# A Nonpoint Source Model for Land Areas Receiving Animal Wastes: IV. Model Inputs and Verification for Sediment and Manure Transport

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## ABSTRACT

A mathematical model describing transport of sediment and manure during unsteady overland flow from land areas receiving animal wastes was presented in a previous paper. Results of a comprehensive literature survey characterizing model inputs due to manure presence are presented in this paper. Inputs are: manure cover on the watershed, manure erodibility factor, and manure particle-size distribution and particle density. Estimated sediment yields were compared with measured data for selected storms on a 1.1-ha pasture watershed near Coshocton, OH. The simulated results agreed reasonably well with these field data.

## INTRODUCTION

A mathematical model describing manure transport from land areas receiving animal wastes was developed by adding manure detachment and transport components to corresponding soil detachment and transport relationships (Khaleel et al., 1979). The model estimates transport of both sediment and manure particles during rainfall-runoff events. Four discrete particle type fractions were considered: (a) fine primary, (b) coarse primary, (c) aggregates, and (d) manure. Total erosion was divided into two sources—that from interrill areas and rill areas of the watershed. Also two manure application modes, surface-applied or soil-incorporated, were recognized. The sediment-manure model requires input from a hydrologic model that provides temporal and spatial estimates of flow discharge and depth of flow for a given storm event. The objectives of this paper are to (a) characterize and estimate, from a literature survey, the model inputs due to manure presence, and (b) test the model using available field data.

Input data requirements for the sediment phase of the model are indicated in Table 1.

## MODEL INPUTS DUE TO MANURE PRESENCE

The parameters required to describe the presence of manure are: (a) manure cover on the watershed, $\xi_m$, (b) manure erodibility factor, $K_m$, and (c) manure particle-size distribution and particle density.

### Estimating $\xi_m$

Manure cover from freely grazing animals varies with time and space. Peterson et al. (1956) found that the negative binomial distribution was most accurate for describing quantitatively the time-space distribution of excreta from freely grazing animals over long periods of

**TABLE 1. SEDIMENT MODEL INPUT DATA REQUIREMENTS.**

| General Data Class | Specific Information |
|---|---|
| A. Watershed data | 1. area |
| | 2. slope length |
| | 3. slope steepness |
| B. Particle sizes | 1. fine primary |
| C. Particle densities | 2. coarse primary |
| | 3. aggregates |
| | 4. manure particles |
| D. Percent sediment fraction | 1. fine primary |
| | 2. coarse primary |
| | 3. aggregates |
| E. Erodibility factors | 1. soil |
| | 2. manure |
| F. Ground cover data | 1. manure cover fraction, $\xi_m$ |
| | 2. nonmanured surface fraction, $\xi_s$ |
| | 3. bare soil fraction, $\xi$ |
| | 4. grass cover fraction, $\xi_g$ |
| | 5. root network and crop residue fraction (Appendix B, Khaleel et al. 1979) |
| G. Flow resistance data | 1. grass |
| | 2. manure |

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time. The proportion, $P_t$, of a pasture without any manure at time t is given by:

$$P_t = 1/g^k, \quad \text{[1a]}$$

where k = a positive parameter measuring the nonuniformity in the tendency for the animal to excrete at a particular point in the pasture, and

$$g = \frac{k + D_t}{k} \quad \text{[1b]}$$

where $D_t$ = mean excretal density at time t given by,

$$D_t = \frac{N_t a}{A} \quad \text{[1c]}$$

where $N_t$ = the total number of defecations in the pasture at time t (obtained as the product of excretal production rate per animal per day times total number of animal days), a = area covered by an individual excretion, and A = total area of the pasture. The portion of manure cover, $\xi_m$, for a pasture at time t is:

$$\xi_m = 1 - P_t. \quad \text{[1d]}$$

On the average, each animal produces a defecation every 2 h (equation [1c]), and each defecation covers an average area, a, of 0.093 $m^2$ (Peterson et al., 1956). The variable k in equation [1b] was given an average value of 2 by Peterson et al. (1956).

### Estimating Manure Erodibility Factor, $K_{im}$, for Surface-Applied Manure

Data on $K_{im}$ values are scarce. Jeschke (1969) estimated a value of 0.021 kg.h/N.$m^2$* for $K_{im}$ for manure solids from unpaved cattle feedlots, whereas Gunther (1974) obtained an average $K_{im}$ of 0.0026 kg.h/N.$m^2$ for liquid swine manure. Prakasam et al. (1974) collected sediment samples and analyzed them for organic matter from field plots where poultry manure had been applied. Using their data on soil loss and organic matter loss, combined with the Universal Soil Loss Equation (USLE), we obtained an average $K_{im}$ of 0.0026 kg.h/N.$m^2$ for poultry manure. A similar procedure was applied to organic matter and soil loss data obtained by Klausner et al. (1976) from field plots receiving dairy manure. Table 2 lists $K_{im}$ values for various types of manure.

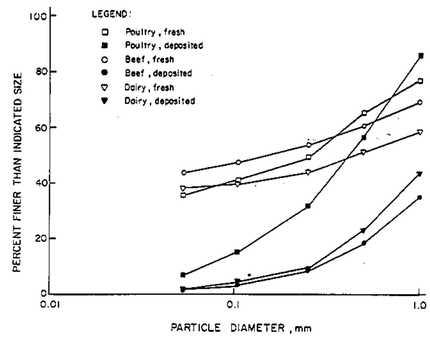


**FIG. 1 Particle size distribution for various manure types.**

### Manure Particle Size and Density

Livestock wastes differ from soil sediments in their particle-size density and distribution (Jones et al., 1971). Sobel (1966) found that 98 and 74 percent of particles passed a No. 16 sieve (1.19 mm) and 72 and 51 percent passed the No. 50 sieve (0.30 mm) for poultry and dairy manure, respectively. The particle-size distribution for swine waste probably falls between that for dairy and poultry manure (Jones et al., 1971). The results of Chang and Rible's (1975) study on particle-size distribution for various manure types are summarized in Fig. 1. The size distribution of solid (deposited) wastes differed significantly from that of freshly-collected wastes, presumably because of decomposition.

Differences in particle-size distribution will significantly influence how each size fraction of waste will be transported by flow. The $d_{50}$ (the size of manure for which 50 percent of the sample is finer) size is assumed to be representative for transport analyses. Typical $d_{50}$ values for several manure types are shown in Table 3.

Sobel (1966) found that 1.8 g/$cm^3$ is a typical estimate of particle density for poultry manure and 1.44 g/$cm^3$ is typical for dairy feces. The particle density for swine manure is expected to be near that of dairy (Jones et al., 1971). Although these values are typical, the density may range widely. Hafez et al. (1974) found values for various manure types ranging from 0.97 to 1.76 g/$cm^3$. Table 3 gives the particle density values we assumed, based on the literature, as representative for various manure types.

## MODEL TESTING

### Selection of Parameter Values.

The model described earlier (Khaleel et al., 1979) was tested using experimental data from a 1.10-ha (2.71-a) pasture watershed (WS-129) near Coshocton, OH. Fig. 2

*An English Universal Soil Loss Equation (USLE) K = 0.1317 kg.h/N.$m^2$, N = Newton. An English USLE R (EI) unit = 1.702 N/h. Example: R = 125 (English) = 213 N/h, K = 0.40 (English) = 0.053 kg.h/N.$m^2$, A = RK = 50 tons/acre (English) = 11 kg/$m^2$.

TABLE 2. MANURE ERODIBILITY FACTORS FOR VARIOUS TYPES OF SURFACE-APPLIED MANURE.

| Type of Manure | Reference | $K_{im}$ factor, kg•h/N•$m^2$ |
|---|---|---|
| Unpaved beef feedlot | Jeschke (1969) | 0.0210 |
| Liquid swine manure | Gunther (1974) | 0.0026 |
| Poultry manure | Prakasam et al. (1974) | 0.0026 |
| Dairy manure | Klausner et al. (1976) | 0.0066 |

TABLE 3. PARTICLE SIZE AND DENSITY FOR VARIOUS MANURE TYPES.

| Manure Types | Particle size, $d_{50}$ mm | Particle density g/$cm^3$ |
|---|---|---|
| Poultry | 0.035 | 1.80 |
| Beef | 0.090 | 1.44 |
| Dairy | 0.100 | 1.44 |
| Swine | 0.070 | 1.44 |

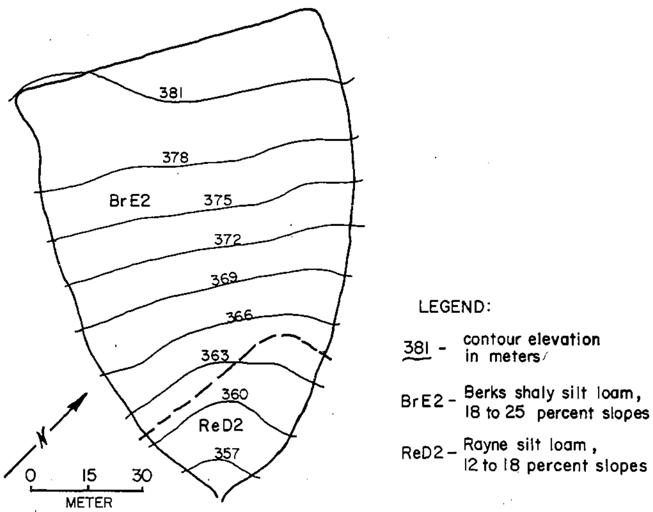


**FIG. 2 Map of watershed WS-129, Coshocton, OH (after Kelley et al., 1975).**

is a topographic map of the watershed. The soils in the watershed are: (a) Berks shaly silt loam, 18 to 25 percent slopes, moderately eroded, occupying an area of 0.93 ha, and (b) Rayne silt loam, 12 to 18 percent slopes, moderately eroded, and occupying an area of 0.17 ha. Kelley et al. (1975) described these soils' textural and physical characteristics.

The particle sizes and densities for fine primary, coarse primary, aggregates, and manure particles, as used in the model, are given in Table 4. The USLE soil erodibility factor K was estimated to be 0.040 kg.h/N.m$^2$ from soil properties data given by Kelley et al. (1975) and the nomograph of Wischmeier et al. (1971). The manure $K_{im}$ was assumed to be 0.013 kg.h/N.m$^2$, which is an average of beef feedlot and dairy manure $K_{im}$'s (Table 2). These values were not varied from storm to storm.

Based on Alberts et al. (1978) findings for the particle-size distribution for a nontilled silt loam soil (similar to pasture condition) and the particle-size distribution for the watershed soils given by Kelley et al. (1975), we assumed that 36 percent of the sediment was aggregates, 9 percent was coarse primary, and 55 percent was fine primary. Such a distribution also agreed with observations of the erosion process on natural soils during simulated rainstorms which indicated that a large fraction of the transported soil move as aggregates (Moldenhauer and Koswara, 1968). Particles were classified as fine, if their diameters were less than 20$\mu$, and coarse if they were greater than 20$\mu$.

**TABLE 4. PARTICLE SIZES AND DENSITIES FOR VARIOUS FRACTIONS.**

| Particle size fraction | Particle diameter, d, mm | Particle density, g/cm$^3$ |
|---|---|---|
| Fine primary | 0.005 | 2.65 |
| Coarse Primary | 0.040 | 2.65 |
| Coarse Aggregates | 0.270 | 2.00 |
| Manure Particles | 0.090 | 1.40 |

For a grassed media with a grass cover of $\xi_g$, the overall resistance factor $\lambda_1$, during flow, is given by (Li et al., 1977):

$$\lambda_1 = \lambda_s + (\lambda_{max} - \lambda_s)\,\xi_g^2 \;,\; 0 \leq \xi_g \leq 1 \quad \ldots\ldots\ldots\ldots [2]$$

where $\lambda_{max}$ = a resistance factor for a grass cover of $\xi_g$ = 1 and $\lambda_s$ = a resistance factor for bare soil. Resistance parameter values were selected from Rovey et al. (1977). Selected values of $\lambda_{max}$ were assumed to be 10,000 during the winter months when the grass height is low, and 40,000 during the summer and fall. The soil resistance factor, $\lambda_s$, was assumed to be 50.

The watershed has been in pasture since November 1976. Estimates of stocking rates and bare soil fraction, $\xi$, were given by White (1978, unpublished data)†. These estimates and estimated percent manure cover, $\xi_m$ (equation [1]) are given in Table 5 for selected storm events. The bare soil fraction, $\xi$, on July 16 (storm 6), as indicated in Table 5, is 0.05. On July 5, 25 cows, 25 calves and 1 bull were moved into the field B-1 (3.1-ha) which includes watershed WS-129. The animals were in this pasture until July 15 when they were moved into another pasture. This grazing and consequent trampling is assumed to have exposed more soil to raindrop detachment than would be assumed with no animal traffic. Consequently, a value of 0.05 for $\xi$ was assumed in Table 5, rather than 0.0 if previous values were extrapolated (White, 1978).

The watershed slope was approximated by a series of four overland flow lengths of 30.5 m, with slopes of 16, 25, 26, and 22 percent respectively. A spatial increment, $\Delta x$, of 10.2 m was used in the numerical solution of the governing equations.

A time step size, $\Delta t$, of 5 min was generally used. However, a smaller $\Delta t$ of 1 min was used for high intensity rainstorms like storm No. 6 (July 16, 1977). We ex-

†White, R. K. 1978. Agr. Eng. Dept., Ohio State Univ., Columbus.

**TABLE 5. STOCKING RATES, MANURE COVER, AND GROUNDCOVER FOR SELECTED STORM EVENTS (WS-129).**

| Storm No. | Storm Date | Stocking rate, heads/ha * | Animal days since | | Mean excretal density $D_t$ | Portion of pasture without manure, $P_t$ | Manure cover, $\xi_m$ | Bare soil fraction, $\xi$ |
|---|---|---|---|---|---|---|---|---|
| | | | Start of grazing | Last storm | | | | |
| 1 | 4/2/77 | 7.9 | 153 | 15 | 0.135 | 0.88 | 0.12 | 0.58 |
| 2 | 4/4/77 | 7.9 | 155 | 2 | 0.137 | 0.88 | 0.12 | 0.57 |
| 3 | 4/28/77 | 0 | 172 | 7 | 0.152 | 0.86 | 0.14 | 0.19 |
| 4 | 5/6/77 | 0 | 172 | 0 | 0.152 | 0.86 | 0.14 | 0.14 |
| 5 | 7/4/77 | 0 | 172 | 0 | 0.152 | 0.86 | 0.14 | 0.01 |
| 6 | 7/16/77 | 8.4 | 187 | 15 | 0.176 | 0.84 | 0.16 | 0.05 |

* 1 animal unit = 1 cow-calf

perienced no problems with convergence or stability in the numerical scheme with these selected spatial and time increments.

Since the purpose of the study was to validate the sediment-manure model, the model parameters in the water routing and hydrology sections were varied to obtain "best" fit of the simulated with the measured flows. Once the flow model was "calibrated," the sediment component of the model was run. No calibrations were, however, made in the sediment phase. The results shown are those obtained with the initial estimates for the parameter values. Computed total sediment yields and time-dependent sediment loads during a storm were compared with measured values.

## Results

The model is based on two important concepts: (a) the actual sediment load is the lesser of the transport capacity of the flow or the availability of material for transport, and (b) total transport capacity is appropriated among the particle types to maximize its utilization. If the transport capacity exceeds sediment availability, transport rate equals the rate of sediment availability from detachment and sediment arriving from upslope. If the transport capacity is less than sediment availability, deposition occurs, and actual transport rates are controlled by the transport capacity of the flow.

When the sediment is a mixture of particle types, the flow is assumed to distribute its total transport capacity among the particle types. When there is excess capacity, i.e., where more capacity is available for a given particle type than there is sediment of that type available for transport, the excess capacity shifts to other particle types. The technique of distributing available excess capacity to deficit types was illustrated by Khaleel et al. (1979).

A further illustration on the technique of appropriating the total capacity among the particle types is presented in Table 6, which shows the computed bedload, suspended load and total load transport capacities for each particle type and for each storm. These are cumulative values for each storm and were obtained by adding the rates at each time step during the storm. The total storm yield values were then divided by the watershed area to obtain average yields per unit area for the watershed. The adjustments in the transport capacities were made each time step rather than at the end of the storm as Table 6 might suggest.

As indicated in Table 6, before redistribution of total transport capacity among particle types, the transport capacity for fine primary, coarse primary, and manure particles exceeded the availability of the sediment load of the respective particles for all storms except storm No. 3. However, the transport capacity for the aggregate type was only a fraction of that for the other three types. This was due to the fact that flow velocities were too small to transport these larger particles. With the redistribution of the excess available transport capacity, however, ample transport capacity was available for the aggregate type except for storm No. 3.

The computed "new" bedload, suspended load and total load transport capacities for each particle type in Table 6 (after redistribution of excess capacity) should not be interpreted as being the actual transport capacities when particles of these sizes and densities are present. In this case, the capacity for the aggregates is the maximum available for that type given the amounts of the other particles. As the amounts of the other particles increase, the transport capacity for the aggregates becomes less because there would be less excess capacity to distribute to the aggregates. Furthermore, storm No. 3 illustrates a case where a particle type cannot be transported because it is either too large or too dense even though excess transport capacity may be available from other particle types. In effect, these nontransportable particles become a part of the surface roughness.

Most of the transport capacity for the fine primary and coarse primary types consist of suspended load (Table 6). For example, for storm No. 6, 98 percent of the total load for the fine primary type is suspended, whereas for the coarse primary type, 86 percent of the total load is suspended. For the same storm, 100 percent of the total load for the aggregate type is composed of bedload. Almost 60 percent of the total load for manure particles is also bedload.

The total sediment yield per unit watershed area measured for each storm and that estimated by the sediment model are shown in Table 7. Estimated sediment yield values for the individual particle types in Table 7 are related to transport capacity estimates (after redistribution of transport capacity) in Table 6. For example, estimated sediment yields for storm No. 1 for fine primary, coarse primary and manure particle types are equal to their respective transport capacities in Table 6,

TABLE 6. COMPUTED TRANSPORT CAPACITIES FOR BEDLOAD, SUSPENDED LOAD AND TOTAL LOAD FOR ALL PARTICLE TYPES USING YALIN AND EINSTEIN EQUATIONS.

| Storm No. | | Fine primary, kg/ha | | | Coarse primary, kg/ha | | | Aggregates, kg/ha | | | Manure particles, kg/ha | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bed* load | Suspended load | Total load | Bed load | Suspended load | Total load | Bed load | Suspended load | Total load | Bed load | Suspended load | Total load |
| 1 | Before† | 817 | 11703 | 12520 | 96 | 225 | 321 | 19.9 | 1.0 | 20.9 | 1204 | 387 | 1591 |
| | After | 20.6 | 150.8 | 171.4 | 4.8 | 9.9 | 14.7 | 436 | 21 | 457 | 18.4 | 4.4 | 22.8 |
| 2 | Before | 636 | 13172 | 13808 | 137 | 438 | 575 | 54.2 | 3.1 | 57.3 | 1009 | 464 | 1473 |
| | After | 2.2 | 25.5 | 27.7 | 1.2 | 2.7 | 3.9 | 962 | 55 | 1017 | 7.1 | 2.3 | 9.4 |
| 3 | Before | 0.56 | 1.79 | 2.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | After | 0.56 | 1.79 | 2.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Before | 98 | 2361 | 2459 | 9.3 | 26.6 | 35.9 | 0.31 | 0 | 0.31 | 153 | 68 | 221 |
| | After | 2.9 | 41.4 | 44.3 | 0.8 | 2.3 | 3.1 | 13.1 | 0 | 13.1 | 1.71 | 0.43 | 2.14 |
| 5 | Before | 58 | 2108 | 2166 | 5.3 | 22.6 | 27.9 | 0.31 | 0 | 0.31 | 90 | 22 | 112. |
| | After | 0.16 | 4.55 | 4.71 | 0.11 | 0.42 | 0.53 | 11.0 | 0 | 11.0 | 0.6 | 0.1 | 0.7 |
| 6 | Before | 161 | 7903 | 8064 | 41 | 238 | 279 | 14.3 | 0 | 14.3 | 285 | 179 | 464 |
| | After | 80 | 4338 | 4418 | 25 | 149 | 174 | 107 | 0 | 107 | 157 | 111 | 268 |

*Bedload and suspended load transport capacities are computed using the Yalin and modified Einstein equations, respectively (Khaleel et al., 1979). Total load = bedload + suspended load.

†"Before" and "after" loads correspond to transport capacities before and after distribution of available excess transport capacity to deficit particle types using the technique described in Khaleel et al. (1979).

since transport capacity for these particles exceeded their availability. Therefore, in the redistribution, their transport capacity was set equal to their availability to determine the excess transport capacity to shift to the aggregates. After redistribution, sediment availability for the aggregates was less than its transport capacity. Therefore the estimated sediment yield (130.48 kg/ha) for the aggregates, as indicated in Table 7, is less than the indicated transport capacity (457 kg/ha) in Table 6. In effect, except for storm No. 3, availability of detached sediment was the factor controlling estimated sediment yield and not transport capacity. Therefore, the degree that the model fits the observed data is a measure of the adequacy of the detachment relationships and not of the transport relationships. Also the lower limit of particle density (Table 3) at which the transport equations in the model fail has not been established, although Davis (1978) found satisfactory results for densities as low as 1.55 g/cm³.

Generally, the estimated sediment yields agreed well with measured data, especially for storm Nos. 3 through 6. Estimated sediment yields differed significantly from measured yields for storm Nos. 1 and 2. No rainfall data were available for these two storms. Instead, the rainfall data for WS-106, which was located about 1.2 km south of WS-129, were used in the model. These rainfall data might have been different from those on WS-129 to cause the overprediction for storm No. 1 and underprediction for storm No. 2. Furthermore, the earlier storm (storm No. 1) might have deposited sediment in the pondage above the flume. The higher discharge during the latter storm (the estimated peak discharge rates for storm Nos. 1 and 2 were 0.016 and 0.023 m³/s, respectively, i.e., the peak discharge for storm No. 2 was 1.44 times that of storm No. 1) may have "cleaned out" some of this sediment increasing the sediment yield. Nevertheless, this same type of error would exist with most other sediment models (Foster et al., 1977a, b; Williams and Berndt, 1977).

The watershed had about the same groundcover for storm Nos. 1 and 2. The estimated peak discharge rate for storm No. 2 increased but not significantly. Sediment yield can only decrease when rainfall amount, peak rainfall intensity and runoff volume decrease (Table 7), whereas other factors do not change significantly. The measured data on sediment yield, however, suggest otherwise. The observed data for storm Nos. 1 and 2 might, therefore, be in considerable error and do not provide a fair test of the model.

The importance of groundcover is illustrated in Table 7. With a 42 percent groundcover ($\xi = 0.58$), the simulated sediment yield is 339 kg/ha, whereas with a 99 percent groundcover ($\xi = 0.01$), the simulated yield is only 9.33 kg/ha. The grass cover reduces the flow velocities to very low values, and most of the shear stresses exerted by the flow are absorbed by the grassed medium. Also, the increased groundcover significantly reduces detachment by raindrop impact.

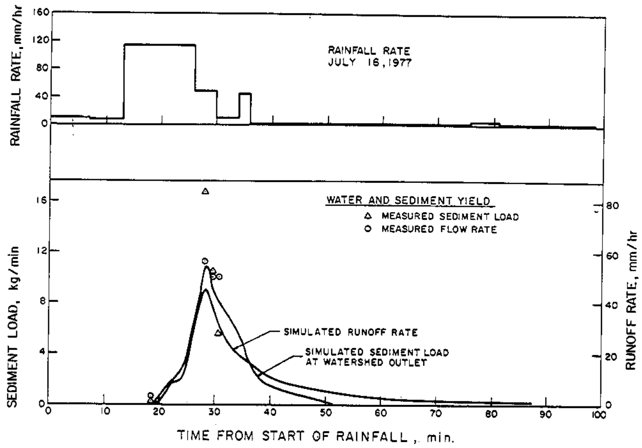


**FIG. 3 Comparison of predicted and measured sediment loads for storm of July 16, 1977.**

Although the percent groundcover for both storm Nos. 1 and 2 were about the same, the sediment particle type fractions for the two storms were different (Table 7). The percents of fine primary, coarse primary, aggregates and manure particles in the total sediment yield for storm No. 1 were 51, 4, 38, and 7 percent respectively, whereas, for storm No. 2, these fractions were 13, 2, 80, and 5 percent, respectively. For storm No. 1, the ratios of percent each fraction present in sediment to percent present in the soil detached by raindrop impact are 1.06 and 0.93 for the aggregate and fine primary type, respectively, whereas, for storm No. 2, these ratios are 2.2 and 0.24, respectively. The difference between the storms represents the increased rill erosion during storm No. 2.

Fig. 3 shows a comparison of the measured and simulated sediment load at the watershed outlet during storm No. 6. Simulated peak runoff rate for the storm was within 16 percent of the measured peak flow and the estimated time to peak was within 1 min of the measured value. However, the simulated peak sediment load is underestimated by almost 35 percent as compared with the measured peak. The peak rainfall rate for storm No. 6 was 11.6 cm/h for 13 min (Fig. 3). The measured and simulated peak sediment loads immediately followed this rainfall.

As indicated in Fig. 3, very few data points are available to adequately describe the shape of the measured sediment load curve. Furthermore, almost all changes in measured sediment load are shown to occur within about 4 min. These measurements might be in error and accuracy of the measured peak sediment load is questionable.

TABLE 7. ESTIMATED AND MEASURED SEDIMENT YIELDS FOR SELECTED STORM EVENTS (WS-129).

| Storm No. | Storm Date | Rainfall amount, cm | Peak 15-min rainfall intensity, cm/hr | Rainfall duration, hrs | Runoff duration, hrs | Runoff volume, cm | | Measured sediment yield, kg /ha | Predicted sediment yield, kg /ha | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Measured | Predicted | | Fine primary | Coarse primary | Aggregate | Manure particles | Total |
| 1 | 4/2/77 | 4.19* | 1.52 | 11.58 | 18.60 | 1.28 | 1.11 | 255.70 | 171.40 | 14.68 | 130.48 | 22.84 | 339.40 |
| 2 | 4/4/77 | 1.14* | 1.02 | 5.80 | 14.85 | 0.56 | 0.65 | 339.83 | 27.68 | 3.93 | 167.30 | 9.40 | 208.31 |
| 3 | 4/28/77 | 1.52 | 1.83 | 5.52 | 9.08 | 0.04 | 0.07 | 8.06 | 2.35 | 0.0 | 0.0 | 0.0 | 2.35 |
| 4 | 5/6/77 | 1.62 | 2.24 | 7.53 | 20.38 | 0.56 | 0.61 | 40.81 | 27.35 | 3.05 | 11.26 | 2.14 | 43.80 |
| 5 | 7/4/77 | 6.10 | 5.38 | 3.93 | 5.30 | 1.13 | 1.08 | 9.33 | 4.71 | 0.53 | 4.24 | 0.70 | 10.18 |
| 6 | 7/16/77 | 3.56 | 9.45 | 1.65 | 4.37 | 1.01 | 1.07 | 70.10 | 41.20 | 5.31 | 35.12 | 9.80 | 91.43 |

* Watershed WS-106 rainfall data

TABLE 8. COMPARISON OF MEASURED AND ESTIMATED TOC FOR VALIDATION OF MANURE TRANSPORT COMPONENT OF THE MODEL.

| Storm No. | Measured TOC, kg/ha | Estimated TOC, kg/ha | | |
|---|---|---|---|---|
| | | manure† | soil‡ | total |
| 1 | 19.9 | 9.1 | 12.6 | 21.7 |
| 2 | – | 3.8 | 8.0 | 11.8 |
| 3 | 0.5 | 0 | 0.1 | 0.1 |
| 4 | 4.6 | 0.9 | 1.7 | 2.6 |
| 5 | 2.0 | 0.3 | 0.4 | 0.7 |
| 6 | 3.3 | 3.9 | 3.2 | 7.1 |

†Estimated contribution from manure = 0.4 times estimated manure particles.
‡Estimated contribution from soil = (Estimated sediment yield excluding manure) x (Soil Org. C) x (Enrichment factor for C)
Enrichment factor = 2.0
Soil organic C = 2.0 percent
Manure organic C = 40.0 percent

The measured sediment yield contains both soil and manure particles (Table 7). However, the manure particles were not separated out of the total sediment. The measured total organic carbon (TOC), which includes contribution from both soil and manure, was used to test the sediment-manure model for the manure transport component. The manure particles were assumed to have an organic C content of 40 percent (Reddy et al., 1979). The soil organic C was given as 2 percent (Kelley et al., 1975). Assuming an enrichment factor for carbon of 2 (Reddy et al., 1979), the contribution of soil component to TOC was obtained by multiplying the estimated sediment yield (excluding manure particles) by the soil organic C and the enrichment factor for C. Table 8 gives the estimated TOC, for soil and manure, and the measured TOC for each storm. The measured data agreed reasonably well, within the same order of magnitude, with the estimated TOC values.

The initial testing of the sediment-manure model indicated relatively accurate simulation of the total sediment yields. The ability of the model to fit well measured sediment yield data for widely varying storms and groundcover indicates that the model equations are relatively accurate and respond well to varying storm-runoff characteristics for this watershed.

## SUMMARY AND CONCLUSIONS

Input parameter values were selected for a mathematical model previously presented (Khaleel et al., 1979) for transport of sediment and manure particles from land areas receiving animal wastes, and the model was used to simulate erosion and sediment yields which were compared with measured data. The model inputs are: (a) manure cover on the watershed; (b) manure erodibility factor; and (c) manure particle-size distribution and particle density. Other inputs are related to the erosion and transport of soil particles. Initial testing of the model has indicated relatively accurate simulation of sediment yields for selected storm events from a small upland pasture watershed. As expected, the results indicated that, for a pasture, groundcover is the most important factor controlling erosion. For this watershed, where detachment was limiting, the model seems to adequately describe the influences of groundcover, varying rainfall intensities, and runoff characteristics on detachment.

No field data were available to test the sediment yields by particle type fractions. Some limited validation of the manure transport component of the model was obtained by comparing the estimated and measured TOC values. Further evaluation of the model for differing manure application modes and watershed conditions is needed. More data on manure erodibility factors and manure particle-size distribution and densities are needed to estimate manure detachment and transport relationships.

The equations and the coefficients used for erosion and sediment transport equations were obtained by combined theoretical-empirical methods (Khaleel et al., 1979). The model input parameters for the sediment phase were obtained from literature, and not by calibration against existing field data. Thus, the closeness between simulated and measured sediment yield without calibration is highly encouraging. This indicates that the erosion-sediment phase of the model might be extended to other watersheds with a minimum of calibration. Although channel erosion, which was not included in this model, can be a significant factor in many upland areas, the model can serve as a useful management tool and provide the framework for many types of estimation of varying complexity.

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