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Distributed Parameter Watershed Sedimentation Model

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The model developed herein uses a detailed geometric description of the watershed and incorporates the kinematic wave approximation of the equations of motion, superposition, and time-lag methods to analyze flood and sediment flows. The watershed is broken down along tributary divides into subcatchments, which are divided along lines of steepest slope into "streamtubes." These streamtubes are further divided according to slope into "segments," such that topographic parameters of each segment are spatially constant over the segment. The flow from the streamtube enters the channel at the mid-point of the streamtube bordering the channel. This point is called a "node." Channel routing is performed from node to node. A unique node numbering and coding system is defined to efficiently order the computations along the streamtubes and channel sections for any arbitrary streamtube pattern. Sediment detachment capacity is expressed as a power function of shear stress and a function of the Universal Soil Loss Equation. Sediment transport capacity is expressed as a power function of shear stress. The rate of sediment transport is computed by substituting the transport and detachment capacity equations into the sediment continuity equation. The model is applied to Ralston Creek, an agricultural watershed in Iowa City, Iowa. Results of this analysis are presented and applicability to other watersheds is discussed.
INDEX DESCRIPTORS: Distributed model, kinematic model, sediment production, watershed modelling, erosion.

Recurring and increasing problems of sediment production and transport and non-point source pollution signal society's failure to adequately understand the nature and role of watersheds and their response to flooding events. There is a recognized and increasing need for watershed models which encompass relevant physical data depicting the interrelationships of weather, topography, sediment production, etc., as mandated by current legislation (PL 92-500 and amendments).

There is still a need for models that: (1) allow easy incorporation and testing of sediment production for overland flows; (2) allow analysis of watershed response to passage of storm cells of differing orientation and spatial and temporal definition; (3) allow analysis of the effects of land use pattern on both flooding and sedimentation; and (4) can be used for ungaged watersheds where information is limited to observable watershed characteristics.

In response to this need, a model has been developed to study sediment production and transport, weather variability, water quality, and physical consequences of soil conservation practices, agricultural production practices, and management practices for water quality.

The model treats the watershed as a distributed system incorporating adequate detail for watershed attributes to modifications in naturally defined drainage components of a given watershed. It has been developed in order to simulate an event on the watershed. It is not developed herein to predict storm hydrographs, but to help predict effects of land use/watershed changes from uniform storms of finite duration.

BACKGROUND

Modelling overland sediment erosion, so as not to become site or storm dependent, is very difficult. At present, the inexact nature of the state of the art allows a wide variety of techniques to be employed for sediment prediction. The most common method used is the Universal Soil Loss Equation (USLE)[1]:

$$A_a = R\ K\ S_a\ L_a\ C_a\ P \tag{1}$$

in which A_a = the predicted average annual soil loss (tons/acre/year); C_a = cropping factor; K = soil erodibility factor; S_a = slope gradient factor, L_a = slope length factor; P = erosion control practice factor; and R = rainfall factor. Wischmeier and Smith presented the storm rainfall factor, based upon kinetic energy considerations of falling rain and based upon empirical multivariate analysis:[2]

$$R = (\sum_{j=0}^{K-1} [916 + 331\ \log_{10} \bar{i}_j]\ I \tag{2}$$

in which $\bar{i}_j$ = average intensity (in/hr) in the time increment $j\Delta t$ to $(j + 1)\Delta t$, I = the maximum 30-minute intensity (in/hr) for the storm; and the summation is carried out over Δt time increments comprising the total storm event of length $T = K\Delta t$.

The USLE was designated to estimate the average annual soil loss from a given watershed. It was derived from erosion data collected over many years using a statistical analysis approach. Because it is based on information related to a watershed, it may be applied to help predict soil erosion on the watershed.

SEDIMENT TRANSPORT

Detachment capacity of sediment from the land surface has been expressed in a number of ways. It has been considered a function of the USLE, a power function of rainfall intensity, a power function of shear stress, a power function of velocity or discharge (and/or critical velocity and discharge), or a combination of the above. Since shear stress and velocity are related either parameter may be used with the appropriate powers attached.

For a given flow condition a maximum detachment exists and this detachment capacity can therefore be expressed as a function of the USLE and shear stress:

$$D_c = f\ (A_a, \tau^n) \tag{3}$$

in which D_c = detachment capacity (tons/ft²/sec), f(•) = function of the terms between the brackets, τ = shear stress (tons/ft²), and n = exponent[4].

Meyer and Monk, and Willis noted that the rate of detachment was affected by the amount of sediment in the flow.[4] Foster and Meyer presented an interrelationship between detachment and sediment transport;[4,5]

$$\frac{D_n}{D_c} + \frac{Cq}{T_c} = 1 \qquad (4)$$

where D_n = net detachment rate (tons/ft²/sec), T_c = transport capacity (tons/ft/sec), C = sediment concentration (tons/ft³), and q = unit discharge (ft²/sec). Foster and Meyer mentioned that, based on observations, the rate of detachment or deposition by flow is a function of the difference between the actual sediment flow and the maximum amount of sediment the flow can transport:

$$D_n = C_1 (T_c - Cq) \qquad (5)$$

where C_1 = constant depending on land use and soil characteristics. Eqs. (4) and (5) then reveal:

$$D_c = C_1 T_c \qquad (6)$$

In the past investigators have employed familiar channel bed load equations to represent the transport capacity. Most may be expressed as:

$$T_c = C_t \tau^n \qquad (7)$$

where C_t = constant depending on flow and sediment characteristics.

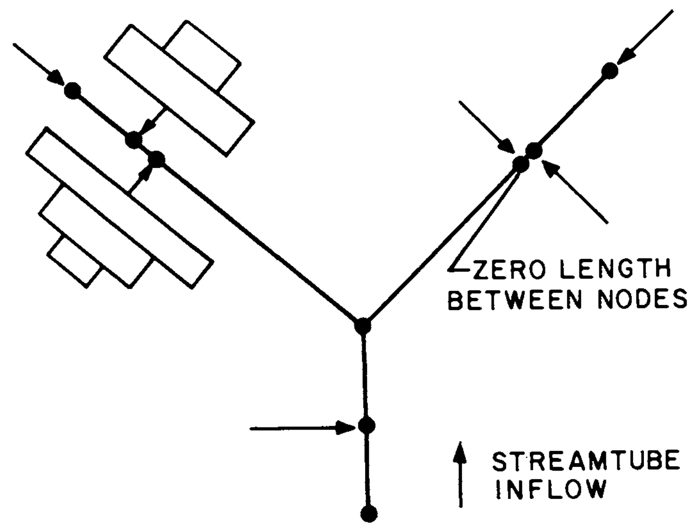

Fig. 2. *Characterization of watershed, streamtubes, nodes and zero-length between nodes.*

WATERSHED TRANSPORTATION

The watershed under study is the 3.01 sq. mile (7.80 Km²) north branch watershed of Ralston Creek, Iowa City, Iowa and is treated as a distributed system where outflows are sensitive to modifications in any portion of the watershed. The watershed is divided along tributary divides into subcatchments. These catchments are further divided along lines of steepest slope into "streamtubes," as in Figure 1.[5,6,7] All watershed characteristics vary along the streamtube. They are bounded by the primary divide on top, the lines of steepest slope on the sides (secondary divides), and the channel at the bottom. The streamtubes are further divided according to slope into streamtube "segments." It should be noted that the hydrologic and topographic properties are spatially uniform within each streamtube segment.

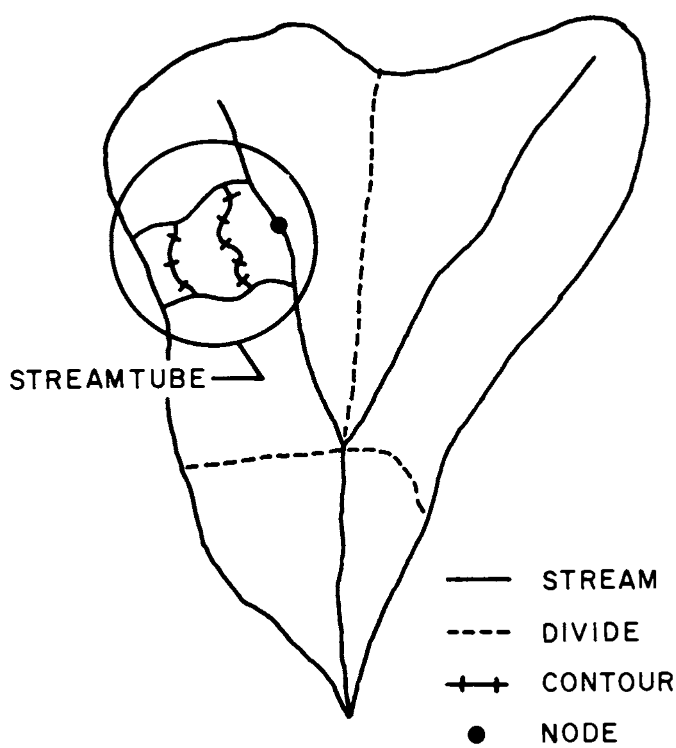

Fig. 1. *Natural watershed and streamtube representation.*

The streamtube flow enters the stream at a point midway along the lower streamtube boundary defined as a "node," pictured in Figure 2. If the distance between the nodes is small, this concept can be a very good approximation to the lateral inflow into the stream. Other conditions under which a node exists are (i) the intersection of two tributaries; (ii) the beginning and ending of a culvert; and (iii) the mouth of the watershed. When the flow from two streamtubes, a streamtube and the intersection of two tributaries or a streamtube and a culvert beginning occur at the same location, then each inflow is represented by a node with zero-length between them. An entire watershed is thus represented by a series of cascading planar elements where the flow enters the stream at nodes and is routed down from node to node to the mouth of the watershed.[5,6,7]

In order to minimize the amount of computer storage, a node numbering and coding scheme and computation logic is defined that will automatically perform streamtube computations, channel computations, and node computations in the correct order for any arbitrary stream pattern and streamtube definition. The following rules for numbering nodes should be adhered to: i) start at the mouth of the watershed and proceed upstream always to the right at tributary junctions until the node at the end of the first branch is reached. This is node number 1; ii) proceed downstream numbering the succeeding nodes 2, 3, etc., until a tributary junction is met. Do not number this point, but proceed upstream on the new tributary always staying to the right until the end is reached. This is the next numbered node; iii) proceed downstream on this second tributary numbering the succeeding nodes as before until a second tributary junction is met. Follow the same rules here as in step ii; iv) continue in this manner until a previously encountered tributary node is reencountered. This node is now numbered; v) continue downstream until all nodes have been defined by repeating steps ii through iv where applicable. The hydrographs are routed down the channel in the sequential order of node numbers. Nodes are coded so the computer recognizes tributaries and other junction types and performs the appro-

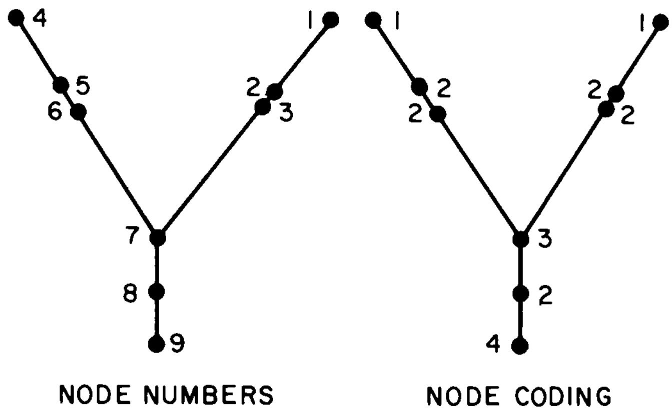

Fig. 3. *Node numbering and coding schemes.*

priate boundary condition calculations. A node code is assigned to each node. This code defines the computational procedure to be employed; i) node code 1 denotes the most upstream node where input is from a single streamtube; ii) node code 2 denotes an intermediate node where input is from a single streamtube and from the immediate upstream channel section flow; iii) node code 3 denotes the junction of 2 tributaries where inflow is from only the 2 upstream channel sections; and iv) node code 4 denotes an outflow point where inflow is from only a single upstream channel section such as a culvert or the mouth of the watershed (but not at a tributary junction). Therefore, in the routing procedure the node numbers assign the logical order for the computations and the node codes convey information as to the procedure to be performed at the node. These both are illustrated in Figure 3.

When a node code 3 exists, the hydrograph computed for the initial tributary is saved while the succeeding tributary's hydrograph is computed. The hydrograph saved is called a "pending" hydrograph. More than one hydrograph may be saved and the last pending hydrograph is the first hydrograph used when a node code 3 is encountered. This scheme presented is simple and fast and results in systematic storage of pending hydrographs at tributaries that allow for their recall in the order they are needed.

The channel flow model allows natural channel shapes to be used in the model as opposed to the traditional geometric cross sections.[5,6,7,8] Flow-area arrays and area-flow derivative arrays have been developed at each node via contour maps for use in the routing of water and sediment flows.[9] Lateral inflow is not considered at points other than nodes. The rainfall excess varies spatially but uniformly over each Thiessen polygon in the Thiessen polygon method. It is thus possible to account for different storms occurring at different locations at different times. It is also possible that a streamtube can have different rainfall excess inputs on different segments even though the rainfall excess is spatially uniform on that segment.

Even though a watershed is complex, a large portion can be based on readily available information characteristic of the watershed. Most of the data needed for the watershed representation is available in the form of tables and maps from ARS, SCS, USDA, COE and USGS.

OVERLAND FLOW MODEL

One-dimensional flow over a streamtube segment can be described by the equations of motion:

continuity:
$$\frac{\partial q}{\partial x} + \frac{\partial h}{\partial t} = i \qquad (8)$$

and momentum (with the kinematic wave approximation):

$$S_o = S_f \qquad (9)$$

in which q = unit discharge (ft²/sec), h = depth of flow (ft), i = lateral inflow (ft/sec), t = time (sec), x = distance (ft), S_o = bed slope, and S_f = friction slope. A third equation employed is the basic flow equation:

$$q = \alpha h^m \qquad (10)$$

in which α = constant depending on slope and roughness and m = constant exponent. Eagleson mentions that Horton and other investigators found natural surfaces gave m $\approx$ 2.[10]

The equations associated with the method of charateristics, time lag routing, and superposition of flows form the basis for the development of the overland hydrographs. A trapezoidal hydrograph is developed on each streamtube segment with the segment bordering the primary divide designated as "1" and the succeeding segments down slope as "1 + 1," "1 + 2," etc. The outflow from segment "1" is represented by the hydrograph developed on segment "1," while the outflow from segment "1 + 1" is represented by the superposition of the hydrograph developed on segment "1 + 1" and the outflow hydrograph from segment "1" lagged by a travel time based upon an average depth of flow.

HYDROGRAPH DEVELOPMENT

The essential parts of the hydrograph to be defined are the peak flow rate (Q_p), the time of concentration (t_c) and the rainfall excess duration (t_r).

$t_r > t_c$

When the limiting characteristic (initial disturbance) has time to reach the end of the segment, the time of concentration is expressed as:

$$t_c = \left(\frac{L(i)^{1-m}}{\alpha}\right)^{1/m} \qquad (11)$$

in which L = length of the segment (ft), i = rainfall intensity (ft/sec), t_c = time of concentration (sec) and t_r = rainfall duration (sec). t_c represents the end of the rising limb of the hydrograph and t_r represents the beginning of the recession limb, as pictured in Figure 4.

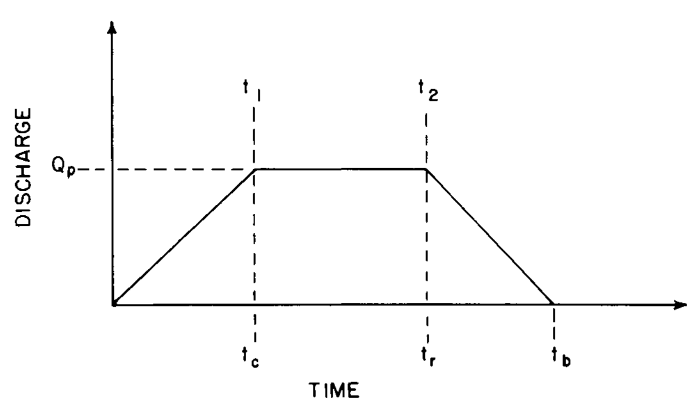

Fig. 4. *Trapezoidal hydrograph for* $t_r \geq t_c$.

The corresponding peak discharge can then be expressed as;

$$Q_p = L\, i\, W \tag{12}$$

in which W = width of the segment (ft).

$t_c > t_r$

When the rainfall excess ceases before the initial disturbance reaches the end of the segment, the time of concentration is expressed as:

$$t_c = t_r + \frac{t_* - t_r}{m} \tag{13}$$

$$\text{where } t_* = \frac{L}{\alpha (h_L)^{m-1}} = \frac{L}{\alpha (it_r)^{m-1}}$$

t_c represents the beginning of the recession limb of the trapezoidal hydrograph and t_r represents the end of the rising limb of the hydrograph, as pictured in Figure 5.

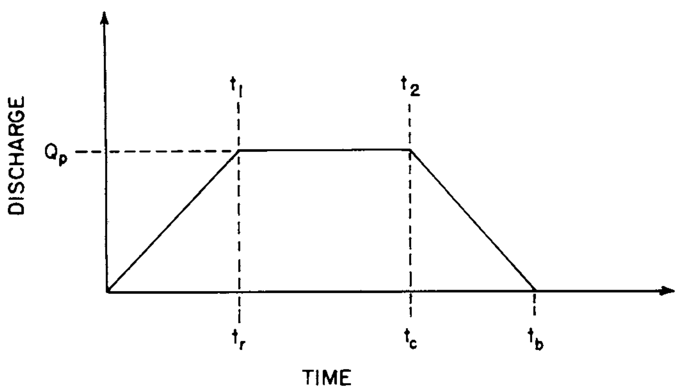

Fig. 5. *Trapezoidal hydrograph where $t_c > t_r$.*

The magnitude of the peak is reduced when $t_r < t_c$ and is expressed as:

$$Q_p = \alpha (i\, t_r)^m W \tag{14}$$

All discharges corresponding to times on the rising and falling limbs of the hydrograph are solved for by linear interpolation. Considering the general derivation of the hydrograph, while considering only an average constant rainfall excess intensity, this assumption appears reasonable. To obtain the base time (t_b) of the hydrograph, the total volume of rainfall excess is equated to the runoff volume:

$$t_b = ([it_r WL - Q_p (\frac{t_1}{2} + (t_2 - t_1))]/Q_p/2) + t_2 \tag{15}$$

where t_1 = end of the rising limb of the hydrograph, and t_2 = start of the falling limb of the hydrograph.

The hydrographs on each segment are calculated in this manner.

TIME LAG ROUTING

Each routed hydrograph is lagged by

$$t_t = \frac{L}{\overline{V}} \tag{16}$$

in which t_t = translation time (sec) and $\overline{V}$ = average flow velocity (ft/sec). The average velocity can be calculated by way of the average discharge:

$$\overline{Q} = \frac{1}{t_b} \left[\sum_{j=o}^{t_b} Q(j) \right] \tag{17}$$

in which $\overline{Q}$ = average discharge (ft³/sec), t_b = hydrograph base time (sec), and Q(j) = discharge at time j(ft³/sec). From the basic flow equation:

$$\overline{Q} = \alpha (\overline{h})^m W \tag{18}$$

and

$$\overline{V} = \alpha (\overline{h})^{m-1} \tag{19}$$

in which $\overline{h}$ = average flow depth (ft). Substituting Eqs. (17) and (18) into Eq. (19) and a further substitution into Eq. (16) gives the lag time for a routed hydrograph:

$$t_t = \left[\frac{L}{\alpha (\frac{\overline{Q}}{\alpha W})^{(m-1/m)}} \right] \tag{20}$$

STORM TRANSLATION

All segments in a streamtube are affected by the same storm. Since the rainfall excess is distributed by way of the Thiessen polygon method, the storm affecting the streamtube and the storm initially affecting the catchment may begin at two different times. This time difference is called the "time to start" (t_s) and is used to lag the streamtube flow rates with respect to the channel flow rates which are based upon the storm which first affects the catchment. The streamtube flow rates are therefore shifted by t_s:

$$Q(j + t_s) = Q(j), \qquad 0 \leq j \leq t_b \tag{21}$$

OUTFLOW HYDROGRAPH

Since the hydrographs which are computed for the individual segments are trapezoidal in shape, they can be computed as:

$$Q(j) = Q_p \left[\frac{j - t_s}{t_1} \right], \qquad t_s \leq j \leq (t_1 + t_s) \tag{22}$$

$$Q(j) = Q_p, \qquad (t_1 + t_s) \leq j \leq (t_2 + t_s) \tag{23}$$

$$Q(j) = \left[\frac{t_b + t_s - j}{t_b - t_2}\right] Q_p, \quad (t_2+t_s) \leq j \leq (t_b+t_s) \quad (24)$$

Only on the segment furthest from the channel do Eqs. (22) through (24) define the outflow hydrograph from a streamtube segment. The outflow hydrograph from segments not bordering the primary divide is computed as

$$O(j) = Q\,(j + t_t)_l + Q\,(j)_{l+1}, \quad 0 \leq j \quad (25)$$

in which O(j) designates the outflow discharge in cfs.

The initial condition at t = 0 for each segment is

$$Q(k,0) = 0, \quad 0 \leq k \leq L \quad (26)$$

in which k = index on distance and Q(k,j) = discharge at a particular location (k) at a particular time (j).

The upstream boundary condition for each streamtube is

$$Q(0,j) = 0, \quad 0 \leq j \quad (27)$$

The boundary conditions of each streamtube segment except for the segment furthest from the channel are

$$Q(0,j)_{l+1} = Q(L,j)_l, \quad 0 \leq j \quad (28)$$

while the downstream boundary condition is

$$QS(j) = Q(L,j)_M, \quad 0 \leq j \quad (29)$$

in which QS = channel discharge (ft^3/sec), Q = streamtube discharge (ft^3/sec), and M designates the segment bordering the channel.

CHANNEL ROUTING MODEL

The channel hydrographs are routed from node to node via time lag routing as expressed by Eqs. (16) through (20). The channel length (L_c) is employed in Eq. (20) as opposed to the streamtube segment length. The channel hydrograph entering the next node from the preceeding channel section is

$$QS(j)_{l+1} = QS\,(j + t_t)_l, \quad 0 \leq j \quad (30)$$

in which "l + 1" and "l" designate the downstream and upstream segments, respectively.

The initial condition at t = 0 is

$$QS(k,0) = 0, \quad 0 \leq k \leq L_c \quad (31)$$

The boundary conditions are for a node code one

$$QS(0,j) = Q(j), \quad 0 \leq j \quad (32)$$

for a node code two

$$QS(0,j)_{l+1} = Q(j) + QS(L_c,j)_l, \quad 0 \leq j \quad (33)$$

for a node code three

$$QS(0,j)_{l+1} = [QS(L_c,j)_1 + QS(L_c,j)_2]_l, \quad 0 \leq j \quad (34)$$

and for a node code four

$$QS(0_j)_{l+1} = QS(L_c,j)_l, \quad 0 \leq j \quad (35)$$

in which the subscripts "1" and "2" designate upstream converging tributaries.

The cross-sectional area can be considered unchanging with distance between nodes. The graphical relationship of QS *vs* A (channel area) and $\frac{d(QS)}{dA}$ *VS* A are computerized and stored and used when needed.[9] The USGS provided Manning roughness values for the channel and they ranged from 0.03 to 0.09. Likewise, Manning's coefficient was used as the roughness parameter in the overland case. A number of investigators have presented values ranging from 0.10 to 0.50.

EROSION MODEL

Overland Erosion Model

The rate of sediment transport from each streamtube segment is determined by using the basic concept that rainfall and runoff detach soil from field surfaces and transport it overland to drainage ways. Routing is based upon the sediment continuity equation:

$$\frac{\partial Cq}{\partial x} + \frac{\partial Ch}{\partial t} = D_n \quad (36)$$

In the past many definitions of detachment have existed. Net detachment rate (D_n) is the rate at which the soil is literally detached and entrained by the moving fluid. Detachment capacity is the maximum rate of sediment detachment for a given land and flow condition. By changing land use the detachment rate will change. From Eqs. (1) and (3) the detachment capacity rate is expressed as:.

$$D_c = C_2 A_a \tau^n = C_d A_a (Sh)^n \quad (37)$$

where

$$(C_d = C_2 \gamma^n)$$

in which h = depth of flow (ft), C_2 = constant of proportionality, n = exponent taken herein to equal 3/2, γ = specific weight of water, S = overland slope. The detachment capacity, D_c, and the transport capacity, T_c, are related according to Eq. (6) and both can be expressed as proportional to τ^n. Expressing the transport capacity by

$$T_c = C_t\,(Sh)^n \quad (38)$$

and combining Eqs. (5), (6), (37), and (38) yield

$$D_n = C_1(C_t\,(Sh)^n - Cq) \quad (39)$$

where

$$C_1 = \frac{C_d A_a}{C_t}$$

in which C_t = constant independent of land use. Combining Eqs. (36) and (39):

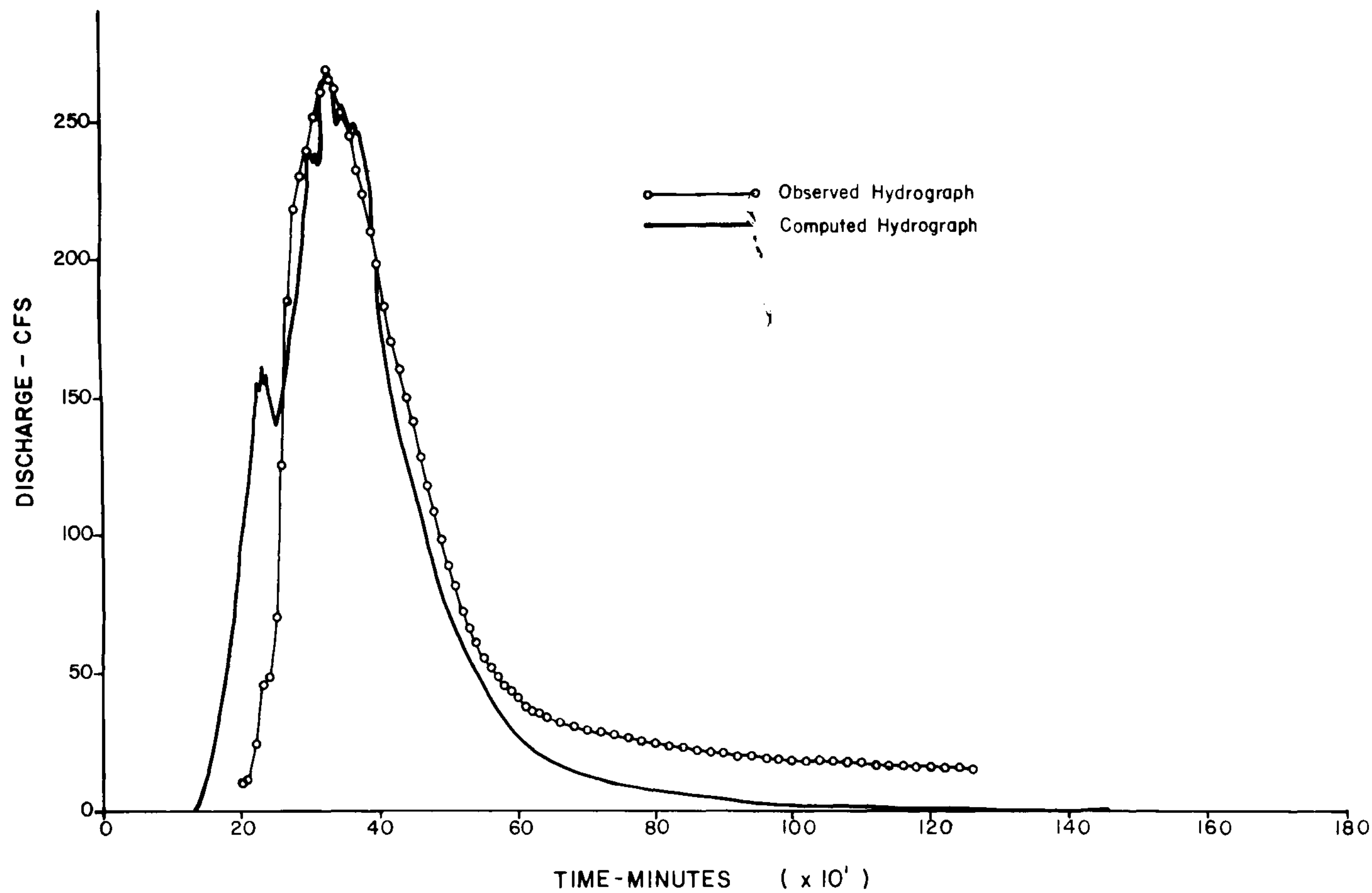

Fig. 6. *Storm-flood hydrograph, May 29, 1974.*

$$\frac{\partial (Cq)}{\partial x} + \frac{\partial (Ch)}{\partial t} = C_l(C_t(Sh)^n - Cq) \qquad (40)$$

Expanding Eq. (40) out and noting $\frac{\partial q}{\partial x} + \frac{\partial h}{\partial t} = i$, then:

$$q\,\frac{\partial C}{\partial x} + h\,\frac{\partial C}{\partial t} = C_l(C_t(Sh)^n - Cq) - Ci \qquad (41)$$

Replacing the differentials with a first-order finite-difference approximation (backward difference form) and solving for the concentration:

$$C^j_{l+1} = \frac{\left[C_l C_t\,(Sh^j_{l+1})^n + \frac{h^j_{l+1}\,C^{j-1}_{l+1}}{\Delta t} + \frac{\alpha(h^j_{l+1})^m\,C^j_l}{L}\right]}{\left[\alpha(h^j_{l+1})^M\,\frac{(C_l L+1)}{L} + \frac{h^j_{l+1}}{\Delta t} + i\right]} \qquad (42)$$

in which "l+1" designates the downstream boundary of the segment, "l" designates the upstream boundary of the segment, the distance increment is the length of the segment, and

$C^j_{l+1} = C(L,j)$, $C^{j-1}_{l+1} = C(L,(j-1))$, $C^j_l = C(0,j)$, and $h^j_{l+1} = h(L,j)$,

The initial conditions for each segment are

$$h(k,0) = 0, \quad C(k,0) = 0, \qquad 0 \leq k \leq L \qquad (43)$$

The upstream boundary condition for each streamtube is

$$h(0,j) = 0, \quad C(0,j) = 0, \qquad 0 \leq j \qquad (44)$$

The boundary conditions of each streamtube segment except for the segment furthest from the channel are

$$h(0,j)_{l+1} = [h(L,j)_l]^{(m_l/m_{l+1})}\left[\frac{(\alpha W)_l}{(\alpha W)_{l+1}}\right]^{1/m_{l+1}}, \qquad 0 \leq j \qquad (45)$$
$$C(0,j)_{l+1} = C(L,j)_l,$$

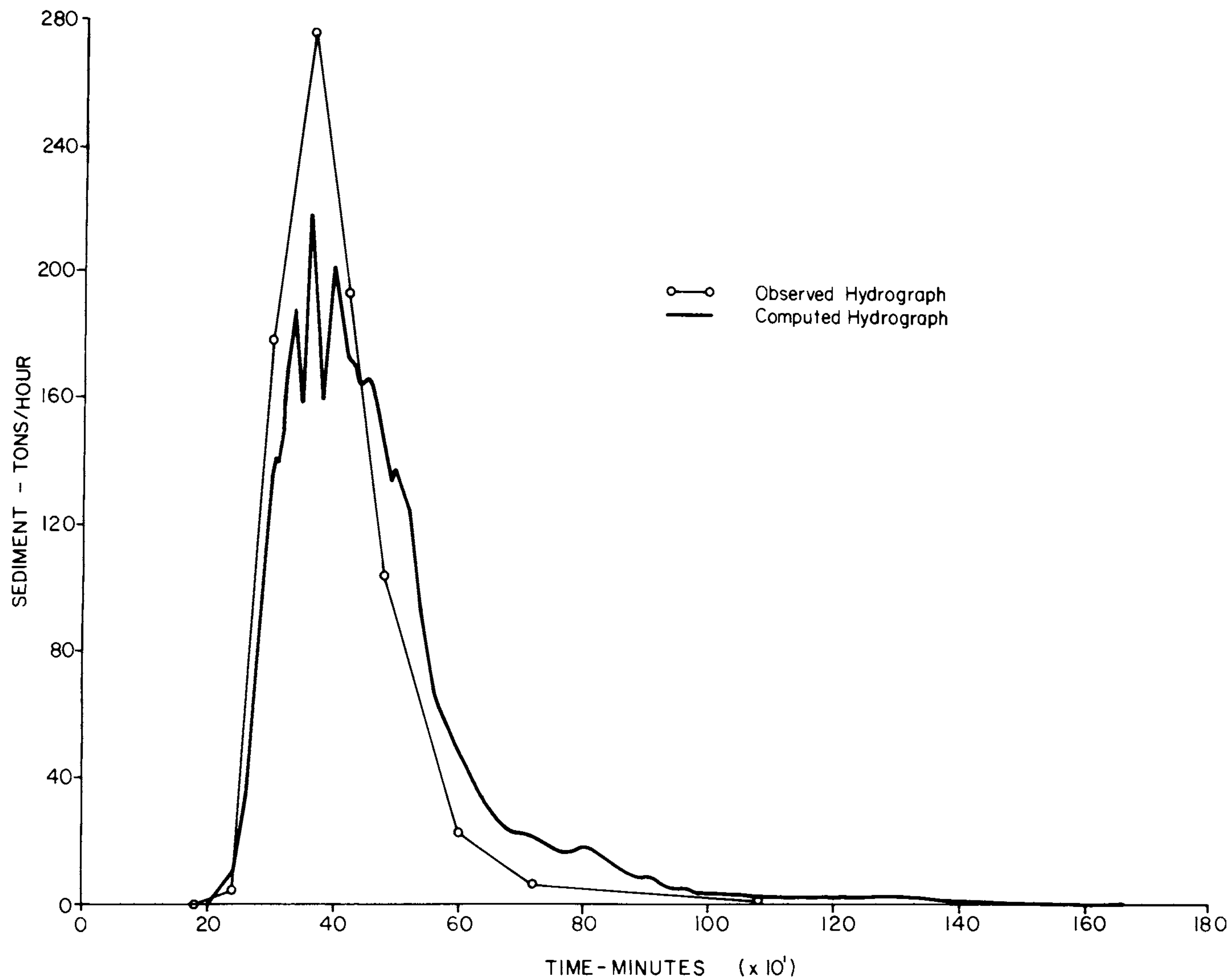

Fig. 7. *Storm-sediment hydrograph, May 29, 1974.*

Routing Procedure

Eq. (42) represents the concentration as a function of time at the downstream end of the segment. C^{j-1}_{l+1} and C^{j}_{l} are determined by initial and boundary conditions, respectively, h^{j}_{l+1} is determined from Eqs. (10) and (25) and is the known rainfall excess information. When C^{j}_{l+1} is calculated (distributed in time), it becomes the upstream boundary condition for the downstream concentration calculation of the succeeding segment (C^{j}_{l+2}). All flood hydrographs for the segment are calculated prior to sediment computations. This procedure repeats itself over the succeeding downstream segments until the channel is reached. The sediment concentration hydrograph is converted to a sediment flow rate hydrograph:

$$S(j) = C(L,j)_M Q(L,j)_M, \qquad 0 \leq j \tag{46}$$

in which S = streamtube sediment discharge (tons/sec). This represents the inflow to the channel from the streamtube at the node.

Channel Sediment Flow Model

The sediment hydrographs in the channel are routed by time translation as described by Eqs. (16) through (20). The assumption here being a fully mixed condition at the nodes and no lateral inflow except at the nodes.

The initial condition at t=0 is

$$SS(k,0) = 0, \qquad 0 \leq k \leq L_c \tag{47}$$

The boundary conditions for a node code one are

$$SS(0,j) = S(L,j)_M, \qquad 0 \leq j$$

for a node code two:

$$SS(0,j)_{l+1} = SS(L_c,j) + S(L,j)_M, \qquad 0 \leq j \tag{49}$$

for a node code three:

$$SS(0,j)_{l+1} = [SS(L_c,j)_1 + SS(L_c,j)_2]_l, \qquad 0 \le j \quad (50)$$

for a node code four:

$$SS(0,j)_{l+1} = SS(L_c,j)_l, \qquad 0 \le j \quad (51)$$

in which SS = channel sediment flow rate (tons/sec)

Results

This model was tested on the 3.01 square mile Ralston Creek watershed which lies northeast of Iowa City, Iowa. Since a uniform storm is required as input, the May 29, 1974 storm was modified to a uniform event. To insure the rainfall excess equalled the flood runoff the Φ-index was used to estimate infiltration. This infiltration index was calculated by determining the following:

1. A constant infiltration rate is superimposed on each hyetograph corresponding to each gage.
2. The rainfall excess is obtained from each gage and multiplied by corresponding Thiessen weights, to obtain rainfall excess contribution.
3. The rainfall excess contributors are summed and checked for total outflow; if they are equal, then the infiltration rate assumed is O.K. Following infiltration analysis the hyetographs were adjusted such that they were continuous so as to simulate a uniform storm.

Figure 6 presents the observed and computed flood hydrographs.[12] Due to the modifications of the rainfall event, the peak discharges were matched in order to obtain a reference with respect to time. The results agree reasonably well considering the methods employed in calculating the flood hydrographs.

Figure 7 presents the observed sediment hydrograph and the computed sediment hydrograph.[12] The predicted sediment hydrograph was calibrated so that the volume of sediment from the predicted hydrograph matched with the volume of sediment from the observed hydrograph. The observed and predicted sediment yields were 864 tons and 874 tons, respectively. For an exponent on shear stress equalling 1.5 [Eqs. (37) and (38)] and assuming that the detachment process controls the sediment mechanism ($C_t = 1.0$), C_d was calibrated as 3.2×10^4.[14] The secondary peaks were expected and probably due to the method employed. Secondary peaks may have also existed in the observed sediment hydrograph, since records were kept in 60 minute intervals. In order to match the predicted and observed sediment hydrographs the sediment coefficients (C_t and C_d) and the exponent on shear stress (n) must be adjusted. As Whelan (1980) points out, increasing the exponent will increase the peak to recession limb ratio, while increasing the coefficients will maintain a constant sediment yield.[14] He suggests a value of 5/2 for the exponent and mentions that the coefficients must be recalibrated.

Conclusions

The model was developed in 3 areas: overland flow, channel flow and sediment. All calculations were performed with the necessary initial and boundary conditions included. For overland flow calculations the watershed has been divided into many streamtubes with their corresponding segments and nodes, where all nodes have a corresponding node code and number. Each streamtube segment also has its own excess rainfall value associated with it, so spatial and temporal rainfall definition occurs over the entire watershed.

For channel flow calculations natural channel shapes are employed as opposed to the traditional geometric shapes. The channel/culvert cross section can be segmented to handle various values of Manning's n depending on the flow depth. Flow-area and area-flow derivative arrays are automatically calculated and used when needed. The pending hydrographs are also stored and recalled automatically.

In the sediment computations a trial and error procedure as to when detachment capacity reaches transport capacity has been avoided. The computation provides a smooth transition between detachment and transport capacity with no discontinuities.

The acceptable agreement between the observed and predicted flood and sediment hydrographs, indicates that this model is a suitable predictor for uniform storms. The model was initially developed in order to simulate an event on the watershed and to help predict effects of land use/watershed changes from uniform storms of finite duration. The total computer cost to run the program is approximately $30, making it relatively accessible.

Applications

With future analysis, experimenting and testing with several other storms, various applications of this model are forseen as feasible. Applications of the model could help with a number of aspects for urban planning of rural areas, land use changes, etc. Water flow and sediment concentrations could be observed from hypothetically developed sections of the watershed. The models could reveal the type of natural or man-made features best suited for sediment reduction. It could look into the effects of holding ponds, detention basins, and dams with respect to flooding. It could deal with and describe the effects of channel realignment or channel improvements (straightening, lining, etc.) with regard to sediment discharge, flow velocity, flooding, etc. Agricultural treatment analysis could be performed to study topsoil erosion. By looking at the watershed on the whole, zoning changes could be analyzed and some idea could be developed as to how the watershed behaves and which sections have the most pronounced effect.

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In Memoriam

Dr. Cyrus W. Lantz

1889-1979

Dr. Cyrus W. Lantz, emeritus professor of biology and former head of the Department of Science, University of Northern Iowa, died 10 September 1979.

Dr. Lantz was born on a farm near Brooklyn, Illinois, 27 June 1889. He received degrees of A.B. with honors, A.M., and Ph.D. degrees from the University of Illinois. His major field was botany.

Before coming to University of Northern Iowa (Iowa State Teachers College) in 1921, he had taught in high schools in Illinois and had been an Assistant Professor of Botany at University of Nevada-Reno. He became head of the Department of Science at the University of Northern Iowa in 1947. He retired in 1957, but he continued to teach on a part-time basis until 1967.

Dr. Lantz was a member of Sigma Xi, Phi Kappa Phi, Kappa Delta Pi, Beta Beta Beta, National Association of Biology Teachers, American Institute of Biological Sciences, and the Botanical Society of America. He was a Fellow of the American Association for the Advancement of Science. He was a Fellow of the Iowa Academy of Science and was president of the Academy in 1942-43. The Academy during the observance in 1975 of the 100th anniversary of its founding gave Dr. Lantz one of the 26 citations that were given to outstanding Academy members and scientists from throughout the state.

He was a member of the Cedar Falls Rotary Club and served as its president in 1937-38. He was a member of the Cedar Falls Library Board from 1946 until 1964 and was president of the Board during a part of this tenure.

In 1976 the lecture-auditorium in the Science Building at University of Northern Iowa was named the C.W. Lantz Auditorium in recognition of his long and valuable services to the University.