Iran Agricultural Research 9:101-120 (1990)

APPLICATION OF THE ANSWERS MODEL FOR PREDICTION OF RUNOFF AND SEDIMENT FROM A SMALL AGRICULTURAL WATERSHED OF IRAN

S. AMIN SICHANI, H. MOMTAHAN. B. A. ENGEL[1]

Irrigation Department, College of Agricugture, Shiraz University, Shiraz, Iran.
(Recieved November 27, 1990)

ABSTRACT

In order to make use of a model to predict results of watersheds in Iran, the model should be tested with conditions common to Iran. A watershed with an area of 4.83 hectares in southern Iran in the Bajgah Valley located northwest of Shiraz was chosen. The ANSWERS model was used to simulate runoff and sediment from watershed using four different rainfall events. The simulated runoff values correlated well with the observed data. Correlation coefficients of the observed and predicted runoff of the four storm events ranged from 0.86 to .98 with an average of 0.93. Therefore, the ANSWERS model Can be used for prediction of runoff in small agricultural watersheds of Iran.

However, for the types of storms commont to the south part of Iran the erosion component of the ANSWERS model was not able to estimate sediment concentrations of the runoff accurately. Therefore, further research for development of a sediment component needed, considering the nature of the erosion of the watersheds of the southern part of Iran.

1- Assistant Professor, former Graduate student, and Assistant Professor, respectively. The address of the third author is Department of Agricultural Engineering, Purdue University, West Lafayette, Indiana, U.S.A.

تحقیقات کشاورزی ایران
۹: ۱۰۱ - ۱۲۰ (۱۳۶۹)

کاربرد مدل ریاضی *ANSWERS* در پیش بینی سیلاب و رسوب از یك حوزه کوچك آبخیز کشاورزی ایران

سیف‌الله امین سیچانی، حسن ممتحن و ب .الف. انگل
به ترتیب استادیار ودانشجوی سابق کارشناسی ارشد بخش آبیاری دانشکده کشاورزی دانشگاه شیراز و استادیار بخش مهندسی کشاورزی دانشگاه پردو، لافایت غربی، آمریکا

چکیده:
بمنظور استفاده از یك مدل ریاضی برای پیش بینی نتایج حاصله از بارندگی روی حوزه‌های آبخیز ایران مدل مورد نظر بایستی در شرایط ایران مورد آزمایش قرار گیرد. حوزه آبخیزی به مساحت ۴/۸۳ هکتار در جنوب ایران در دره باجگاه واقع در شمال شیراز انتخاب گردید و مدل *ANSWERS* برای شبیه سازی سیلاب وحمل رسوب از این حوزه آبخیز مورد استفاده قرار گرفت. برای شبیه سازی سیلاب و یا حمل رسوب از چهار بارندگی که در دره اتفاق افتادند استفاده شد. نتایج شبیه سازی نشان دادند که ارقام مشاهده شده و شبیه سازی سیلاب هم خوانی نزدیکی با هم دارند و ضریب همبستگی سیلاب مشاهده و شبیه سازی شده دارای محدوده ۰/۸۶ تا ۰/۹۸ بودند (معدل مقادیر ضریب همبستگی ۰/۹۳ می باشد). لذا مدل *ANSWERS* می تواند برای پیش‌بینی سیلاب از حوزه‌های کوچك کشاورزی مورد استفاده قرار گیرد.
به هر حال برای بارندگی‌های خاص جنوب ایران قسمتی از مدل *ANSWERS* که محاسبه مقادیر فرسایش را به عهده دارد نتوانست بدقت مقادیر رسوب را پیش‌بینی نماید. بنابراین جهت بکارگیری این مدل برای پیش بینی فرسایش خاك از حوزه‌های آبخیز مطالعه و تحقیق زیادتری لازم است تا بتوان با توجه به شرایط جنوب ایران و مکانیسم فرسایش مربوطه قسمتهائی از مدل را که فرسایش را محاسبه می‌نماید تغییر داد.

INTRODUCTION

Soil is one of the most important resources in the production of food. It is estimated that 9.6×10^{8} metric tons of soil are washed from Iranian watersheds each year (12). Assuming a bulk density of 1.2 ton m^{-3} , this quantity of soil would represent a volume with depth of 0.025 m and an area of 3200 thousand hectares. Because soil erosion is a selective process with respect to particle size, the higher fraction of plant nutrients, organic matter, and fine colloidal particles are lost from the soil and transported to the standing waters by runoff flow.

Estimates of soil erosion and sediment yield from watersheds are needed to select the best management practices to control sediment yield and improve water quality. Mathematical models are used to estimate runoff and sediment movement from various agricultural watersheds. The increase of computation capacity in the last decade has allowed "distributed" parameter models to be used to simulate erosion, runoff, and water quality of different sized watersheds. The ANSWERS model (S) is a distributed parameter model that uses a grid system to define a watershed area for simulation. The watershed under study is divided into a number of small elements or cells. These cells are independent from each other in soil characteristics, slope, topography, crop coverage, and management. The size of each cell must be such that uniformity of all hydrological characteristics of the cell can be assumed (9). Important hydrological and soil erosion parameters are defined in a predata file for a watershed before a storm event is simulated.

The ANSWERS model is an event-oriented model which predicts the complete hydrograph of a runoff event and gives the total volume of runoff at the end of the simulation of a single event. The model is capable of predicting the impact of alternative land management practices on sediment yield from an agricultural watershed. It calculates the total sediment yield and the concentration of the sediment corresponding to the time increments of hydrograph. The ANSWERS model also shows the total erosion or deposition for each element of the watershed under consideration. Therefore, a land planner can easily find the critical points in a watershed. The model has been applied, tested, and verified on different watersheds for various climatic conditions in locations including Illinois, Iowa, Ohio, Oklahoma, Pennsylvania, Texas, Virginia, and Ontario, Canada(6). The ANSWERS model has been used to simulate phosphorus transport in surface runoff (1), heavily forested watersheds (14), and distribution of transported sediment particles from agricultural watersheds (4). The ANSWERS model was applied in different watersheds with high intensity rainfall events of the USA, therefore, for application of the model in Iran, which in most part the rainfall amount and intensities are low, the model should be tested and verified for runoff and sediment prediction.

EXPERIMENTAL WATERSHED

The ANSWERS model was applied using data from a small agricultural watershed located at the Agriculture College of Shiraz, Iran (10). This small agricultural watershed has an area of 4.83 hectares and short time of concentration of 15 minutes due to slope steepness and small size. The watershed has an average slope of 2.6% with minimum slope around 0.2 percent and a maximum slope of around 4.8% . A topographic map of this watershed is shown in Fig.1 . This small agricultural watershed was used because it is representative of the major portion of the watersheds of the Fars province in south of Iran. Precipitation occurs primarily during November to May each year with greatest frequency during February. Average rainfall of the valley is 400 mm $year^{-1}$ and rainfall events fit the B distribution form. The experimental watershed contains two soil types; Kuye-Asatid (Loamy-skeletal over fragmental, carbonatic, mesic, Fluentic, Xerorthents) sandy loam lies in the upper portion of the watershed and Ramjerdi (Fine, mixed, mesic, Fluentic, Xerochrepts) clay loam in the lower portion. A 15 cm (6 inches) parshall flume was installed at the outlet of the watershed to measure the runoff flow rate from the site. As the flow was measured, water samples were taken for laboratory measurement of

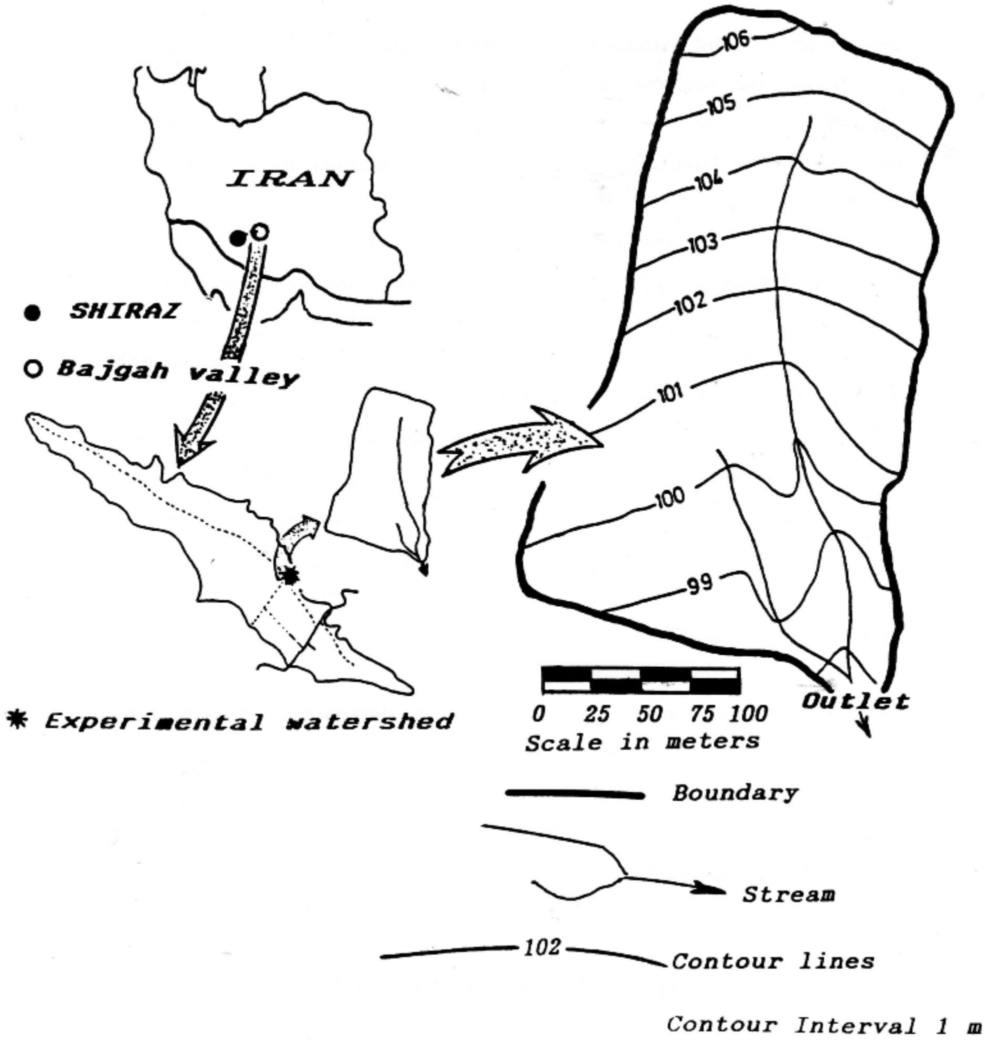

Fig. 1. Location of the experimental watershed in Bajgah valley in the north of Shiraz and its contour map.

the suspended solid materials. Four different storms in 1988 were selected to simulate the response of the watershed. A grid system of 25 m was adapted on the watershed to simulate the four rainfall events. The rainfall data used were from the Agricultural college weather station. The storm events used in this study are representative of those received in this regoin of Iran. Information concerning soil texture, total porosity, soil types, and the area of each soil type in the watershed was collected from Solhi (13), (Table 1). Soil samples were taken intermittently during the course of the study in order to update the antecedent soil moisture information, ASM, needed in the simulation. Representative plots of each soil type were completely saturated in order to measure the field capacity of the soils. This was determined by taking samples over two days. Infiltration capacity of the soils were determined by the double ring infiltrometer method. The soil erodibility factor, K, was determined using particle size distribution of the soils of the watershed under study, and the graphs of the Agricultural Handbook 537 (15), (Table 1).

Channel sizes and specifications were determined through direct measurements using the topographic map of the watershed. Other Pieces of information were extracted from the ANSWERS user's manual (14) according to the given tables. At the time of simulation, the upper part of the watershed was planted by dry farming wheat, while the lower part was fallow.

RESULTS AND DISCUSSION

Recommendation of the ANSWERS model for simulation of runoff and sediment from agricultural watersheds of Irán needs the application of the model on a small experimental watershed. Therefore, the ANSWERS model was used to simulate four storm events during the months of February and

Table 1.Taxonomy, area, physical, and erodibility factor of soils of the small watershed under

Soil Aweiwa	USDA Soil Taxonomy	Area (ha)	Horizo depth (cm)	*Particle size distribution%*				*field*† capa- City	Total § poro- sity	Infil. capa- City (mm/hr)	Erod. factor K
				Clapy	Fine silt	Coarse silt	Sand				
r=Kuye Astaid	Loamy-skeletal over fracmental, carbonaticmesic, FluenticXerorthents FluenticXererthents	1.70 Al	0-20	13	7	40	40	0.74	0.48	4.5	0.45
amjerdi	Fine,mixed, mesic, Xerochrepts	R3.13 AP Fluentic,	0-25	29	6	41	24	0.45	0.38	8.3	0.50

† % saturation; § % volume.

March 1988. A brief discussion of each event follows, with a summary of all the storm events given in Table 2.

Rainfall Event of February 18, 1988

The depth of the rainfall was 26.4 mm with a duration of 7 hr. Simulation of this storm showed a volume of 0.67 mm runoff and 80 kg ha^{-1} sediment yield. The simulated and observed hydrograph of runoff and sediment are depicted in Fig. 2. As Fig. 2 shows the first peak of the runoff occurred about 40 min. after the first part of the storm event in which the intensity of the storm was about 7.2 mm hr^{-1}. However, most part of this storm was used to fill up the saturation capacity of the soil. Therefore, the first peak of the simulated runoff hydrograph belonged to the low flow rate of about 0.06 mm hr^{-1}. The second peak occurred 120 min after the beginning of the storm event. As Fig. 2 shows the runoff flow rate was not measured around the peak period of the runoff. Consequently for this storm the discussion about the observed versus predicted runoff flow is limited to those points for which we had observed data values. As these results show, predicted and limited observed values for runoff are very close. The close agreement between observed and predicted runoff by the ANSWERS model for different sized watersheds are reported by many researchers (2,3,5,6). Unfortunately, we could collect the sediment samples only during the first and third hr. of the watershed response to that rainfall. However, the limited observed sediment values are close to the predicted values for ascending part of the hydrograph but in the descending part they are far apart. It seems that the rainfall intensity does not have much effect on detachment for the range of intensities in this storm. These rainfall intensities are less than 10 mm hr^{-1} so detachment energy is low and flows are due to ground water release.

Table 2. Predicted and observed runoff and sediment load from the experimental watershed for the four srorms.

Strom Date	*Depth mm.*	*Duration hr.*	*Predicted runoff mm/hr $x10^2$*	*Observed runoff mm/hr $x10^2$*	*Predicted sediment load ppm.*	*Observed sediment load ppm.*
21/18/88	26.4	7.0				
			5.6	4.5	8750	3910
			6.0	6.0	8450	6720
			4.9	6.7	8600	3440
			8.5	8.5	10000	8300
			7.6	10.1	9600	1875
			6.4	5.6	7300	1565
			5.5	5.4	7200	1250
2/25/88	49.5	15.7				
			36.8	56.6	14000	5600
			26.3	13.2	10000	5800
			17.1	9.2	22000	6000
			13.2		22000	6000
			51.3	51.3	19600	10000
			94.7	96.0	17200	9000
			109.0	107.8	16400	5800
			71.0	71.0	16400	
			25.0	21.0	10800	
			17.1	21.0	14400	
			18.4	10.5	24000	20000
			55.3	31.6	20000	
			92.0	147.4	16400	
			173.7	210.5	14200	19600
			244.0	236.8	14000	
			160.0	48.7	12800	16800
					14800	11200
					16000	10000
					16400	8800
					15200	5200

Table 2. Cont. :

Strom Date	*Depth mm.*	*Duration hr.*	*Predicted runoff mm/hr x10²*	*Observed runoff mm/hr x10²*	*Predicted sediment load ppm.*	*Observed sediment load ppm.*
3/05/88	16.5	3.7				
			22.8	13.6	16500	17000
			47.2	46.4	16700	8120
			37.6	27.2	19000	4000
			28.0	22.4	20000	3780
			21.6	18.0	19000	3120
			16.0	14.4	14500	2900
			12.0	12.0	11560	2560
			8.8	8.8	9500	2000
			7.2	6.8	8000	1900
			6.8	7.6	7100	1800
			5.2	6.4	7100	1750
			5.2	5.8	7000	1700
			4.7	5.8	7100	
3/24/88	20.8	5.0				
			29.38	58.12	14070	3125
			66.9	78.75	26560	3450
			75.0	78.75	21875	2820
			52.50	51.88	18440	2970
			41.25	31.25	17190	2500
			25.00	21.25	15625	1600
			25.00	21.25	14065	2190
			46.25	35.0	26880	2190
			50.00	46.25	20310	2050
			41.25	33.75	20310	1875
			28.13	30.0	14690	
			26.25	29.4	14065	
			21.25	21.25	12190	

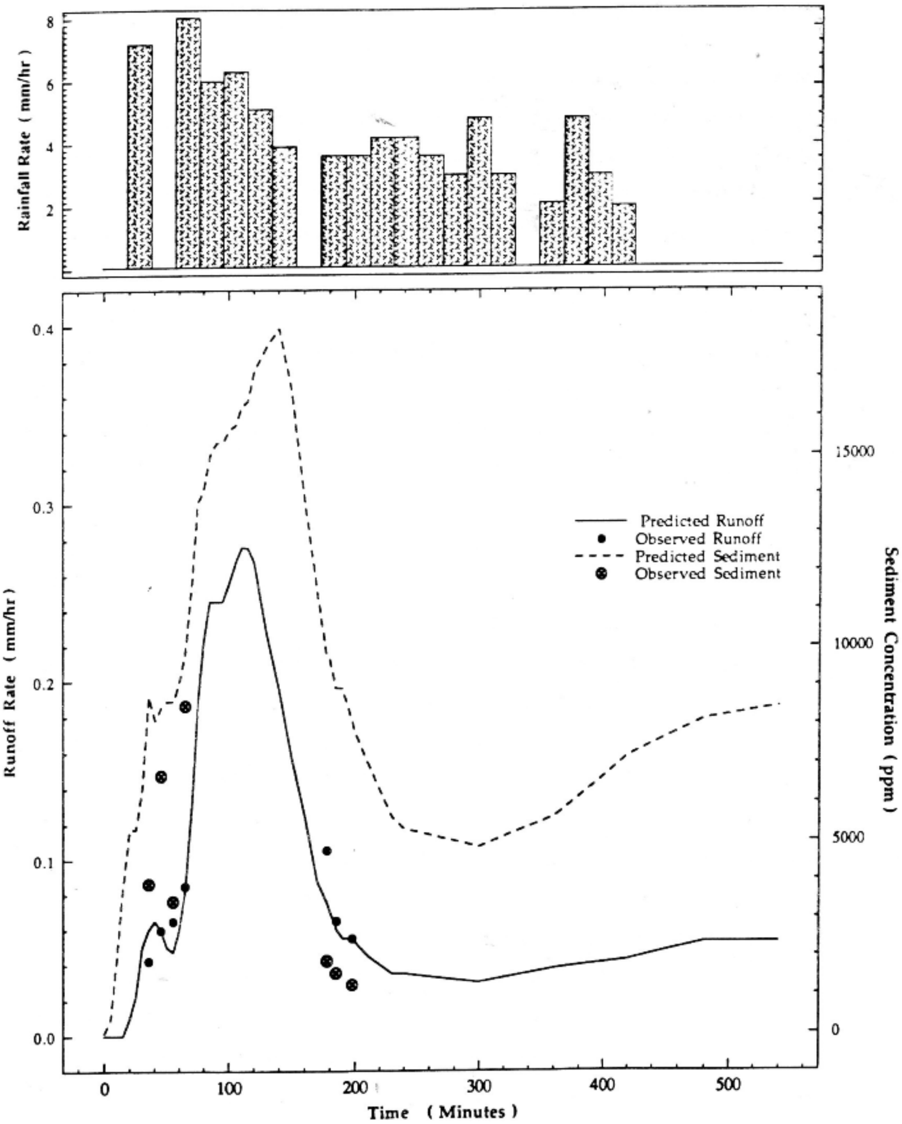

Fig. 2. Rainfall rate, predicted and observed runoff and sediment from the experimental watershed, storm of 2/18/88.

Storm Event of Febraury 25, 1988

In this event, the total depth of rainfall was 49.5 mm with 15 hr and 40 min duration. The simulated runoff values for this event was 6.94 mm with average soil erosion of 893 kg ha^{-1}. The results of the simulation and observed values for runoff and sediment concentration of this storm are shown in Fig. 3. As Fig. 3 shows the observed values of the runoff flow rate are scattered well enough in the last part of the storm duration (550-850 min from beginning of the storm event). The simulated values of runoff are in very close agreement with observed values especially at the peaks which occurred at 610 and 850 min after the runoff start. This means that the ANSWERS model is able to predict the peak flow rates of runoff.

Storm Event of March 5, 1988

This event produced 0.97 mm of runoff from 16.5 mm rainfall with a duration of 3 hr and 40 min. The results of this event are shown in Fig 4. As Fig 4 shows the simulated hydrograph of runoff flow rate has the same trend of the observed values of the runoff from the site. The observed peak of the runoff is defined closely by the simulated value. The predicted values of sediment concentration are very close in the ascending part of the sediment curve but after the peak of the rainfall, the sediment concentrations are lower than the predicted values.

Storm Event of March 24, 1988

The depth of the rainfall for this event was about 21 mm with the duration of 5 hr. The value of the runoff from this storm was 1.53 mm with an average soil loss of 196 kg ha^{-1}. Fig. 5 shows the results of this storm. As Fig. 5 shows that the storm simulation results are in close agreement with the observed values of the runoff discharge from this small catchment area. The ascending and descending parts of the observed values, and the peak values of runoff are defined with the same trends, amounts,

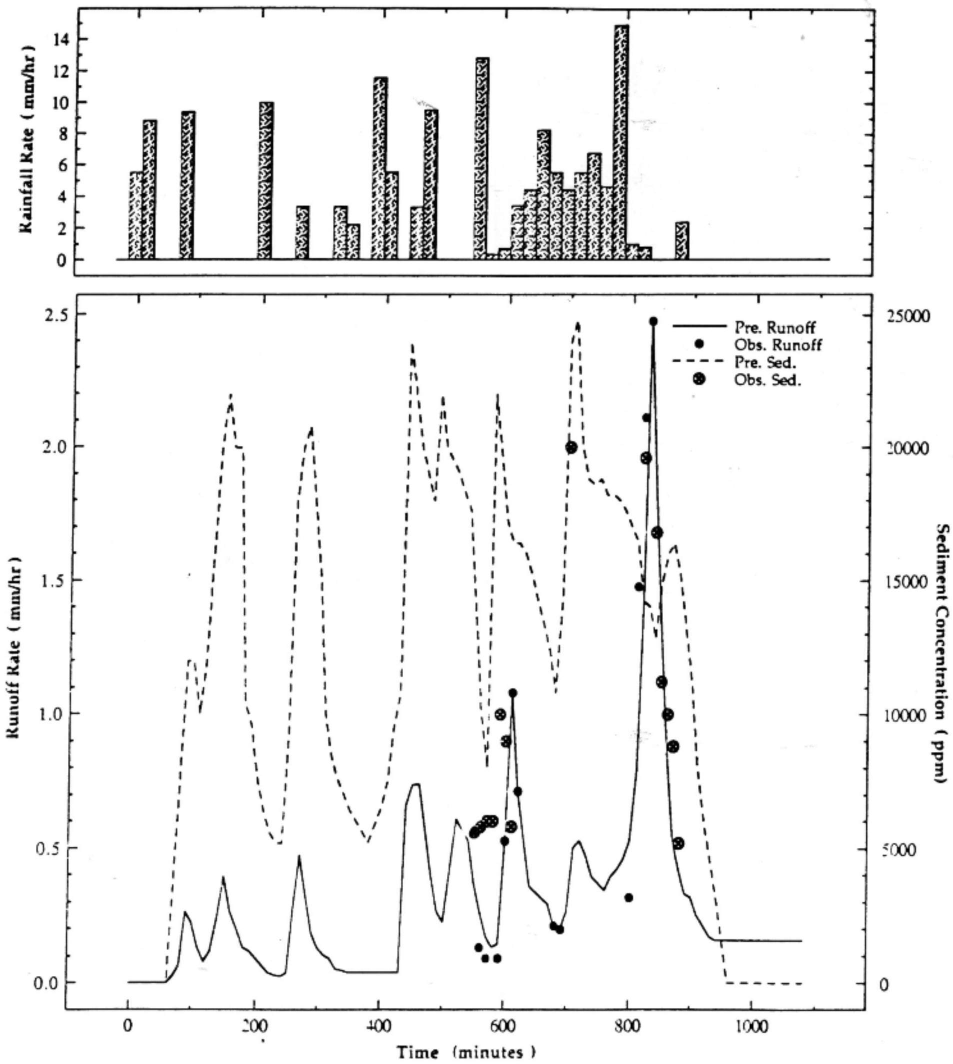

Fig. 3. Rainfall rate, predicted and observed runoff and sediment from the experimental watershed, storm of 2/25/88.

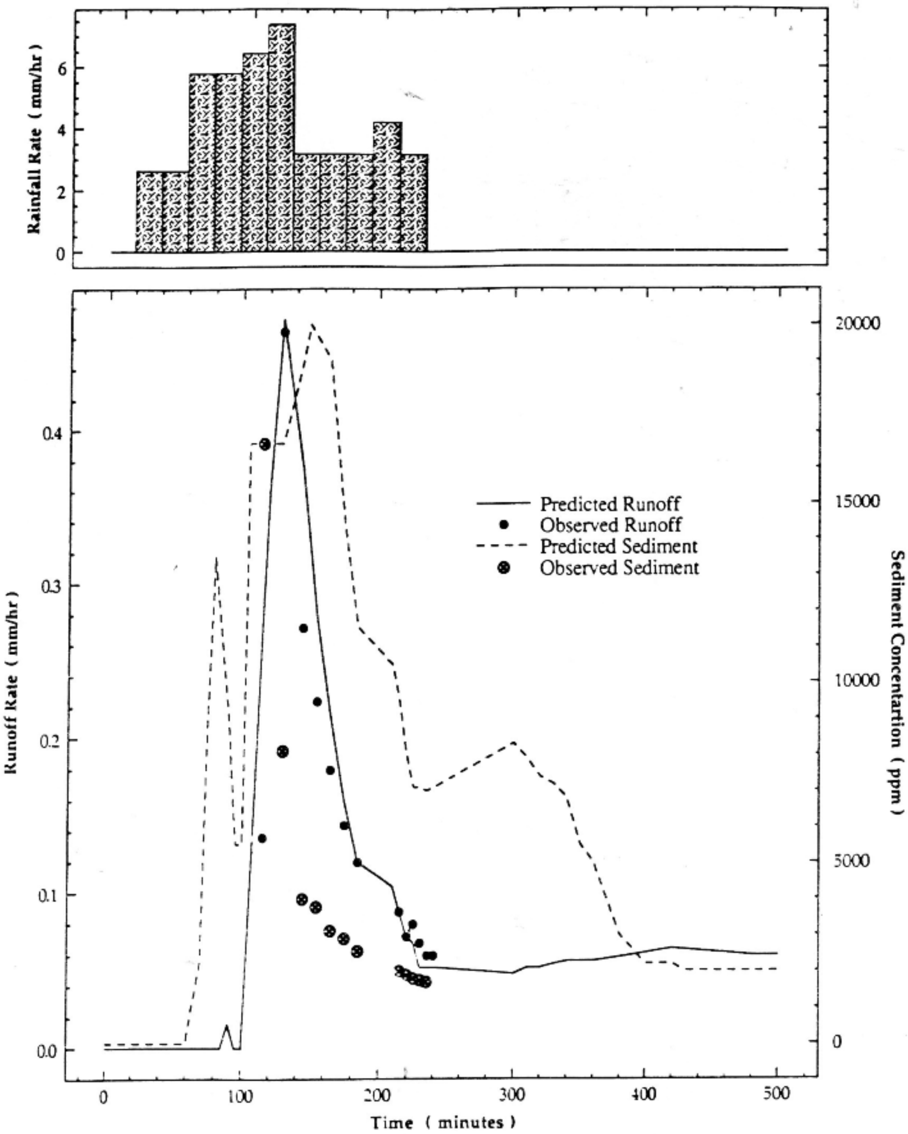

Fig. 4. Rainfall rate, predicted and observed runoff and sediment from the experimental watershed, storm of 3/5/88.

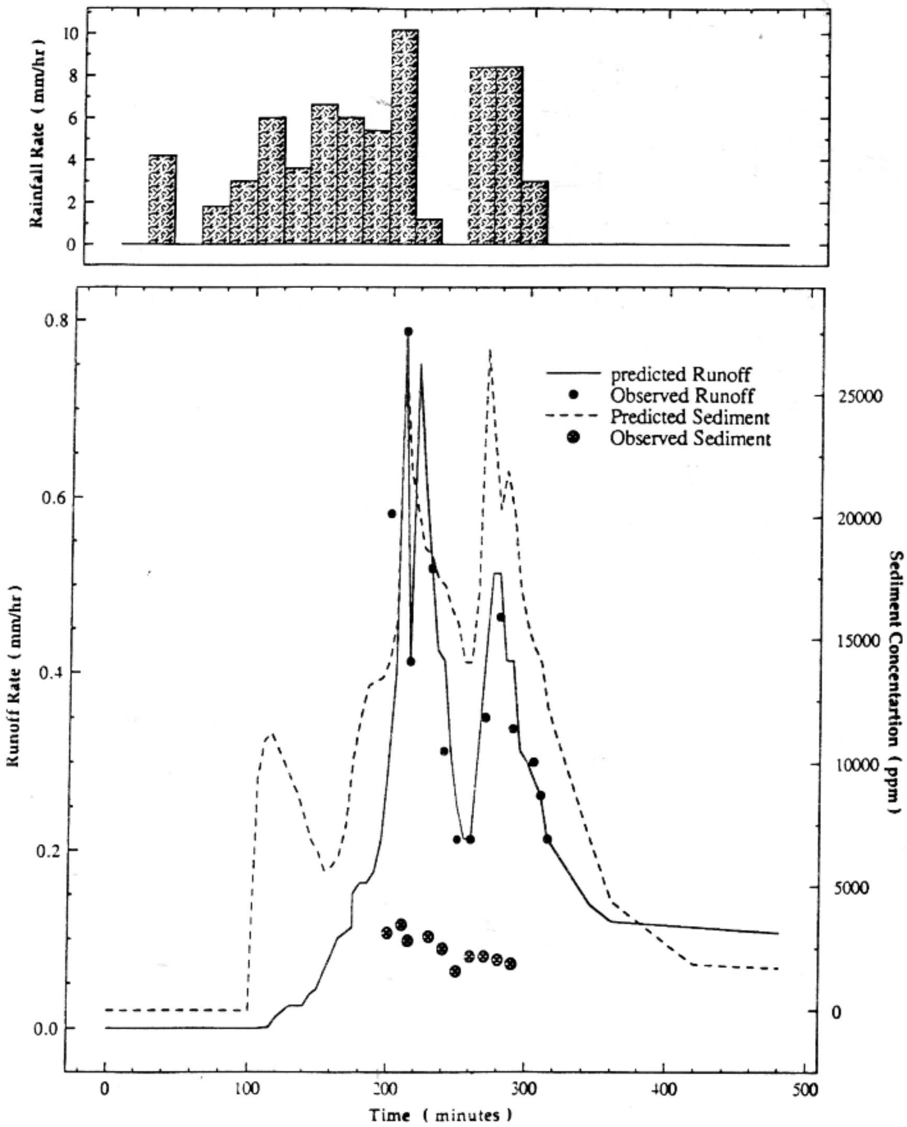

Fig. 5. **Rainfall rate, predicted and observed runoff and sediment from the experimental watershed, storm of 3/24/88.**

and timing by the predicted runoff hydrograph. Therefore, the ANSWERS model demonstrated a very close agreement of the actual hydrographs for different sizes of storm events. This agreement between the predicted and observed values of runoff are discussed in the literature for different watersheds in different parts of USA and Canada (1). A summary of the results of the four events is shown in Table 2. As Fig. 2 to 5 show the hydrology part of the ANSWERS model predicted runoff rates from our small basin with high accuracy. The values of the observed and predicted sediment concentration are shown in columns 6 and 7 of Table 2, respectively. They do not show a very close agreement for the storm events used in our study (Fig. 2 to 5). These are due first, to the complexity of the soil erosion process from the watershed by surface runoff flow and rainfall detachments and secondly the model is developed for the high rainfall intensity regions of the USA which are very different in crop coverage, soil type, and climatic conditions with respect to our situations in south of Iran. However, the simulation results of the sediment component of the ANSWERS model even in the USA watersheds showed the same trend as the watershed in Iran (11). This means that the erosion/sedimentation part of the ANSWERS model should be worked out with the recently new equations of the soil erosion, or the coefficients involving in the flow regime of the model responsible for the detachment, should be changed according to our conditions in Iran. Otherwise, the coefficients of the rainfall and flow detachment should be changed on the basis of several years of data collection from different size of watersheds with differences in crop coverage and management. This means that the model in the sedimentation part should be calibrated before application for simulating sediment loads for a watershed in Iran. However, more intense storms and watersheds of different sizes in different climatic conditions in Iran are needed to be used.

Although there were not very close agreements between the observed and predicted values of the sediment concentrations in runoff flow, the simulation results of the ANSWERS model are in closer agreement than the results from lamped parameter models (8). The differences between observed and predicted values obtained by the ANSWERS model are the same as those in the other distributed parameter models(7).

Some part of the error associated with the sediment results may be due to the error in water sampling for determination of sediment suspension solid. However, the results of the sediment component of the ANSWERS model indicate that it needs modification to adapt the model to the condition in Iran, especially for the low intensity rainfall. Because of these reasons, the regression analysis was performed only for the runoff results.

The linear regression analysis was performed to correlate the observed and predicted runoff values for the storms used in the simulation study. Correlation coefficients of the regression analysis are shown in Table 3. The correlation coefficients has the minimum value of 0.86 and maximum of 0.98, showing high correlation between observed and simulated runoff rates from our small site. The ability of the ANSWERS model for prediction of the runoff rates from ungaged watersheds is well demonstrated by simulation of the storm events over the experimental watershed in our study.

Table 3. The correlation coefficient for predicted and observed values fo four storm events from the experimental watershed.

storm	*R*
2/18/88	0.86
2/25/88	0.94
3/ 5/88	0.94
3/24/88	0.98

CONCLUSIONS

The ANSWERS model is able to accurately estimate runoff values and the runoff hydrograph for the study watershed which is typical of southern Iran agricultural watersheds. However, for the types of storms common in this region of Iran, ANSWERS was not able to accurately estimate sediment concentration in runoff. Finally, it is proposed that the erosion components of the ANSWERS model require modification more to estimate more accurately the erosion for the low intensity rainfalls of southern Iran.

LITERATURE CITED

1. Amin Sichani, S. 1982. Modeling of phosphorus transport in surface runoff from agricultural watersheds. Ph.D. thesis. Purdue University, West Lafayette, Indiana 47907 USA. 157 pp.

2. Amin Sichani, S. 1989. Prediction of runoff and sediment from agricultural watersheds using mathematical models. I: Introducing ANSWERS. Iran Agric. Res. 8: 75-92.

3. Amin Sichani, S. and B.A. Engel. 1990. Prediction of runoff and sediment from agricultural watersheds by a mathematical model. II: Watershed simulation. Iran Agric. Res. 9: 1-16.

4. Beasley, D.B. and L.F. Huggins. 1982. ANSWERS user's manual. EPA-905/9-82-001. U.S. Environmental Protection Agency, Great Lakes National Program Office. Chicago, IL. 54 pp.

5. Beasley, D.B., L.F. Huggins and E.J. Monke. 1980. ANSWERS: A model for watershed planning. TRANSACTIONS of the ASAE 23: 938-944.

6. Dillaha, T.A.,III. 1981. Modeling the particle size distribution of eroded sediments during shallow overland flow. Ph.D. thesis. Purdue University, West Lafayette, Indiana 47907 USA. 189 pp.

7. Foster, G.R. 1980. Soil erosion modeling: Special consideration for nonpoint pollution evaluation of field size areas. *In*: Overcash, M.R. and J.M. Davidson (eds.), Environmental impact of nonpoint source pollution, Ann Arbor, MI. pp. 213-240.

8. Foster, G.R., L.J. Nowlin, J.M. Laflen and R.A. Young 1980. A model to estimate sediment yield from field size areas: Development of model. *In*: Knisel, W.G. (ed.), CREAMS. A field scaled model for chemicals, runoff, and erosion from agricultural management systems. Conservation Res. Rept. No. 26, USDA-SEA. pp. 36-64.

9 Huggins, L.F. and E.J. Monke. 1966. The mathematical simulation of hydrology of small watersheds. Technical Roeport No. 1. Water Resources Research Center. Purdue Univer. West Lafayette, Indiana 47907 USA. 130 PP.

10. Momtahan. H. 1989. Application of the ANSWERS model for prediction of runoff and sediment from small agricultural watersheds of Iran. M.S. thesis. Irrigation Department of College of Agriculture, Shiraz University, Shiraz, Iran. 218 pp.

11. Purschwitz, M.A., 1981. Using ANSWERS on Indiana and Texas watersheds with four element sizes. M.S. thesis. Purdue University, West Lafayette, Indiana 47907 USA. 95 pp.

12. Soil Conservation Office, 1981. An exploratory analysis of the economical and social effects of watershed management. Iran Agricultural Ministry. (In Persian).

13. Solhi, M. 1988. Soil genesis, morphology, physiochemical properties and classification of Bajgah region soils (Fars province). M.S. thesis. College of Agricultue, Shiraz University, Shiraz, Iran. 140 pp. (In Persian).

14. Thomas, D.L. 1984. A physically-based, distributed parameter, forest hydrology model. Ph.D. thesis. Purdue University, West Lafayette, Indiana 47907 USA. 260 pp.

15. Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses. Agricultural Handbook No. 537. Science and Education Administration, U.S. Deparment of Agriculture. 58 pp.