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Simulation of selected events on the Catsop catchment by KINEROS2
A report for the GCTE conference on catchment scale erosion models

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Abstract

Data from the Catsop catchment in South Limburg, Netherlands was simulated with the model KINEROS2. The results of calibration and validation on a split set of runoff and sediment data are reported and the variations in apparent parameters are analyzed. Calibration was performed with regard to the temporal distribution of runoff and sediment rather than single values such as total or peak rates. Based on the simulations, soil erodibility was considerably higher in 1993 than earlier years. Sediment discharge is quite sensitive to hydrologic simulation, as the amount and velocity of runoff affects sediment transport capacity which in turn determines the delivery of soil disturbed by rainsplash. Overall ability of the model to reproduce the measured data was considered relatively good. Published by Elsevier Science B.V.

Keywords: Catsop catchment, Netherlands; KINEROS2; Runoff; Sediment

1. Introduction

KINEROS2 was one of two similar dynamic, distributed models that participated in this workshop. Data was furnished to workshop participants for two catchments, one (Catsop) in South Limburg, Netherlands and another from a research catchment in Kwazulu/Natal Province, South Africa. An inspection of the data from the latter catchment revealed immediately that much of the runoff there was produced by interflow/subsoil flow, which KINEROS2 does not include. Thus it was decided to

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concentrate our efforts on the Catsop data, which for the most part represents Horton-type runoff. All workshop participants were furnished a common set of 10 events for each catchment, five for model calibration and five for validation, to be simulated without knowledge of the measured runoff or sediment concentrations, and the results of the participating models compared. The Catsop calibration data included measured points on the hydrograph, two of which also included a few points where sediment samples were taken.

This report will briefly describe the features of KINEROS2 and discuss its simulation of the given events on the Catsop catchment. KINEROS2 was reasonably successful in simulating the Catsop runoff and sediment production, but several important aspects of erosion modeling and the difficulties presented by unknown variables are highlighted by this study.

2. Features of KINEROS2

KINEROS2 is an improved version of KINEROS (Woolhiser et al., 1990), most of whose new features are described by Smith et al. (1995). KINEROS2 provides for simulation of sediment with a mix of particle sizes, has improved infiltration simulation capabilities and other new features.

KINEROS2 is a dynamic, distributed simulation model which treats a catchment as a network or assembly of rectilinear surfaces and channels. Since the overland flow surfaces are not necessarily flat, complex natural topography must be decomposed or abstracted into rectilinear surfaces. Converging flow, for example, may be simulated by cascading planes of decreasing width. A hillslope section with irregular slope may be treated as a set of cascading planes, one for each distinct slope segment. In this manner most hydraulically significant features can be represented. Fig. 1 illustrates the geometric abstraction of a watershed into KINEROS2 elements.

KINEROS2 is an event model rather than a continuous simulation model, although it has a rather robust method to estimate the recovery of infiltration capacity due to soil water redistribution during a storm hiatus (Corradini et al., 1994). It is a model of Hortonian hydrology, and does not have a means to simulate interflow, subsurface hillslope response, or groundwater flow. However, saturation overland flow can be simulated, where runoff occurs after surface soil lying above a restrictive layer becomes saturated.

Runoff is calculated from the rainfall rate pattern $r(t)$ by finding effective scaled infiltration rate, $\hat{f}$, as follows:

$$\hat{f} = r_* \left\{ 1 + \left[\frac{r_*}{\alpha} \left(e^{\alpha I_*} - 1 \right) \right]^c \right\}^{-1/c} \tag{1}$$

in which α is a factor from 0 to 1 representing soil hydraulic behavior: Green–Ampt infiltration is represented as $\alpha \rightarrow 0$, and the Smith–Parlange equation is represented as $\alpha \rightarrow 1$. Infiltrability, f, is usually more efficiently related to infiltrated depth, I, than to time. The parameter c is directly related to areal heterogeneity of the surface soil (Smith

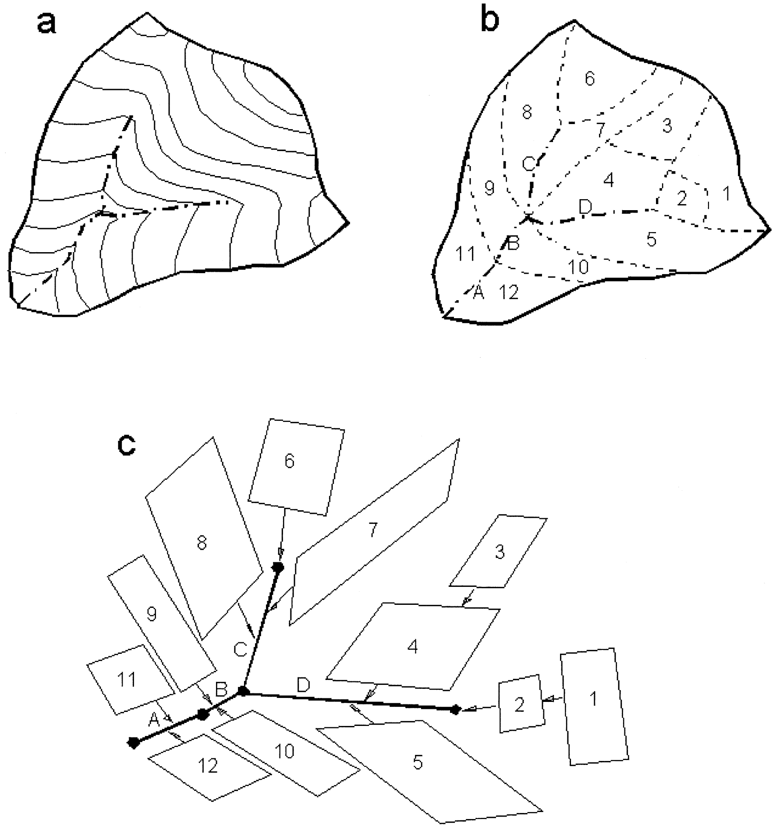

Fig. 1. Schematic illustration of the geometric subdivision of a hypothetical catchment into a network of surfaces and receiving channels for KINEROS2 simulation. Slopes, areas, and mean flow lengths are all preserved.

and Goodrich, 1996): c is a function of the coefficient of variation of K_s. Scaled values are defined as follows:

$$r_* \equiv \frac{r - K_e}{K_e}$$

$$\hat{f} \equiv \frac{f - K_e}{K_e} \qquad (2)$$

$$I_* \equiv \frac{I}{G \Delta \theta_i}$$

K_e is the areal effective value of the saturated hydraulic conductivity, K_s, and is also a function of the heterogeneity of K_s, characterized by its coefficient of variation, $Cv(K_s)$ (Smith and Goodrich, 1996). G is the common capillary scale or capillary drive parameter, and $\Delta\theta_i$ is the initial soil water deficit. In this manner, infiltration responds dynamically to the rainfall rate, soil properties, random soil variability, and initial conditions.

Runoff in KINEROS2 is estimated by dynamic routing of rainfall excess, $q(t) = r(t) - f(t)$, over soil surfaces and through channels along paths determined by the network described above. A 4-point implicit numerical scheme is used to solve the kinematic wave runoff equation:

$$\frac{\partial A}{\partial t} + \frac{dQ}{dA}\frac{\partial A}{\partial x} = wq(x,t) \tag{3}$$

in which: A is local cross sectional area of flow [m^2], x is distance along the flow path [m], Q is local discharge rate [m^3/s], t is time [s], w is local flow width [m], and q is the rainfall excess defined above [m/s].

The term dQ/dA is the kinematic celerity, controlled by hydraulic roughness and surface geometry. The relation between Q and A is found through the Manning normal flow relation, with roughness parameter n. Surfaces may exhibit microtopographic features such as rills and furrows, which can be defined by an average spacing and an average relief. Infiltration and runoff are interactive: During periods of higher rainfall $q(x,t)$ is positive, and during lower rainfall periods, q may be negative, withdrawing surface water from rills and increasing hydrograph recession rates.

Erosion and sediment transport rates are determined by solution to the sediment balance relation:

$$\frac{\partial(AC_s)}{\partial t} + \frac{\partial(QC_s)}{\partial x} - we(x,t,C_s) = q_c(x,t) \tag{4}$$

in which: C_s is the sediment concentration [m^3/m^3], e is the local rate of erosion or deposition [m^3/s/m^2], q_c is the rate of sediment inflow, as for lateral inflow to a channel.

Erosion rate e is composed of rainsplash erosion, $e_s(r,h)$, and hydraulic erosion, e_h. Splash erosion is a function of rainfall energy, often related to the square of rainfall intensity. KINEROS2 relates e_s to the rainfall rate, r, the fraction of covered soil, γ, and mean runoff depth $\bar{h}$:

$$e_s = \mathrm{Spl}(1-\gamma)\exp\left(-c_d\bar{h}\right)r^2 \tag{5}$$

Parameter Spl represents soil vulnerability to rainfall detachment, and c_d represents the effect of water depth in damping splash energy. The exponent function expresses a reduction in e_s with increasing depth of surface water, reflecting its dampening effect on splash energy.

Hydraulic erosion may be positive or negative (deposition), depending on the local transport capacity. Transport capacity is assumed to represent a concentration, C_m, in which erosion and deposition rates are in balance and e_h is 0, assuming there is no resistance to particle entrainment. Deposition is theoretically related to settling velocity, v_s, and thus a relation for e_h may be found:

$$e_h = \mathrm{Ch}\,v_s(C_m - C_s) \tag{6}$$

The coefficient Ch is inversely related to soil cohesion or any other restriction on soil entrainment by flowing water, and is 1.0 during deposition ($C_s > C_m$). C_m is estimated in KINEROS2 by a modified form of the Engelund and Hansen transport relation (Engelund and Hansen, 1967).

Further details of KINEROS2 may be obtained in the publications heretofore referenced. Calibration of hydrologic parameters — manning n and K_s — and erosion parameters Ch and Spl were the major part of this exercise.

3. Application to the Catsop catchment

Fig. 2 illustrates the 47 overland flow subareas and 11 channel sections into which the 41.2 ha Catsop catchment was subdivided for simulation purposes. As the illustration suggests, this subdivision was performed along streamlines, and the elements were selected to distinguish and conserve the management areas indicated in the furnished maps. These subareas were treated as rectangles of equivalent area, with length and mean slope preserved. This subdivision was a compromise, in so far as some local slope variations could have been represented only by using far more elements. It was later learned that furrow directions in some cases did not match the topographic trend, which would affect the derivation of slope and flow length for areas with significant furrow depths. The data did not specify furrow geometries, which were assumed according to crop type.

3.1. Catsop data preparation for KINEROS2

The rainfall data set furnished provided time and rainrate pairs, (t_1, r), in which the time t_1 is the end of the period for which the corresponding rate applied. KINEROS2 presumes a (t_0, r) data set in which t_0 is the time at which rate r begins, so the basic data transformation was straightforward. However, consolidation or integration of rain data was required when rainrate interval length Δt was shorter than the time step required by the numerical solution to Eq. (3) or Eq. (4).

The erosion and runoff related parameters were not always estimable from data furnished by the GCTE workshop organizers. Hydraulic roughnesses in the form of Manning n values were given, apparently determined by calibration with the LISEM model, but those used by KINEROS2 were ultimately fitted by calibration. Likewise, the values of K_s furnished in the data varied in some cases by more than 3 orders of magnitude, and this data was not helpful for modeling. In simulations, somewhat higher values of K_s (on the order of 50%) were generally assigned to those areas indicated to be covered in perennial grass. Soils were assumed to be sufficiently uniform over the catchment such that a uniform value of G (300 mm) (Eq. (2)) could be assumed. Subsequent results indicated there may have been some areas more prone to runoff than others, due to differences in soils or persistence of wetter initial conditions. Yet we found no basis for assigning significant differences in soil hydraulics based on furnished soils data. Soil cohesion and estimates of initial soil water content for each event and crop type were used with some modification, and crop type and cover conditions were incorporated into the parameters of KINEROS2 exactly as furnished.

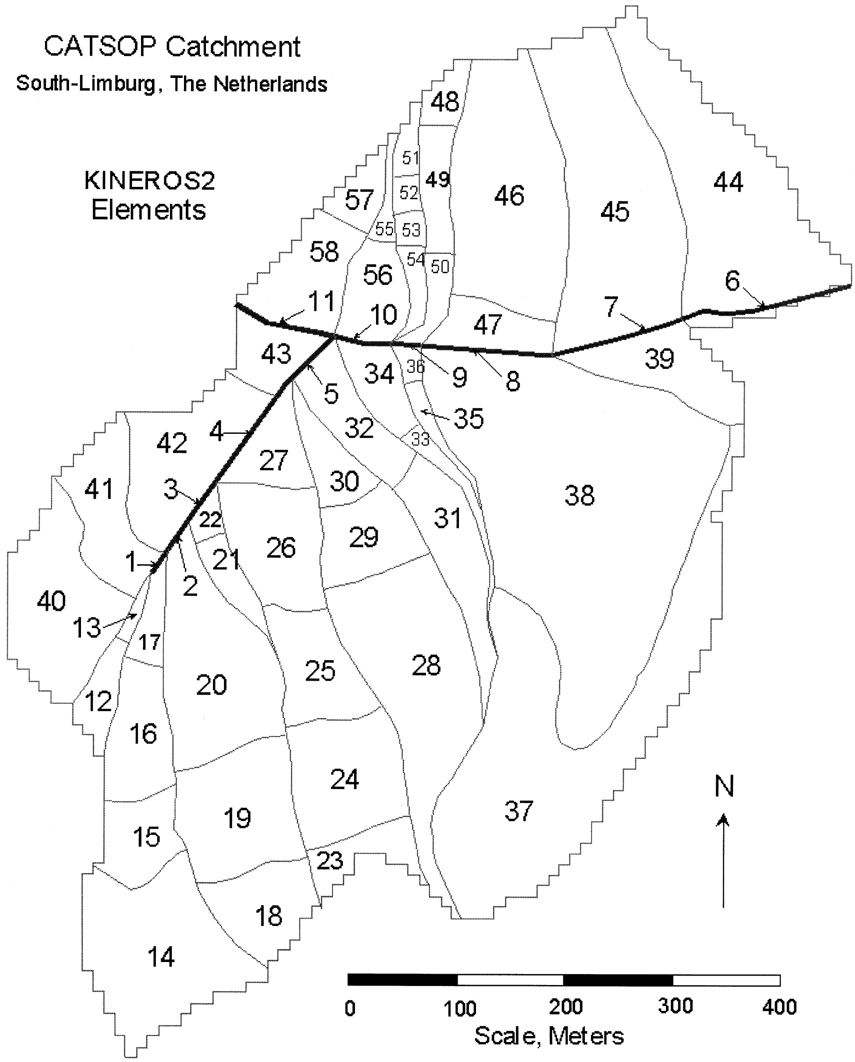

Fig. 2. Literal boundaries of the elements into which the Catsop catchment was subdivided for KINEROS2. It was assumed, in the absence of detail on furrow depth and direction, that flow follows topographic directions. Other subdivision were made to preserve management units.

It is worth mentioning some important information which was not furnished. There was no indication of the timing and types of field cultivation to which the various crops or management units were subjected during the period of interest. This is important for estimation of the initial soil state and estimations of induced changes in infiltration properties. Although the organizers furnished their estimates, in relative terms, of the initial wetness of the catchment, there was no knowledge on the participants' part of the overall rainfall history. For example, it is useful to know how many rains may have occurred since the last field cultivation. While there was mention of some flow barriers and locations of ‘‘alluviation sites’’, it was not clear what role these played. It would have also been very valuable to know the aggregate distribution of the soil, rather than the primary particle sizes. As discussed below, it seems reasonable that aggregates took up most of the clay size fractions reported. Treating the clay fractions as primary particles probably caused some added error in the KINEROS2 simulations.

3.2. The calibration data set

Table 1 summarizes the five events (marked ‘C’) furnished for calibration. Notably, only two contained data on sediment concentration, and that data was quite sparse. As it turned out, validation results could have been significantly improved had the more detailed data from at least one of the events in 1993 been given for calibration. It is reasonable to say that the calibration data set was inadequate for calibration of sediment dynamics on this catchment. However, hydrologic simulation is often required in such data-poor cases, and results are relative.

The parameter files for each of the calibration events were created using plant cover information directly. Calibration proceeded by overall adjustment of values for splash coefficient, soil cohesion, Manning n, and mean K_s, using multipliers applied to all elements. A feature of KINEROS2 allows for interactive entry of multiplicative factors for several key calibration parameters at runtime. The values of that parameter for all elements are adjusted during simulation. Visual criteria were used, as no parameter optimization is provided. Base K_s, for example, was arbitrarily 15 mm/h on cultivated soil and 25 mm/h on perennial grass areas (and 0 on paved roads). Corresponding base values for the other adjusted parameters were 0.15 and 0.25 for n, 0.35 and 0.05 for Ch, and 100 for Spl.

The K_s multiplier ranged from 0.15 to 0.30 during calibration, so that K_s values on cultivated soil ranged from about 2.25 to 4.5 mm/h. In some cases, calibration also included estimating spatial distribution of the initial soil wetness, e.g., lower elevation areas were made wetter than more upland areas, and in the warm season more heavily vegetated areas were made somewhat drier than bare areas (assuming plant water usage).

Results for the two ‘calibration’ events with sediment data are shown in Figs. 3 and 4. It was difficult for KINEROS to match the reported concentrations of event 18.08.87 during the flow recession, although data was not reported for the last part of the recession. The results for the 26.06.87 event are somewhat better, although the timing of the reported data is not reproduced. Indeed the delay or ‘‘time of concentration’’ for many of the reported flows could not be reproduced with remotely reasonable values of hydraulic roughness. This is discussed in more detail in Section 3.4.1.

3.3. The validation data set

Figs. 5 and 6 illustrate a validation test of calibrated parameters for two events very near in time. Data for the event of 22 Dec. 89 was provided for calibration, and rainfall data for the event of 15 December, one week earlier, was presented for validation. While

Table 1
Summary of the Catsop events

Event date	Rain depth, mm	Max. rain rate,[a] r mm/h	Runoff depth, mm	Peak runoff, mm/h	Hydrograph type	Total estimated sediment, kg	Sediment sample points
26/06/87 C[d]	8.9	31	1.17[b]	1.96	single	1900[b]	20
18/08/87 C	18.1	36	1.20[b]	1.51	single	870[b]	15
28/09/88 C	27.2	34	4.73[b]	1.68	multiple	–	0
07/08/89 C	17.0	23	1.00	1.13	single	–	0
22/12/89 C	16.8	12	0.72	0.19	double	–	0
13/05/87 V[d]	11.3	24	**1.13**	**0.75**	double	622[c]	24
15/12/89 V	23	18	**0.92**	**0.25**	single	–	0
22/01/93 V	11.8	103	**0.58**	**0.83**	single	2914	16
30/05/93 V	14.2	144	**0.87**	**2.97**	double	29350	12
14/10/93 V	18.4	29	**5.89**	**1.33**	multiple	9038[c]	24

[a] Based on unaggregated data.
[b] Estimated from very few points.
[c] Part of hydrograph unmeasured.
[d] C = calibration set, V = validation set.

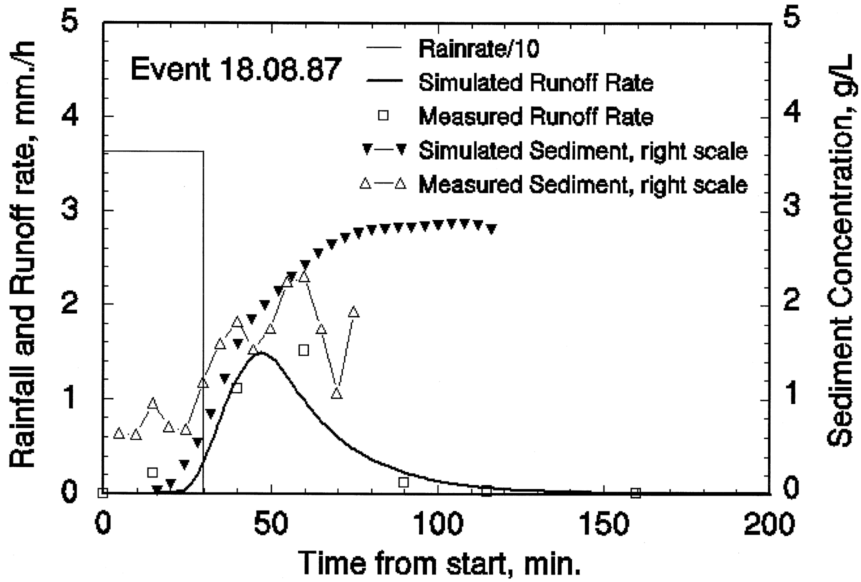

Fig. 3. Calibrated KINEROS2 and measured results for the event of 18.8.87.

much could change in a week, the fact that this was almost certainly a fallow period makes these two events likely to be similar. In both cases the workshop organizers indicated the initial condition to be very wet, but nothing is known of the weather between the events. Unfortunately, both events exhibit evidence of some saturation

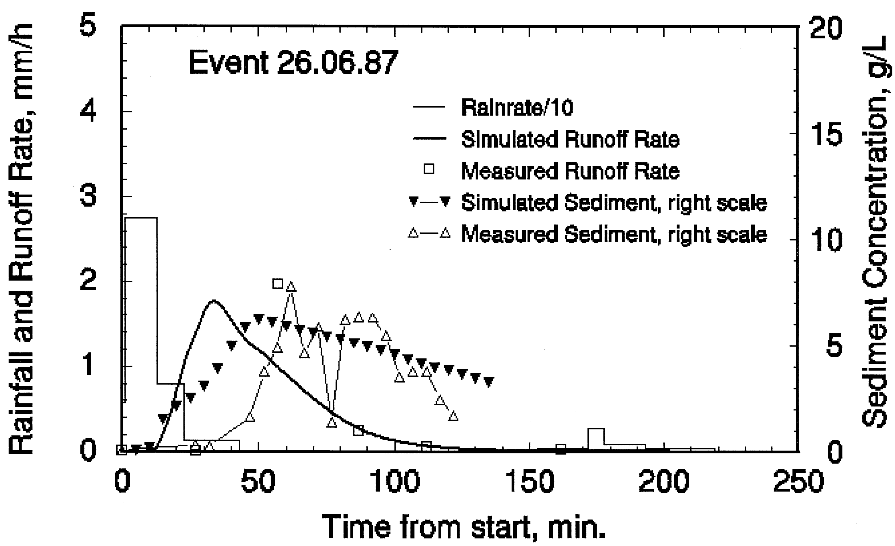

Fig. 4. Calibrated KINEROS2 and measured water and sediment discharges for the event of 26.06.87.

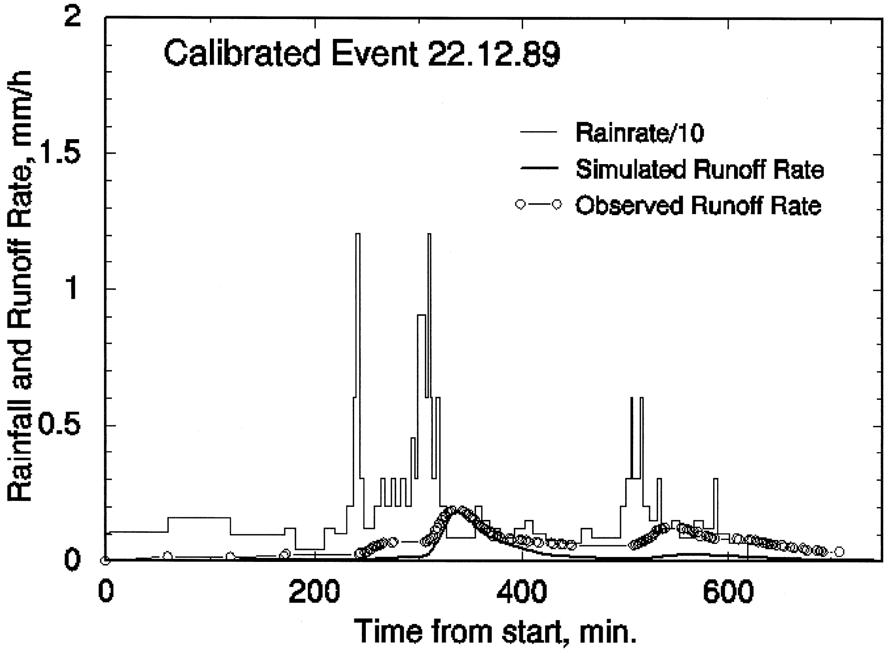

Fig. 5. Calibrated simulation of wet winter storm on 22.12.89.

return flow or interflow, which KINEROS2 does not simulate. The long sustained runoff during the later part of the 22 Dec. storm is during a period in which rainfall is much

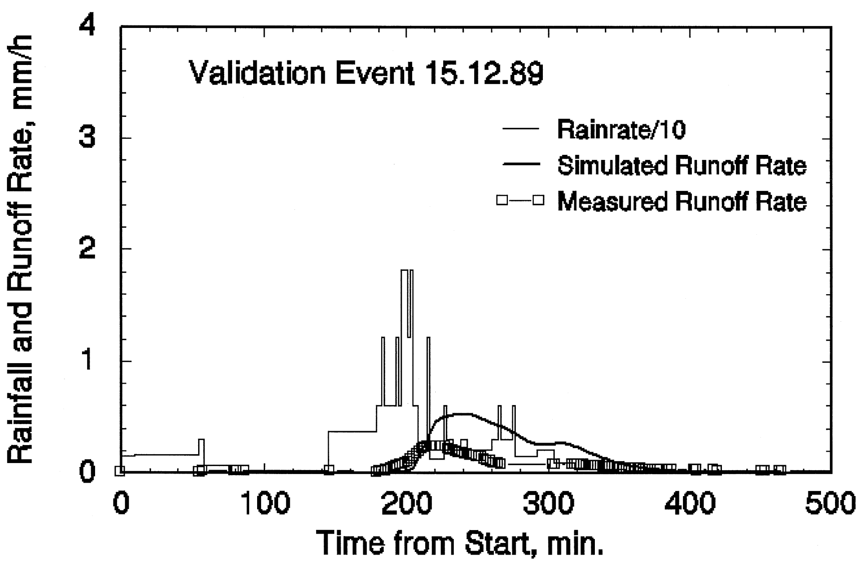

Fig. 6. Simulation of wet winter storm of 15.12.89 using parameters calibrated from event shown in Fig. 5. Both events apparently include interflow components for which KINEROS2 is not suited.

lower than K_s, and the runoff is what would be expected from a partial saturation of the catchment rather than a Hortonian type response. For this reason one should not expect calibratable response for these events. The value of K_s found for the later, presumable wetter event, is somewhat too high for the earlier event. Since this fitted parameter is helping to control runoff amount (in reality, the extent of saturated area) the validation results are consistent with the hypothesis of partial catchment saturation and a wetter condition for the second event.

3.4. Overall application results

Table 2 summarizes the parameters and results for all events with the corrected model. The most remarkable thing about the events in this set is the significant difference in sediment production in the 1993 events as compared to the two 1987 events provided for calibration. This is particularly revealed in the coefficient of rainsplash or ''interrill'' erosion required to simulate the amount of sediment reported. There is no possibility to have anticipated this with the calibration data given from 1987. Values of K_s within the catchment were made different between crops (and therefore between fields) only to reflect an expected increase in K_s for grass covered areas. The multipliers reported in this table reflect the relative overall adjustment of this parameter to reflect general field condition differences between events.

Figures shown in this report give sediment data in terms of concentration, C_s, rather than sediment discharge, Q_s, for two reasons. First, there were often concentration values reported when there was no discharge data; if sediment discharge were illustrated, far fewer points would be available. Second, sediment discharge is highly correlated to water discharge; $Q_s = QC_s$, and reporting concentration removes this inherent data correlation.

3.4.1. Hydrology

The events in 1987 and 1988, Figs. 3, 4, 7 and 8, consisted of only a few sample points, and so it is difficult to be certain of the exact hydrograph shape and peak values. It would appear, however, (see Figs. 3 and 4) that the measured recession rates were significantly more rapid (the flow dropped more quickly) than the KINEROS2 simulation. This hydrograph property is related to the rate of infiltration during the recession and to the hydraulic roughness value n. Making the surface smoother by reducing n also steepens the rise of the hydrograph and decreases the time of concentration. Increasing the base infiltration rate K_s also decreases the total runoff. Thus there is interaction in calibrating these parameters. There is no reason, from information given, to expect the channels would have infiltration rates significantly larger than the surrounding soil.

As pointed out in Section 3.2, there is reason to doubt the timing accuracy of some of the reported runoff, relative to the rainfall, where the simulations show large time discrepancies relative to the data. To study this, a model experiment was run in which all runoff came from the most remote part of the watershed. The reported time delays could still not be obtained. It was concluded that a timing error was likely, based on these results and the following reasoning.

Table 2
KINEROS2 simulation results for the 10 Catsop events

Event (ordered by date)	Event condition measures			Simulation result indices					Parameter scale values			
	Rain, mm	Σr[b]	%wet[a]	Runoff, mm	Peak, mm/h	Simulated sediment, kg	Measured sediment, kg	Peak C, g/l	$M(K_s)$	$M(n)$	M(Ch)	M(Spl)
13.5.87	12.4	0.033	90%	1.06	0.757	1009[b]	622*	7	0.3	0.7	0.1	200
26.6.87	8.9	0.048	89	1.26	1.76	2418	1900	6	0.25	0.6	0.5	20
18.8.87	18.1	0.184	40	0.93	1.49	814	870	3	0.24	0.8	0.05	10
28.9.88	27.2	0.111	63	5.0	4.28	–		–	0.16	0.5	–	–
7.8.89	17.0	0.066	60	0.94	1.33	–		–	0.16	0.7	–	–
15.12.89	13.8	0.020	88	0.84	0.53	–		–	0.33	0.8	–	–
22.12.89	16.8	0.013	88	0.35	0.21	–		–	0.33	0.8	–	–
22.1.93	10.8	0.079	80	0.58	0.94	3880	2914	34	0.25	0.45	1.0	5000
30.5.93	14.4	0.236	55	1.66	3.23	38900	29350	83	0.17	0.3	0.5	2000
14.10.93	20.2	0.030	90	1.93	1.34	8717	9038	15	0.31	0.6	0.5	20000

[a]Overall mean, varies with crop and position.
[b]Includes more of the multiple peaks than the measured data. See Fig. 9.

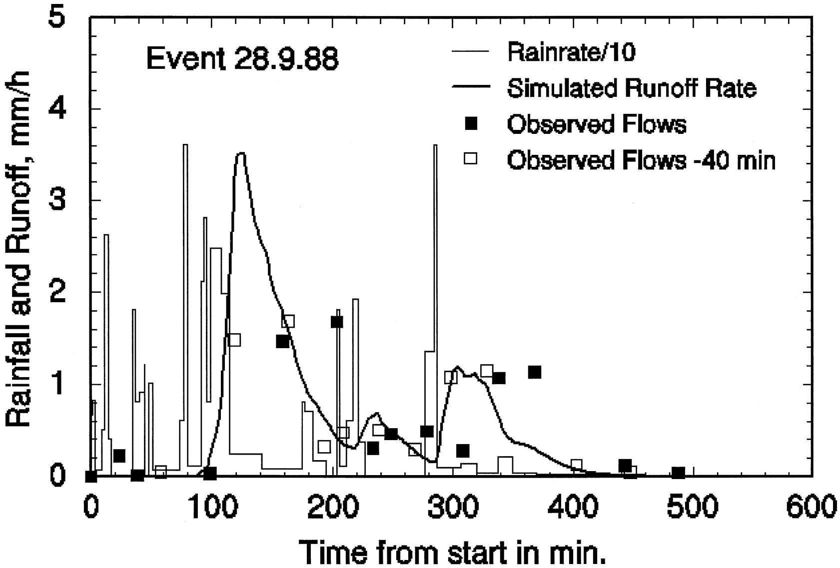

Fig. 7. Measured and simulated runoff for event of 28.9.88. Note that approximately 40 min change in time makes for an excellent match with the simulated flows.

(a) It is not realistic, given the relatively uniform soils, to expect runoff to be confined to remote portions of the catchment.

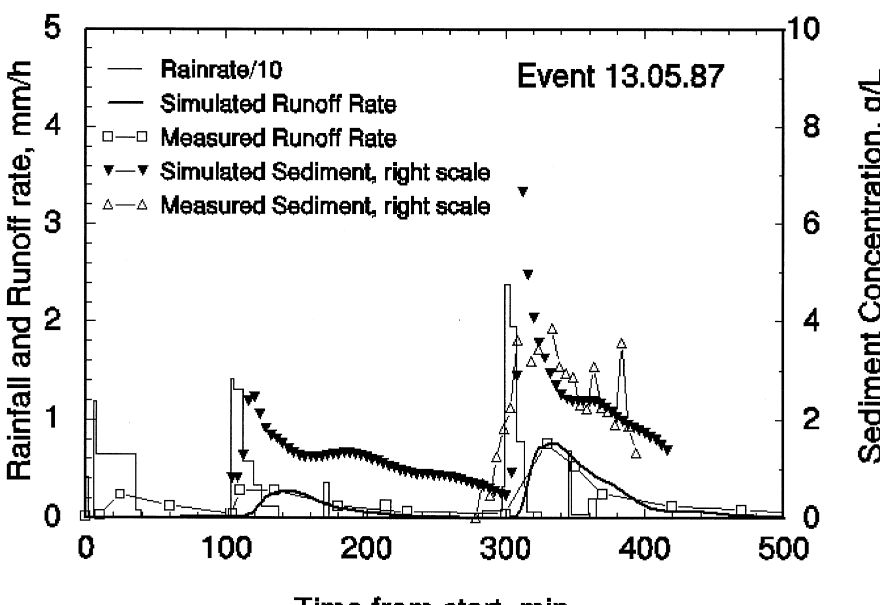

Fig. 8. Measured and simulated runoff for event of 13.5.87.

(b) Even if runoff were confined to remote subareas, those areas would have to be nearly impervious to obtain the required net catchment runoff.

(c) Slowing the runoff through the channels by use of larger Manning roughness coefficients will change the shape of the hydrograph significantly, and the reported hydrograph recession rates indicate that the channel is not excessively rough.

Timing errors are dramatically indicated in the results for simulation of event 28.9.88 shown in Fig. 7. Here it is demonstrated that an adjustment of observed flows of about 40 min results in remarkably close agreement in detail to the simulated hydrograph. This also shows that the reported flow data probably missed the actual runoff peak. Thus because of the paucity of measuring points we should consider the reported runoff (and sediment) totals as being rough estimates only.

The data for event 7.8.89 shown in Fig. 9 suggests other possible data problems. The relatively flat top portion of this hydrograph is characteristic of a measurement problem. The shape of the peak, with a sharp break at the early part and a gradual curve at the later part, is quite the opposite of the expected response to a step rainfall input. The sharp break at the top of the rise may be the result of a restriction at some level in the measuring chamber of the flume — we have seen such cases in other runoff measurements. Thus we have chosen to allow our calibrated flow to exceed the reported peak; the actual peak may have been even higher. This event again exhibits a time offset in comparison to the simulated outflow. But other events such as 22.12.89 did not exhibit such differences, so the error is not systematic.

The parameter adjustments reported in Table 2 illustrate that both apparent hydraulic roughness, n, and K_s exhibited temporal changes. K_s seemed to stabilize at higher

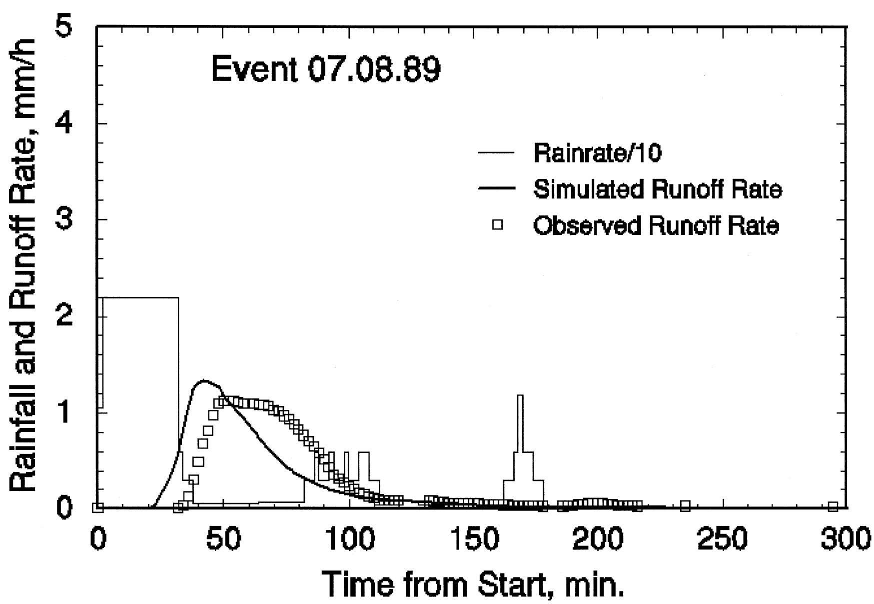

Fig. 9. Measured and simulated runoff for event of 7.8.89.

values in the fall and winter. The hydraulic roughness seemed to change less, but was apparently lower in 1993 than earlier. It should be recalled that these two parameters exhibit some interaction, so strong conclusions are not appropriate.

3.4.2. Erosion

Measured sediment data are only reported for events in 1987 and 1993. There are clear differences in the apparent erosive behaviour of this catchment for these two periods. Events from 1993 are illustrated in Figs. 10–12. To match the reported flow concentrations, small changes in soil cohesive resistance to erosion (Ch) were required, and very large changes in the splash erodibility [M(Spl)]. These two parameters affect the sediment production pattern in different ways, so there is small parameter interaction (with the possible exception of very short intense storms). If these fitted parameters have physical significance, as they should, the soil is more erodible in spring and erodibility may be related to tillages, freeze–thaw processes, or other factors. The calibrated splash erodibility Spl varies over 3 orders of magnitude for these events. A seasonal trend is not evident, but there is a clear and unexplained difference between erodibilities in 1987 and 1993.

The third column in Table 2 gives the second moment of the rainfall record, $\Sigma r^2 \Delta t$. Since KINEROS2 assumes rainsplash soil disturbance to be a function of r^2, this should give an indication of the relative erosivity of the rainfall. These values demonstrate that the difference in splash erosion coefficients, reflected in the multiplier M(Spl), does not compensate for a different rain erosive energy function, such as r^n with $n > 2$. Note for

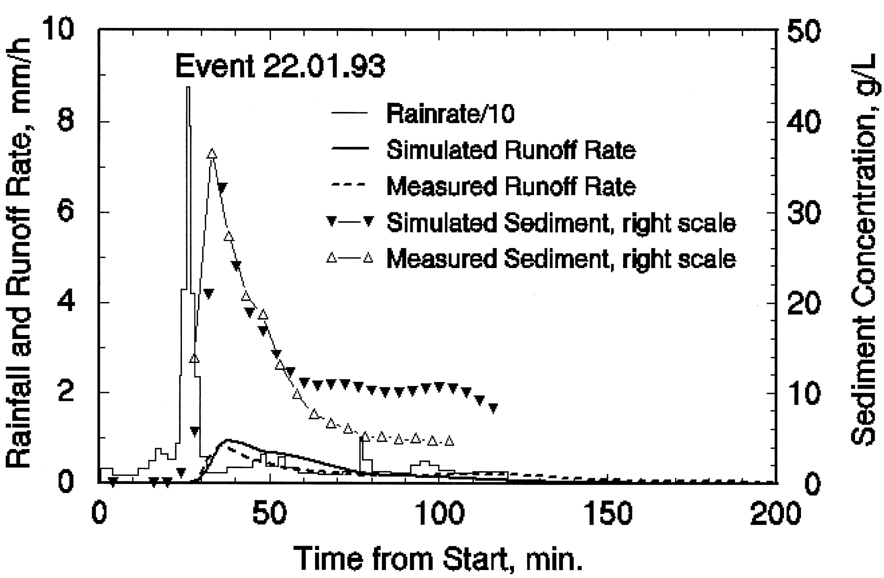

Fig. 10. Measured and simulated runoff for event of 22.1.93. There is an order of magnitude increase in the scale of 1993 sediment concentrations, compared with the 1987 events.

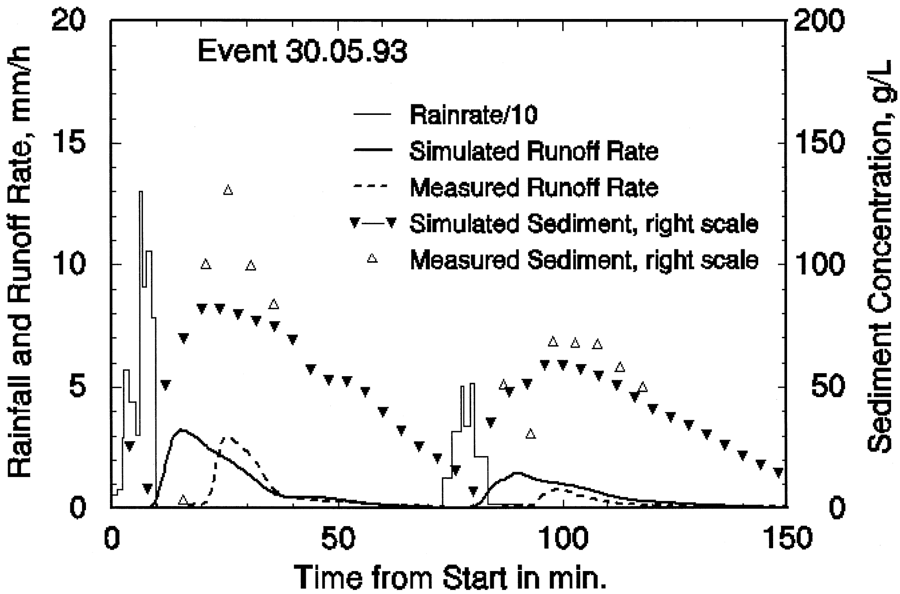

Fig. 11. Measured and simulated runoff for event of 30.5.93.

example that the events of 13.5.87 and 14.10.93 have very similar values of $\Sigma r^2 \Delta t$, but required very different values for M(Spl). Splash erodibility may be significantly

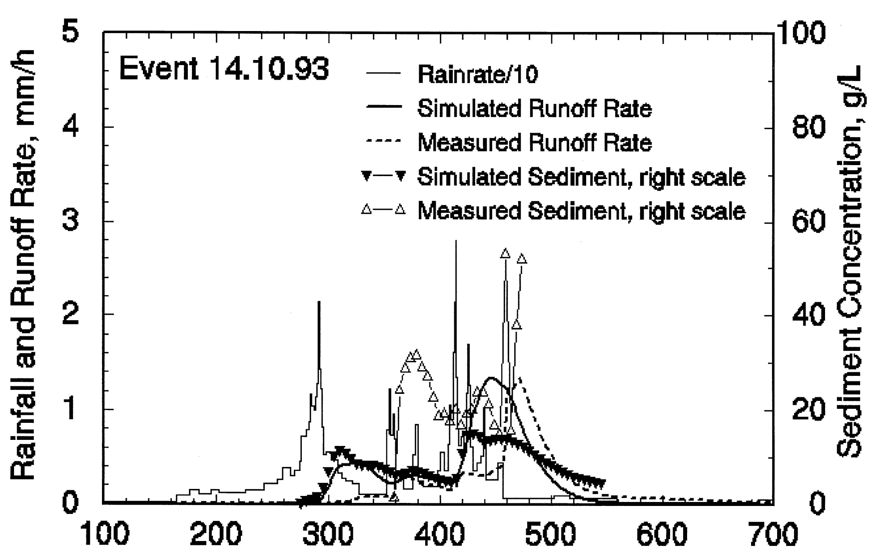

Fig. 12. Measured and simulated runoff for event of 14.10.93.

changed by soil crust conditions and by recent soil tillage. There is some indication that higher Ch is associated with higher Spl, consistent with general soil erosion resistance, but there is no apparent relation between K_s and these parameters.

The KINEROS2 model does exhibit some physically related limits for these parameters. For the 1993 events requiring large values of Spl, the sensitivity of this parameter is diminished when the values of C_s are large, because the sediment movement process becomes transport capacity limited. Large values of Spl are apparently required, but as values are increased above a certain level, the increase in sediment production is limited because of the transport capacity limitation. The transport capacity in KINEROS2 is set by the adoption of the Engelund and Hansen (1967) relation, which has no calibratable parameters. Values of Ch, which affects rate of erosion by flowing water, are generally smaller for the 1987 events because data for these events indicated relatively low and rapidly decreasing concentrations after runoff peaks. Values of these two erosion related parameters were chosen not just on the basis of total sediment outflow, but on the temporal distribution of concentration indicated by the data, as shown in the accompanying figures.

The given particle size distribution included about 10% of the soil with particle size less than 0.002 mm (2 μ). Treating this fraction as unaggregated particles caused increased concentrations during flow recession, since this clay size settles slowly. Incorporating this fraction into an aggregate improved the simulation results, but the lighter weight of aggregates still caused some concentration persistence due to higher transportability and lower settling velocity.

Table 3
Sensitivity of selected results to fitted parameters

Event	Parameter	Runoff Total			Peak Runoff			Sediment		
		mm	m^3	Δ%	mm/h	l/s	Δ%	q_s, kg/s	Total, kg	Δ%
18.08.87	(base)	0.9227	385.3	–	1.489	171.9	–		813.6	–
	Ch + 10%	0.9227	385.3	–	1.489	171.9	–	0.3457	818.9	0.65
	Ch − 10%	0.9227	385.3	–	1.489	171.9	–	0.3430	808.3	−0.7
	Spl + 10%	0.9227	385.3	–	1.489	171.9	–	0.3460	853.8	4.94
	Spl − 10%	0.9227	385.3	–	1.489	171.9	–	0.3284	775.3	−4.7
	K_s + 10%	0.7910	330.3	−14	1.272	146.8	−14.6	0.3033	700.5	−14
	K_s − 10%	1.087	451.9	17.3	1.745	201.5	17.2	0.3916	944.8	16.1
	n + 10%	0.8327	347.7	−9.8	1.245	143.7	−16.4	0.2500	622.5	−23
	n − 10%	1.023	429.5	11.5	1.796	207.4	20.7	0.4840	1075.5	32.2
30.5.93	(base)	1.669	694.6	–	3.230	373.0	–	27.23	43386	–
	Ch + 10%	1.669	694.6	–	3.230	373.0	–	27.28	43497	0.26
	Ch − 10%	1.669	694.6	–	3.230	373.0	–	27.19	43268	−0.3
	Spl + 10%	1.669	694.6	–	3.230	373.0	–	27.53	44055	1.54
	Spl − 10%	1.669	694.6	–	3.230	373.0	–	26.62	42528	−2
	K_s + 10%	1.438	601.0	−13	3.022	349.0	−6.43	24.65	35795	−17
	K_s − 10%	1.791	748.4	7.75	3.464	400.0	7.24	30.19	46308	6.73
	n + 10%	1.544	645.5	−7.1	2.803	323.7	−13.22	19.56	34376	−21
	n − 10%	1.766	738.1	6.26	3.778	436.3	16.97	38.33	54606	25.9

4. Sensitivity analysis

Two events were chosen to illustrate parameter sensitivity in KINEROS2. One was the event of 18 Aug. 1987, with lower sediment concentration, and the other was the 30 May event of 1993 with quite large concentrations. Table 3 summarizes the results of this sensitivity test. There were four primary fitting parameters: K_s, n, Ch, and Spl, the latter two of which only affect erosion. It is clear from the results in this table that because of the sensitivity of the sediment transport capacity to flow hydraulics, sediment yield from the catchment is more sensitive to changes in runoff and flow velocity than the splash and hydraulic detachment parameters. It is also important to understand that from physical considerations, there are enormous differences in sensitivity to various parameters in different flow regimes and conditions. Note that there is more sensitivity to the splash parameter for the smaller flow event than the larger event. Still, the range of runoff amounts for these 10 storms is relatively narrow, with insufficient data from smaller runoff events to perform a robust model calibration.

5. Conclusions

The dynamic and spatially distributed simulation which KINEROS2 can perform is generally able to match most of the features of all Horton-type runoff and erosion events in this set of data. However, to predict the runoff and erosion for several events on the basis of a few data points from two calibration events is beyond the capability of any known model. Thus performing the validation exercise requires some guesswork and contains an element of chance. This is especially true given the lack of information on field cultivation schedules and rainfall between those events chosen for this exercise.

The simulations based on this data have demonstrated the importance of detailed hydrologic simulation to successful erosion simulation. This is because, at least for this catchment, the erosive energy of the rainfall is usually able to saturate the transport capacity of the resultant runoff. Thus accurate simulation of the velocity and depth of flow may be even more important than an accurate splash erosion parameter. Also, parameter selection is quite difficult without better knowledge of the changes in soil conditions between events. Application of more physically realistic and detailed models may better be done with continuous simulation rather than isolated events.

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