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Investigating prediction capability of HEC-1 and KINEROS kinematic wave runoff models

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Abstract

In this study, two distributed parameter, physically based, kinematic wave hydrologic models, HEC-1 and KINEROS, were tested on a 30.4 ha watershed located near Treynor, Iowa. The study had two objectives: (1) to determine the ability of the models to predict runoff with very limited calibration; (2) to determine how accurately the models can simulate runoff given accurate model parameters. The results show that HEC-1 can achieve good prediction of runoff with very limited calibration. It was not, however, possible to achieve the same level of prediction with the KINEROS model. Given good calibration, both models can simulate the rainfall–runoff process with great accuracy.

1. Introduction

The appeal of physically based hydrologic models rests principally on the promise of reliable prediction of runoff from ungaged catchments and, by the same principle, a capability for evaluating hydrologic response to land-use changes. The expectation is founded on the implication that the parameters of the physically based models have a physical basis and, therefore, reliable simulations can be achieved without calibration.

Until recently, surface water hydrology at the watershed scale has been studied using simpler linear models such as unit hydrograph methods, and the use of nonlinear and physically based models has been limited to the field-size scale. A significant boost to nonlinear methods came from Lighthill and Whitham (1955),

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who developed the kinematic wave method as an approximation for the St. Venant equations. Application of the kinematic wave equation to hydrology has been extensively demonstrated by many researchers, including Wooding (1965a, b, 1966), Woolhiser and Liggett (1967), Eagleson (1970), Overton and Meadows (1976), Miller (1984) and Hjelmfelt (1986). Woolhiser and Liggett showed that, in theory, the kinematic wave model is limited to slopes that are rolling to moderately steep.

Although the kinematic wave method has been used extensively as a research tool for well over two decades, its application in practice has lagged considerably behind. The US Army Corp of Engineers' rainfall–runoff (HEC-1) model (Hydrologic Engineering Center, 1990) is the most widely used model that allows use of the kinematic wave approach. Recently, another rainfall–runoff model that incorporates the kinematic wave method (KINEROS; Woolhiser et al., 1990) has become available. Both models need validation for applicability to watersheds of varying topography including, specifically, ungaged watersheds.

The aim of this study was to test these two models, using kinematic wave solutions, for prediction capability and model accuracy. This will be done using historic data from a field-size agricultural watershed.

The models were tested with several rainfall events observed at an Agricultural Research Service (ARS) research watershed located near Treynor, Iowa. This field-size watershed was specifically selected because it is located on a rolling topography for which the kinematic wave approach should be appropriate. The watershed has been gaged since 1964, and the records enjoy a high level of confidence. Application of the models was used to determine their applicability in modeling the hydrology of ungaged catchments.

In related studies, Wilcox et al. (1990) successfully predicted runoff from ungaged rangeland catchment without model calibration. They used the Soil Conservation Service (SCS) curve number method and Green and Ampt infiltration model. Dawdy (1991) made a theoretical comparison of the US Geological Survey (Dawdy et al., 1978) and HEC-1 kinematic wave runoff models, and concluded that both models will give similar results if they model a basin in the same manner. Luce and Cundy (1992) improved hydrograph prediction with the kinematic wave–Philip model by incorporating detention storage in a manner similar to the use of initial moisture loss in this study.

1.1. Study catchment

The study catchment is Watershed 1 (WS-1), one of the four field-size research watersheds that make up the Deep Loess Research Station of the US Department of Agriculture (USDA) ARS located near Treynor, Iowa, approximately 24 km east of Council Bluffs. The area is typical of the deep loess soils bordering the Missouri River. The Ida and Monona Silt Loam soils of the watershed have moderate to moderately rapid infiltration capacity. The area-weighted slope is about 9%, with maximum slope of 18%. WS-1 has an area of approximately 30.4 ha.

The outlet of the watershed is in a gully that cuts into the zone of saturated ground water. The flow is perennial, but baseflow was negligible for the runoff events used in this study. Flow is measured with a weir situated in the gully. Rainfall is measured using three gages, all of which are located on the periphery of the watershed.

Research records on the watershed began in 1964. From the start, WS-1 has been cropped to corn using conventional tillage. Surface runoff from the catchment averages 67 mm $year^{-1}$. The only criteria for selection of events used in this study were that (1) runoff was a large portion of the rainfall and (2) runoff was supplied primarily by surface runoff so that baseflow was negligible. For modeling in this study, WS-1 was divided into five sub-basins ranging in area from 3.18 to 8.07 ha.

1.2. Model descriptions

Both HEC-1 and KINEROS are distributed parameter, physically based, single-event hydrologic models. The kinematic wave equation forms the basis for both HEC-1 and KINEROS models to route runoff across the watershed. The difference between the two models from the point of view of runoff routing is strictly algorithmic. Each model treats infiltration differently.

2. Procedure

This study was carried out in two stages. The first stage started with model parametrization in which model infiltration parameters were assigned values based strictly on physical characteristics of the basin and very limited calibration. These parameters attained their numerical values from descriptive information on soil type, moisture status, and geographic features of the catchment. These parameters, which varied with individual storms, were used in the models to predict runoff from each rainfall. In the second stage, parameter adjustments were undertaken to ascertain how accurately each model can simulate the rainfall–runoff process, given correct values of its parameters. Geometric parameters of the basin were kept constant and were the same for both models.

2.1. The HEC-1 hydrologic model

The HEC-1 runoff model controls volume and time distribution of runoff through three parameters: (1) surface roughness coefficient, or Manning's n; (2) initial moisture loss (this is initial infiltration and depression storage that must be satisfied before runoff commences); (3) constant rate of infiltration during Hortonian overland flow. The model also offers a choice of other loss estimators such as SCS curve number; but, for this study, the initial loss and constant infiltration rate option was selected. The following section describes the model parametrization.

Surface roughness coefficient

In this study, the values of Manning's n recommended by Engman (1986) and Hjelmfelt (1986) were used. In assigning values to the roughness coefficient, we relied heavily on the Miscellaneous Publications of the USDA Agricultural Research

Table 1
Moisture infiltration rates of Ida Silt Loam Soil (Iowa) (crop stage: no crop)

Identification		% antecedent moisture, 0–15 cm	Rainfall intensity ($cm\ h^{-1}$)	Time to initial runoff (min)	Mean rate ($cm\ h^{-1}$)							
Rep.	Dup.				1.5 min	5.5 min	10.5 min	15.5 min	20.5 min	25.5 min	30.5 min	35.5 min
Initial run (June–July 1962)												
1	1	25.5	11.4	8.0	11.4	11.4	9.7	6.1	5.1	4.8	3.5	3.8
1	2	25.5	11.2	10.0	11.2	11.2	10.2	7.1	5.8	5.8	4.6	5.3
2	1	23.9	10.4	13.0	10.4	10.4	10.4	9.1	6.4	5.1	4.6	4.1
2	2	22.2	10.9	14.5	10.9	10.9	10.9	9.9	8.1	7.4	6.9	6.4
3	1	15.8	10.4	14.0	10.4	10.4	10.4	9.1	7.4	6.4	5.6	5.6
3	2	18.6	11.2	12.0	11.2	11.4	10.9	7.1	5.3	4.6	4.6	3.6
Wet run (June–July 1962)												
1	1	35.5	10.7	2.0	10.4	7.9	1.0	1.8	1.3	1.8	0.3	1.8
1	2	33.3	11.2	4.0	11.2	6.6	2.5	1.5	1.5	1.5	1.5	1.5
2	1	28.2	10.4	9.0	10.4	10.4	5.6	3.8	3.0	2.5	2.5	2.0
2	2	27.4	10.7	5.5	10.7	9.7	6.6	5.1	5.3	5.1	5.1	4.3
3	1	30.7	11.2	4.0	11.2	9.1	4.3	3.3	3.3	2.8	3.6	2.8
3	2	34.6	10.4	5.0	10.4	7.9	3.6	2.8	1.0	2.0	1.8	1.0

Source: University of Illinois Agricultural Experiment Station (1979). Conversion to S.I. units by the authors.
[a]Wet-run equilibrium values calculated by applying field data to Phillip's equation (Eq. (8)).

Identification		% antecedent moisture, 0–15 cm	Rainfall intensity ($cm\,h^{-1}$)	Time to initial runoff (min)	Mean rate ($cm\,h^{-1}$)						
Rep.	Dup.				40.5 min	45.5 min	50.5 min	55.5 min	60.5 min	65.5 min	Equil. rate[a]
Initial run (June–July 1962)											
1	1	25.5	11.4	8.0	3.8	2.0	3.0	4.6	3.8	3.6	3.3
1	2	25.5	11.2	10.0	3.8	4.6	4.3	4.6	4.3	4.8	4.3
2	1	23.9	10.4	13.0	4.1	3.8	3.8	4.8	3.8	3.0	3.8
2	2	22.2	10.9	14.5	6.1	5.3	6.4	6.9	5.6	6.1	6.1
3	1	15.8	10.4	14.0	5.8	5.1	5.1	5.8	5.6	5.6	5.6
3	2	18.6	11.2	12.0	3.6	3.3	4.6	4.3			3.6
Wet run (June–July 1962)											
1	1	35.5	10.7	2.0	2.3	1.0	1.0	0.5	1.0		0.5
1	2	33.3	11.2	4.0	2.3						0.5
2	1	28.2	10.4	9.0	2.0	2.0	4.3	1.8	2.0		1.8
2	2	27.4	10.7	5.5	5.1	5.1	4.8	4.8	4.3		4.3
3	1	30.7	11.2	4.0	4.3	4.8	4.8				3.0
3	2	34.6	10.4	5.0	0.8	3.0	2.0	1.0	1.0		0.8

Source: University of Illinois Agricultural Experiment Station (1979). Conversion to S.I. units by the authors.
[a]Wet-run equilibrium values calculated by applying field data to Phillip's equation (Eq. (8)).

Service (1964–1981), which gave catchment rainfall history before the rainfall events, and land surface and vegetation status of the catchment at the time of the events.

Constant infiltration rate

Bulletin 760 of the University of Illinois Agricultural Experiment Station (1979) presents the results of infiltration experiments on representative soils of the North Central Region. Table 1 is an extract from that publication, specifically for the Ida Silt Loam Soil of Iowa. The soils of WS-1 were assumed to have infiltration characteristics similar to those of the Ida Silt Loam tested. Table 1 gives the range of constant infiltration rate, for the wet run between 0.5 and 4.3 cm h^{-1} under clean-tilled conditions. Eliminating the outlying value of 4.3 cm h^{-1} results in a mean value of 1.3 cm h^{-1}. This value was used.

Initial moisture loss

Initial moisture loss, or initial rainfall abstraction, is an important and sensitive parameter in the kinematic wave option of the HEC-1 hydrologic model, and depends on antecedent soil moisture and soil type. How to arrive at a truly representative value for this parameter for a particular catchment condition is obviously important.

From Table 1, a minimum of 0.3 cm (for wet conditions) and up to 2.6 cm (for dry conditions) of rainwater goes into abstraction before runoff starts. The challenge here is to create a correspondence between purely qualitative description of catchment antecedent condition and the quantitative initial moisture loss to be expected from a subsequent precipitation on the catchment. What value (quantitative) of initial moisture loss in the range of 0.3–2.6 cm, for example, would be truly descriptive of a silt loam soil estimated to be at field capacity at the time of precipitation? To create a correspondence of scales, the first of 12 rainfall events used in this study (rainfall of 22 June 1964) was taken as the pilot event. The rainfall history of the catchment before this event and catchment geographic features were studied. Factors that received careful note were dates and magnitudes of all rainfalls in the 30 days preceding the rainfall event of interest, with greatest weight put on rainfalls within 2 weeks of the event, and type and growth stage of vegetation on the basin.

A plot of the cumulative rainfall for the rainfall event of 22 June 1964 was prepared. The associated runoff hydrograph was superimposed on the cumulative rainfall plot. The portion of the cumulative rainfall from the start of rainfall to the beginning of hydrograph rise was abstracted as the initial moisture loss. The value thus obtained was 0.8 cm. Using initial moisture loss of 0.8 cm as a starting point, the hydrograph associated with the rainfall event of 22 June 1964 was reconstructed with the HEC-1 model. Parameter adjustments led to 0.94 cm as the final value of initial abstraction which resulted in the best overall match between the computed and observed hydrographs. Fig. 1 is a representation of the match. Thus, within the scale of 0.3 cm for very wet conditions and 2.6 cm for very dry conditions, a rainfall on WS-1, when rainfall history and vegetation status are similar to those of 22 June 1964, would be subject to initial moisture loss of the order of 0.94 cm

Use of rainfall and runoff data to reconstruct the hydrograph of 22 June 1964, to which other events were later referenced, was a departure from the ungaged analysis

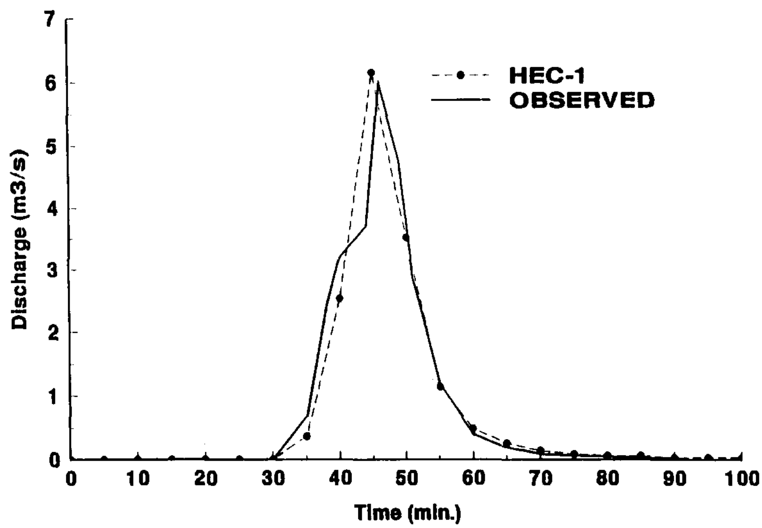

Fig. 1. Matching Observed and Computed Hydrographs, 22 June 1964.

procedure. However, it was felt that using this approach to investigate the use of simple indices for moisture loss rate, in place of soil moisture accounting models which also require calibration, justifies the deviation.

Runoff prediction

In each of the 11 remaining cases, initial moisture loss was assigned a value after noting the rainfall history and vegetation status of the catchment at the time of rainfall and referencing that catchment condition to the condition of 22 June 1964. The surface roughness coefficient was taken from Engman (1986) or Hjelmfelt (1986), and the constant rate of infiltration was kept at 1.3 cm h^{-1}. Parameters of the watershed required by the model were measured from a topographic map at the scale of 1 cm to 24 m (1 in represents 200 ft). Using these parameters, the runoff hydrograph associated with each rainfall event was predicted. Table 2 shows the prediction. This exercise was intended to test the ability of the HEC-1 model to predict runoff with very limited calibration.

Parameter adjustment and model accuracy

As expected, the runoff hydrographs predicted using the procedure outlined in the preceding paragraph did not, in all cases, yield the best possible match with the observed hydrographs. A second aim of this study was to determine how accurately the HEC-1 model can predict runoff from rainfall given adjusted model parameters.

Returning to the hydrographs predicted in the execution of the first aim, initial moisture loss was adjusted to obtain the best possible simulation of the observed hydrograph based on established criteria specified in a later section. The surface roughness and constant infiltration rates used in the prediction were assumed to be correct so that the same values were retained and used here. However, it happened

Table 2
Parametrization of HEC-1 hydrologic model and prediction of runoff

Rainfall event	Estimated surface coefficient		Estimated constant moisture loss ($cm\,h^{-1}$)	Estimated[a] initial moisture loss (cm)	Predicted peak runoff ($m^3\,s^{-1}$)	Observed runoff ($m^3\,s^{-1}$)	% Error	Predicted runoff volume (cm)	Observed runoff volume (cm)	% Error
	Overland flow	Channel flow								
22 June 64	0.03	0.06	0.5	0.94	6.15	6.00	+2.50	1.49	1.47	+1.36
22 Sep. 64	0.19	0.19	0.5	1.3	2.58	2.78	−6.18	1.68	1.03	+63.11
29 June 65	0.04	0.06	0.5	0.3	9.01	8.84	+1.92	2.81	2.18	+28.90
26 June 66	0.03	0.06	0.5	0.6	4.19	4.16	+0.72	1.08	0.93	+16.13
20 June 67	0.03	0.06	0.5	1.0	12.35	12.40	−0.40	12.10	10.73	+12.77
02 Aug. 70	0.10	0.10	0.5	0.9	13.82	11.07	+24.84	4.68	2.30	+103.48
10 May 71	0.03	0.06	0.5	0.6	3.23	3.88	−16.75	1.48	2.97	−50.17
18 May 71	0.03	0.06	0.5	0.6	6.97	6.74	+3.41	2.13	2.52	−15.48
05 May 72	0.05	0.06	0.5	1.1	4.62	4.16	+11.06	1.78	1.55	+14.84
02 May 77	0.04	0.06	0.5	2.0	2.97	3.48	−14.66	1.79	2.02	−11.39
19 May 78	0.03	0.06	0.5	1.7	1.81	5.72	−68.36	0.49	0.86	−43.02
02 June 81	0.04	0.06	0.5	1.5	2.97	2.83	+4.95	0.78	0.77	+1.30

[a]Estimated from rainfall history and vegetation status (see Table 3).

that in some cases a given value of initial infiltration produced a hydrograph that matched the peak and volume of the observed hydrograph excellently, but the computed hydrograph either started its rise earlier than, or lagged behind, the observed hydrograph. This was interpreted to mean that the initial moisture loss used in the simulation was too low or too high, respectively. Luce and Cundy (1992) made a similar observation, and succeeded in improving model performance by adjusting depression storage. When the phenomenon was observed, the value of initial infiltration was increased and surface roughness reduced to effect a delay in the rise of the computed hydrograph while retaining the already achieved match between the runoff peaks and volumes of the predicted and observed hydrographs. Reducing initial infiltration while increasing roughness coefficient value had the opposite effect on the computed hydrograph rising pattern. The cases that required this type of two-parameter adjustment were relatively few, and the amount of adjustment in surface roughness was generally small. Table 3 gives the final values of the model parameters as used.

2.2. The KINEROS hydrologic model

The KINEROS model employs Smith and Parlange (1978) infiltration expression and determines the volume and time distribution of runoff through: (1) surface roughness coefficient or Manning's n; (2) effective saturated hydraulic conductivity (K_s); (3) effective net capillary drive (G); (4) initial water content of the soil (θ). The infiltration rate responses to rainfall were described with an analytical expression credited to Smith (1983), which employs G and relative saturation deficit of the soil. The expression is

$$B = G\phi(S_{max} - S_i) \tag{1}$$

where ϕ is the soil porosity, S_i is the initial relative saturation and S_{max} is the maximum relative saturation. Woolhiser et al. (1990) presented a summary of

Table 3
Final HEC-1 model parameters after adjustments to improve model simulation accuracy

Event identification	Infiltration losses		Surface roughness coefficient	
	Initial loss (cm)	Constant loss (cm h^{-1})	Overland flow (n)	Channel flow (n)
22 Sep. 64	1.14	1.3	0.190	0.19
29 June 65	0.31	1.3	0.038	0.06
26 June 66	0.64	1.3	0.035	0.04
20 June 67	1.02	1.3	0.030	0.06
02 Aug. 70	2.16	1.3	0.100	0.10
10 May 71	0.51	1.3	0.025	0.06
18 May 71	0.89	1.3	0.030	0.06
05 May 72	1.83	1.3	0.050	0.06
02 May 77	1.93	1.3	0.040	0.06
19 May 78	0.69	1.3	0.030	0.06
02 May 81	1.55	1.3	0.040	0.06

hydraulic data from Rawls (1982) from which K_s and the variables from the right-hand side of Eq. (5) can be taken.

The effective saturated hydraulic conductivity (K_s) and initial relative saturation (S_i) are coded in the computer program as FMIN and SI, respectively. These symbols will be used here.

Surface roughness coefficient

These were again taken from Engman (1986) or Hjelmfelt (1986), and were the same as used in the HEC-1 model.

Effective saturated hydraulic conductivity

Woolhiser et al. (1990) gave an average K_s value of 0.7 cm h^{-1} for silt loam soil. No range was given. The K_s values were credited to Rawls et al. (1982). W.J. Rawls (personal communication) gave a K_s range of 0.02–9.91 cm h^{-1}.

Woolhiser et al. (1990) implicitly recommended that under imbibation half the average value of K_s should be used as FMIN in the KINEROS model. This recommendation was followed in this study.

Initial relative saturation

This is related to initial moisture loss as used in the HEC-1 model, and accounts for the soil moisture antecedent to the rainfall of interest. This parameter has the range $0.03 \leq S_i < S_{max}$.

Effective net capillary drive

Woolhiser et al. (1990) showed this parameter to vary from 4.3 to 118.1 cm for silt loam soil, with a recommended mean of 20.3 cm. This mean was used in the study.

Runoff prediction

In investigating the utility of the KINEROS model for ungaged watersheds, two approaches were used, on the basis of the recommendation of Woolhiser et al. (1990) discussed above.

Cases of precipitation under distinctly wet conditions were isolated. One event from this group was selected, and FMIN was assigned a value of 0.35 cm h^{-1}, that is ($K_{s/2}$). With this value, a corresponding value of SI that simulated the hydrograph well was determined by trial. These values for FMIN and SI were then used to generate a runoff hydrograph from each of the rainfall events in the group. This approach failed to produce consistently accurate simulations of observed hydrographs.

A second approach was tried. In this case, storms that occurred under dry basin conditions were grouped together. One of them was selected, and SI was assigned a value of 0.27, the value of SI at permanent wilting point. On the basis of rainfall history before rainfall events in this group, there was no evidence to suggest that soil moisture could have gone below wilting point.

With SI = 0.27, a corresponding value of FMIN that gave a good simulation of observed hydrograph was determined. Again, these values for FMIN and SI were used in an attempt to simulate the runoff hydrographs from other storms which

Table 4
Final KINEROS model parameters after adjustments to improve model simulation accuracy

Event identification	Effective net capillary drive (cm)	Effective saturated hydraulic conductivity ($cm\,h^{-1}$)	Initial relative moisture saturation
22 Sep. 64	20.3	0.48	0.66
29 June 65	20.3	0.66	0.64
26 June 66	20.3	0.69	0.57
20 June 67	20.3	0.36	0.50
02 Aug. 70	20.3	0.97	0.22
10 May 71	20.3	0.36	0.80
18 May 71	20.3	0.53	0.70
05 May 72	20.3	0.69	0.54
02 May 77	20.3	1.12	0.20
19 May 78	20.3	0.84	0.52
02 June 81	20.3	1.14	0.30

occurred under similarly dry conditions. The generated hydrographs were not, in all cases, good simulations of the respective observed hydrographs.

Parameter adjustment and model accuracy

The same approaches used under runoff prediction were continued except that both FMIN and SI were varied freely with the only constraint that for wet conditions FMIN was kept below $0.7\,cm\,h^{-1}$ whenever possible, and for dry conditions SI was kept as close to 0.27 as possible. Table 4 shows the final model parameters that generated hydrographs which matched observed hydrographs well.

3. Evaluation criteria

Observed and simulated runoff were subjectively compared in all cases. The attributes used were the runoff peak rate, time to peak, and runoff volume. In addition, the pattern of hydrograph rise and fall was compared. In the case of predicted hydrographs, an objective evaluation was added by computing the coefficient of efficiency (E) between predicted and observed runoff. The equation used (Nash and Sutcliffe, 1970) was

$$E = 1 - \frac{\sum(Q_o - Q_p)^2}{\sum(Q_o - Q_m)^2} \tag{2}$$

where Q_o is the observed peak runoff rate (L^3T^{-1}), Q_p is the predicted peak runoff rate (L^3T^{-1}) and Q_m is the mean observed runoff rate (L^3T^{-1}).

The coefficient of efficiency is the proportion of the variance of the observed runoff accounted for by the model, and is always lower than the coefficient of determination (R^2). Values of E can range from one to negative infinity. $E = 1$ would imply perfect prediction. A negative value for E indicates that Q_m is a better predictor of peak runoff than Q_p.

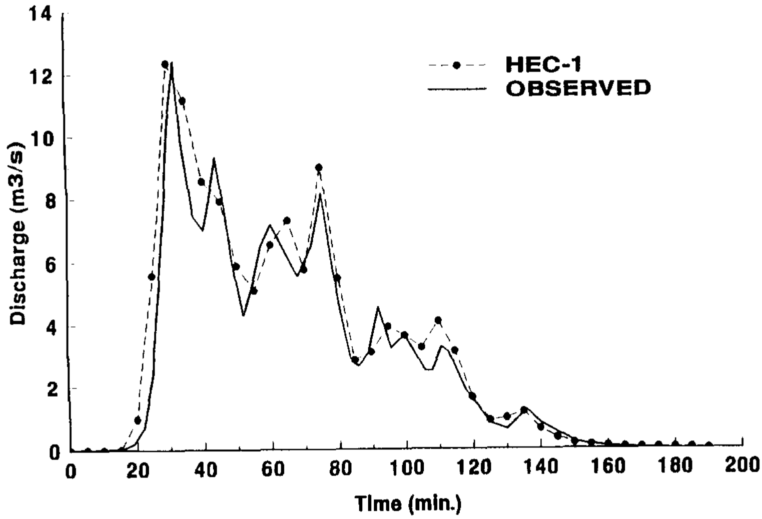

Fig. 2. Observed vs. predicted hydrographs, 20 June 1967.

4. Results

Table 2 summarizes the performance of the HEC-1 model that can be realistically expected when the model is used to predict runoff from an ungaged watershed. Figures 2 and 3 are sample graphical representations of the same information in Table 2, with the added dimension that the pattern of hydrograph rise and fall can be viewed. They are typical of the results obtained. Model prediction of peak

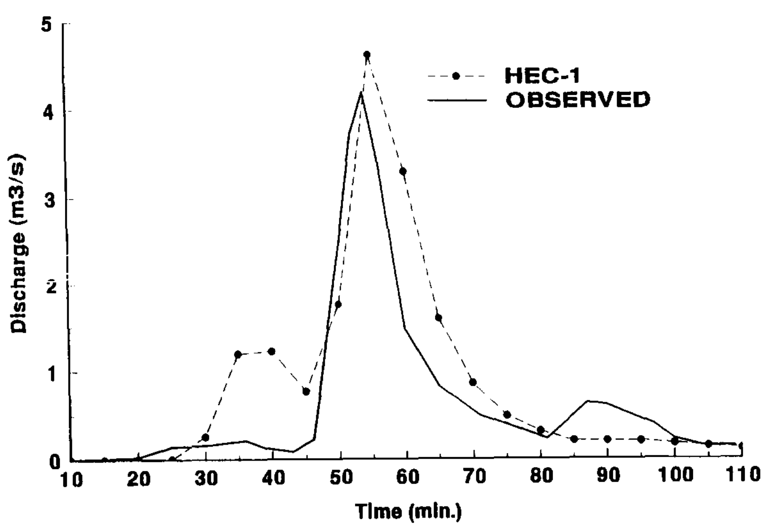

Fig. 3. Observed vs. predicted hydrographs, 5 May 1972.

Table 5
Comparison of observed hydrographs vs their simulations with HEC-1 and KINEROS hydrograph models

Rainfall		Peak discharge rate (cms^{-1})			Peak time (min)			Runoff volume (cm)		
Date	Accumulation (cm)	Observed	HEC-1	KINEROS	Observed	HEC-1	KINEROS	Observed	HEC-1	KINEROS
22 Sep. 64	3.912	2.75	2.78	2.78	76	80	90	1.026	1.745	1.542
29 June 65	4.191	8.84	8.89	8.88	37	35	40	2.176	2.791	2.337
26 June 66	2.362	4.16	4.19	4.19	19	20	17	0.927	1.077	0.838
20 June 67	15.469	12.40	12.35	12.43	32	30	38	10.726	12.101	12.934
02 Aug. 70	6.706	11.07	11.16	11.13	13[a]	20	24	2.296	3.510	3.139
10 May 71	3.835	3.88	3.31	3.46	91	90	91	2.967	1.621	2.111
18 May 71	4.597	6.74	6.94	6.83	76	75	74	2.520	2.093	2.073
05 May 72	4.521	4.19	4.25	4.22	54	55	51	1.549	1.295	1.263
02 May 77	5.055	3.48	3.57	3.54	112	110	114	2.024	1.872	1.306
19 May 78	2.794	5.72	5.72	5.66	17	10	10	0.861	1.361	0.930
02 June 81	2.489	2.83	2.83	2.89	35	35	38	0.767	0.757	0.508

[a]Observation error is suspected as records show that runoff hydrograph peaked before the causative rainfall.

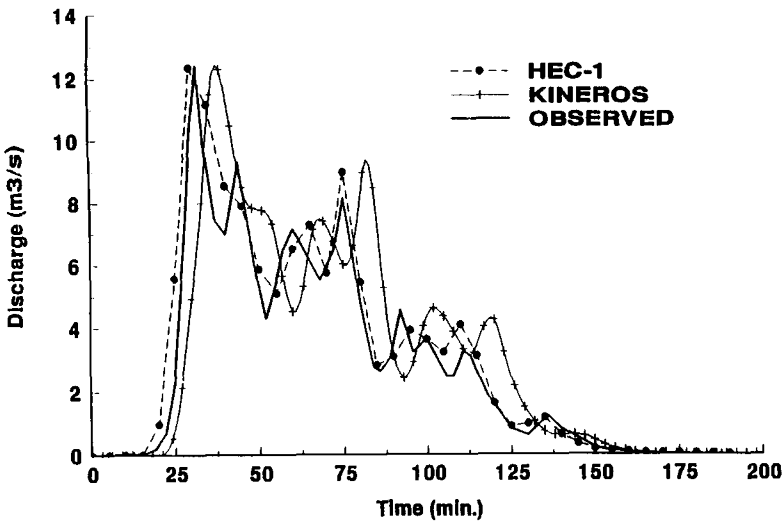

Fig. 4. Observed vs. computed hydrographs, 20 June 1967.

discharge rates comes within 10% of the observed hydrograph in six of the 11 cases and within 20% in nine of 11 cases or 82%. The apparent 'poor performance' of the model in two cases will be taken up in the next section. Model prediction of runoff volume comes within 40% of the observed in eight of 11 cases studied.

Table 2 and Figs. 2 and 3 provide subjective comparison between predicted and observed hydrographs. To aid this subjective comparison, prediction efficiency (E), for peak runoff, was computed using Eq. (2). When the coefficient of efficiency was

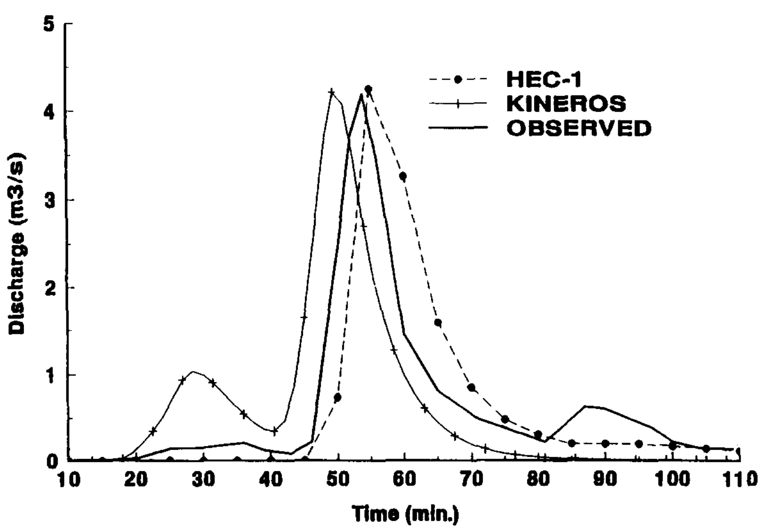

Fig. 5. Observed vs. computed hydrographs, 5 May 1972.

computed with all 11 cases, the computation gave a coefficient of 0.80. When the two 'bad predictions' were excluded, $E = 0.99$.

Table 5 gives the result of adjusting model parameters to achieve the best overall match between predicted and observed hydrographs. Figures 4 and 5 are a sample graphical representation of Table 5. The table and figures combine to testify positively to the ability of both models to simulate runoff hydrographs very well, when the models are calibrated to individual events.

5. Discussion and conclusions

The results summarized in Table 2 affirm that the HEC-1 model can be used, with very limited calibration, for predicting runoff from ungaged catchments and for evaluating future land-use masterplans. However, two cases show poor agreement between predicted and observed hydrographs.

Prediction was achieved by assigning a value to initial moisture loss based on catchment moisture and vegetation status at the time of precipitation. In the case of the 2 August 1970 event, there was a rainfall of 4.1 cm 3 days before the event of interest and another rainfall of 2.7 cm 1 day before. Soil moisture status near field capacity may be expected. Owing to the actively growing corn crop, evapotranspiration should be accounted for; thus initial moisture loss was put at 0.9 cm. This value led to gross overestimation of runoff.

An initial loss of 2.2 cm was required to simulate the observed hydrograph (see Table 3), which would suggest that the catchment initial moisture status was 'very dry'. This certainly was not the case. It should be noted also that this event shows a very low value of initial relative saturation for the KINEROS model.

The integrity of the observation of 2 August 1970 is further challenged by hydrograph peak time. The hydrograph was recorded as peaking at 21:53 h whereas the causative rainfall peaked at 21:54 h. The lack of agreement between the predicted and observed hydrographs for the event of 2 August 1970 was probably due to observation error.

In the case of 19 May 1978, there was only one major rain event in the 30 days preceding 19 May. This rainfall came 11 days before the event and had a total accumulation of 5.2 cm. A value of 1.7 cm was nominated for initial infiltration. This produced a very poor simulation, which, on closer examination, was found to be logical and should have been expected.

Table 3 shows that initial moisture loss of 0.69 cm accurately simulated the observed hydrograph. This event was caused by a very advanced storm. The storm intensity distribution was 25.4 cm h^{-1} for the first 3 min, 13.7 cm h^{-1} for the next 3 min, and 4.2 cm h^{-1} for another 3 min. The intensity then dropped off to insignificance. Thus, this was a case of practically 'instantaneous' rainfall, with very little opportunity for infiltration.

On the basis of the results obtained in predicting runoff from rainfall, it is appropriate to conclude that the HEC-1 model can be successfully used to evaluate the impacts of land use on the hydrologic cycle without extensive calibration. We were less successful in the attempt to predict runoff using the KINEROS model without calibration. It was not possible to achieve consistency in predicting runoff using effective saturated hydraulic conductivity based on soil type and initial relative saturation based on rainfall history and vegetation status. Both the HEC-1 and KINEROS models can give excellent simulation of runoff hydrographs when model parameters are fitted to the individual events.

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