. RIM loads are calculated using the USGS's ESTIMATOR software, which calculates monthly and annual constituent loads on the basis of a statistical analysis of the relation between constituent concentrations and flow, time, and seasonality. Langland et al. (2001) has more details on the RIM program and ESTIMATOR. That comparison is also relevant to the integration of the SPARROW Model with Phase 5.3 as the SPARROW Model is based on ESTIMATOR.

Figures 9-11, 9-12, and 9-13 compare the log-transformed monthly sediment loads from ESTIMATOR with Phase 5.3 Watershed Model loads for the RIM stations at Chain Bridge on the Potomac River, the Patuxent River at Bowie, and the Choptank River near Greensboro. There is good agreement between ESTIMATOR and the Phase 5.3 Model, both in the overall magnitude of the loads and their variability.

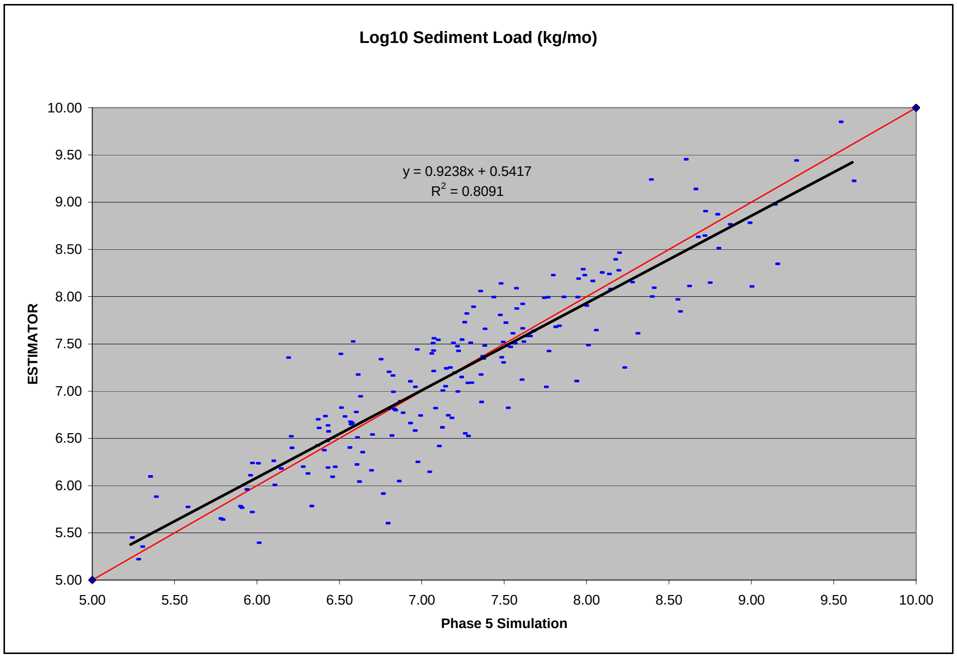


Figure 9-11. Monthly sediment loads, Potomac River at Chain Bridge.

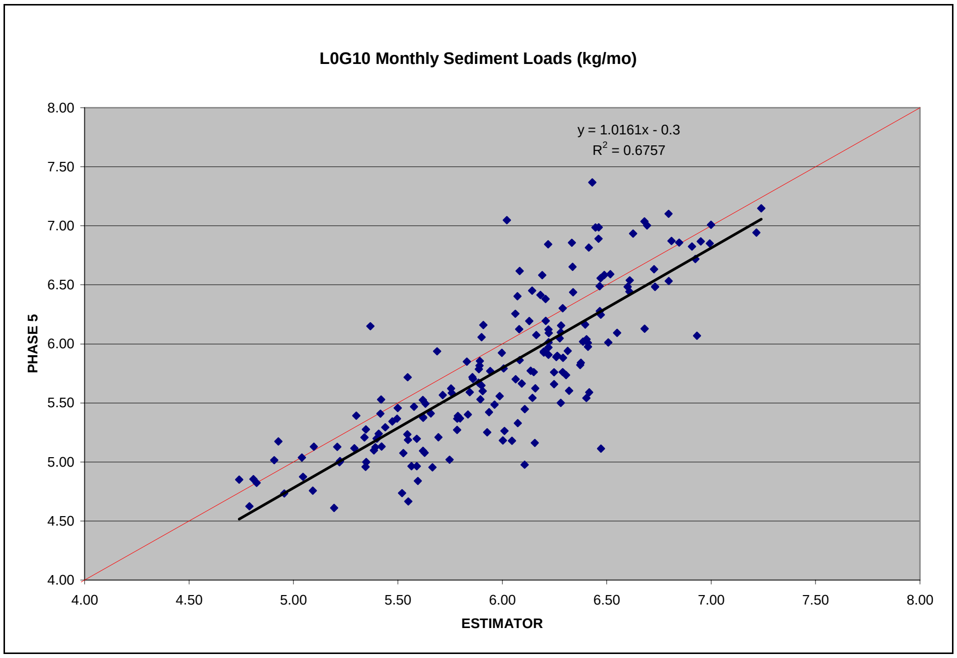


Figure 9-12. Monthly sediment loads, Patuxent River at Bowie.

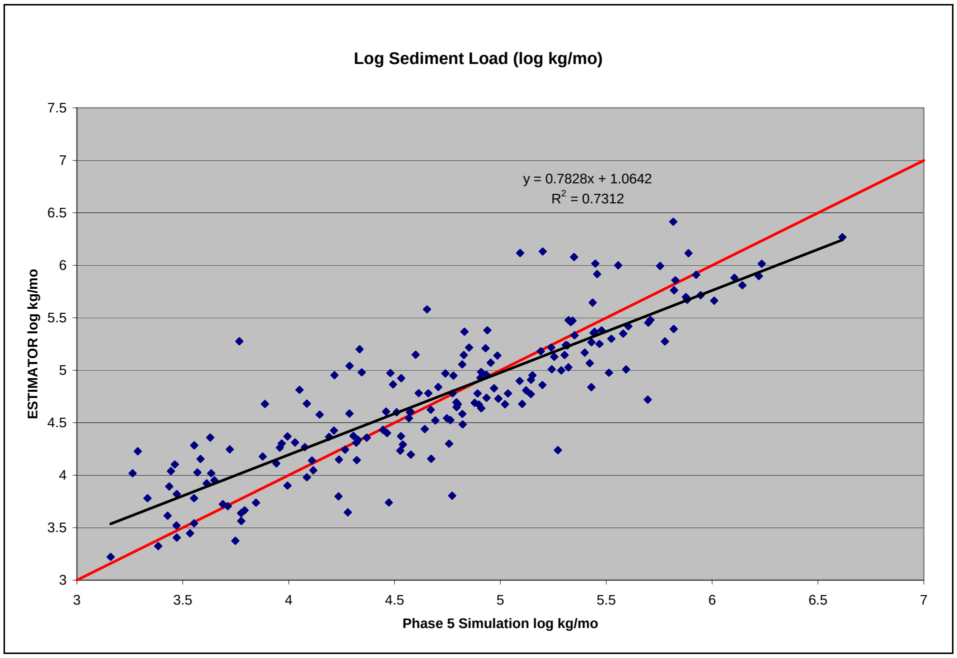


Figure 9-13. Monthly sediment loads, Choptank River at Greensboro.

9.6.3 Calibration of Sand, Silt, and Clay Fractions

Phase 5.3 simulates sand, silt, and clay separately in the river reaches. The CBP adds the three sediment components, plus freshwater phytoplankton, to get simulated TSS consistent with observed TSS at monitoring stations.

The RIM stations have some data on observed splits of sand and fines (silt and clay). Using all available observations taken at the Chesapeake Bay RIM stations, which correspond to the last water quality monitoring station before discharge to tidal waters (also called the fall line monitoring stations), CBP finds the TSS observed loads were mostly fines (Table 9-17). The major basins of the Susquehanna, Potomac, and James have median percent fines of 97 percent, 91 percent, and 85 percent, respectively (Figures 9-14, 9-15, and 9-16). Usually, rivers with significant impoundments, like the Susquehanna, have a greater percentage of fines, and the sand fraction is more typically 5 percent. Surprisingly, no correlation was seen between flow and percent fines.

To reflect the observations of the proportions of sand and fines observed TSS, the annual average target of percent sand was set at 15 percent for all river reaches except for those reaches that have impoundments. In the case of impoundments—as in the Susquehanna observations with the impoundments of Conowingo, Safe Harbor, and New Haven just above the monitoring station—an annual average target of 5 percent sand was set, which approximates the observed median and mean of 3 percent and 4.7 percent, respectively.

Only three samples are available for the silt/clay splits, and they indicate that the percent clay was 52 percent and 46 percent on two occasions in the Patuxent, and 79 percent on one occasion in the Potomac.

Table 9-17. Percent fines (silt and clay) in Chesapeake rivers

Basin	% fines Median	% fines Mean	% fines Max	% fines Min
Susquehanna	97%	95.3%	100%	71%
Potomac	91%	87.6%	100%	47%
Patuxent	92%	89.9%	100%	49%
Rappahannock	85%	80.6%	100%	6%
Mattaponi	81%	76.9%	100%	5%
Pamunkey	87%	84.5%	100%	9%
James	85%	81.1%	100%	19%
Appomattox	90%	85.1%	100%	47%
Choptank	90%	86.3%	100%	50%

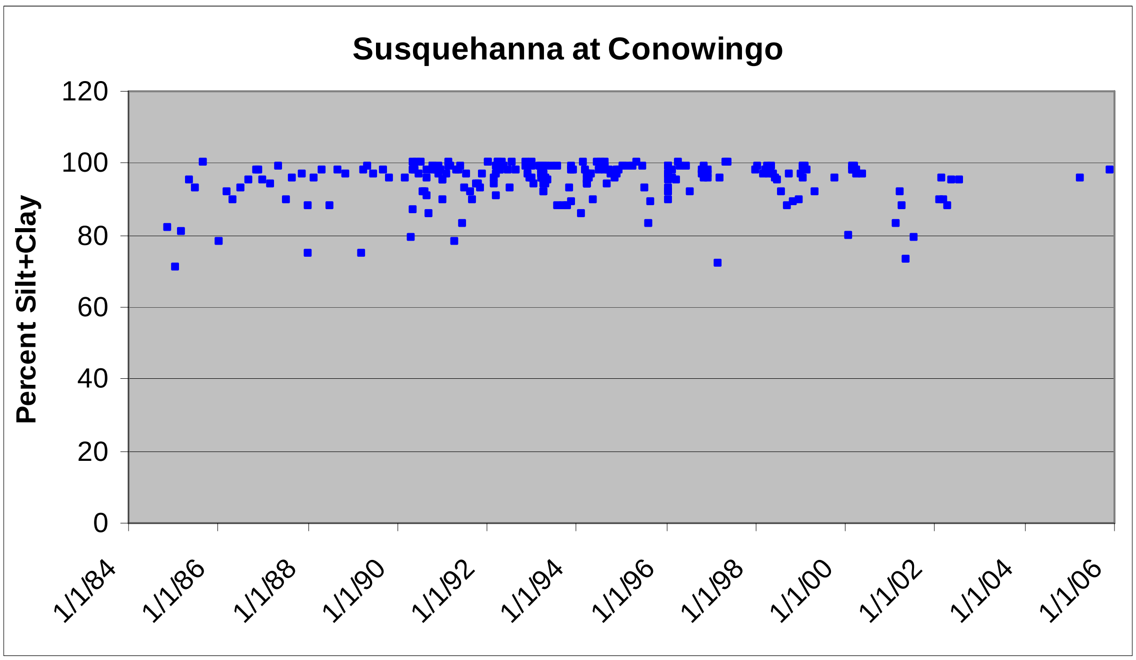


Figure 9-14. Percent fines (silt + clay) of all observed data from 1985 to 2005 at the Susquehanna Conowingo monitoring station.

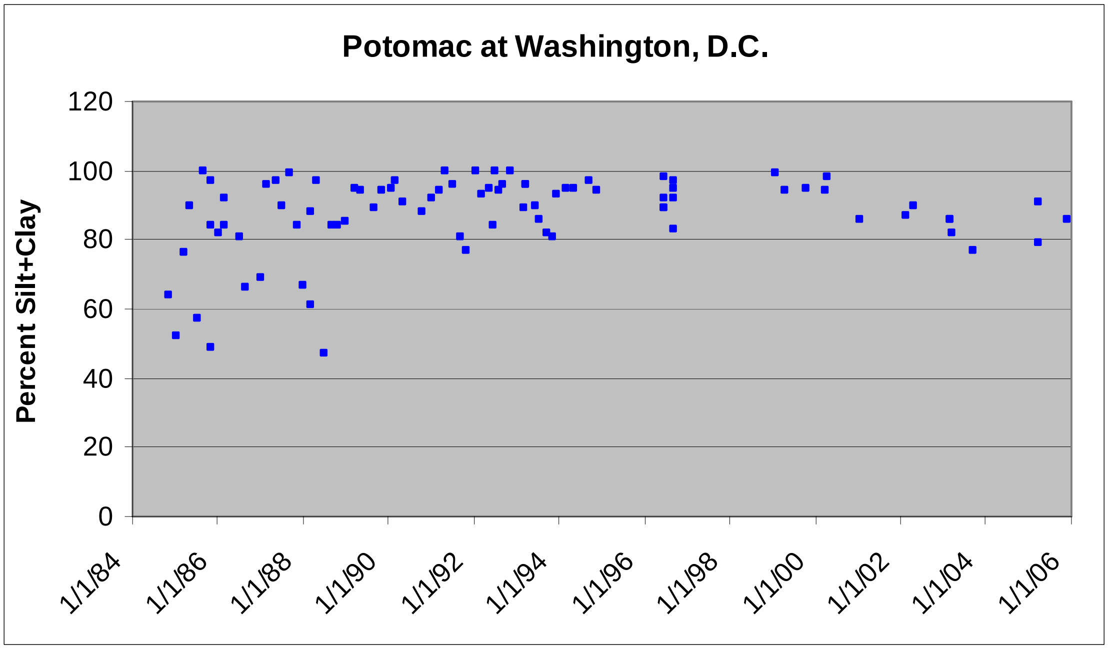


Figure 9-15. Percent fines (silt + clay) of all observed data from 1985 to 2005 at the Washington, D.C. Potomac monitoring station.

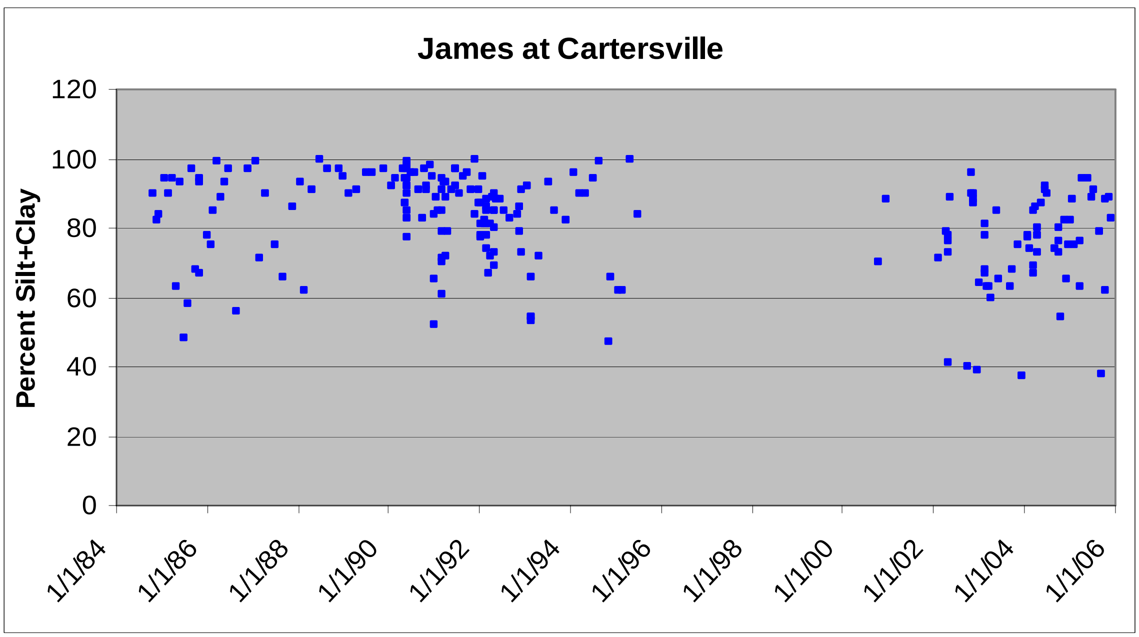


Figure 9-16. Percent fines (silt + clay) of all observed data from 1985 to 2005 at the James Cartersville monitoring station.

9.7 Assessment of Sediment Loads in the Watershed

Sediment is conservative, and its fate after mobilization is to be either stored somewhere in the watershed or transported to tidal waters. A study by Trimble (1999) in Coon Creek, a tributary to the Mississippi River, found that much of the sediment eroded from the land is stored somewhere in the watershed, either on adjacent lands, the reverse slopes of fields, lower order streams, or in river valleys and flood plains. Trimble and others (Walling 1983; Trimble 1999; Trimble and Crosson 2000; Walter et al. 2007; Walter and Merritts 2008) have described these legacy sediments stored in the watershed as having times of transport to tidal waters like the Chesapeake on the order of decades to centuries. That sediment lag time also arises from mechanisms specific to the Chesapeake watershed, since the colonial settlement of the East Coast and development of water power sources from relatively low head dams right up to the close of the 19th century (Walter and Merritts 2008).

To account for the difference between sediment from the land sources and BMPs used to control the sediment, and the sediment loads from legacy sediment and the very different management practices needed to control this source, methods were developed in Phase 5.3 to differentiate between the two. The erosion loads from the land are defined in Phase 5.3 to be the erosion loads from the land, developed by calibration to the targets derived either from the NRI erosion data set, or by literature values, and then decremented by a transport factor relating an EoF erosion load to from a land use to an EoS load. This is considered to be the load from land controlled by BMPs.

Another portion of the sediment load delivered to the Bay is the sediment load mobilized in river reaches and is defined as the difference between the EoS erosion load and the sediment load scoured and mobilized in the simulation during high flows. That scour term is best conceptualized as high flow and scour from any stream reach, stream bank or flood plain within a model segment. The sediment loads from scour can, in total or in part, be from legacy sediment loads, but greater discernment among the sediment load sources within the Phase 5.3 simulation system is impractical.

In Phase 5.3, the legacy sediment is described as an unknown portion of the sediment load delivered to the Bay that was attributed to scour in the watershed from a source other than that of the land uses. That is done with the scour term that is related to the velocity of the river flow (TAUCS). Above some threshold of flow, scour occurs at a specific rate. At lesser flows, another critical point is reached, and at flows less than that point, sediment settling and deposition occurs. The rate of scour, deposition, and the critical flows where those processes occur are specified in the calibration and are values that best represent the sediment concentration at the ~130 monitoring stations monitored for sediment. The system allows a representation of estimated erosion rates from the land, and estimated sediment loads derived from scour or remobilization of sediment within a model segment. Both the estimated erosion rates from land and the river network are calibrated, one from NRI estimates and one from river monitoring gages. The sediment loads for each of the Phase 5.3 model segments are represented as both an estimated land erosion load and a river network sediment load.

9.8 Linkage of Sediment loads to the Water Quality and Sediment Transport Model

The Phase 5.3 Model estimates the general splits between sand, silt, and clay with the fractions changing as the hydrologic condition changes yielding larger size fractions in larger flows. The daily splits of sand, silt, and clay as estimated by the Phase 5.3 Model were directly input in the Water Quality Sediment Transport Model (WQSTM), although the portion of silts and clays was poorly defined by available observed data.

For sediment loads from the coastal plain regions, loads were determined solely by the sediment EoF loads as adjusted by the EoF to EoS sediment transport factors. That has the effect of damping the effect of high flows on sediment loads because the river reach simulation amplifies high sediment loads under high flows and low sediment loads under high flows because of the model’s scour and deposition parameterization. Such a simulation approach on the coastal plain is perhaps consistent with the coastal plain’s low gradients and competency to move sediment in relatively small basins. Another factor that could contribute to lower sediment loads from the Delmarva Peninsula are the sandy soils of high permeability in the surficial aquifer found there.

In Phase 5.3 Model simulated coastal plain regions, the sand/fines splits are set by the STATSGO assessment of percent sand in the land segments (Schwarz and Alexander 1995). The STATSGO percent sand is what is assumed to be eroded at the EoF and the EoS percent sand is assumed to be an order of magnitude less than that. That varies from land-segment to land-segment but, on average, is about 5 percent sand and 95 percent fines in the loads delivered to tidal waters from coastal plain regions without a Phase 5.3 reach.

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