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Application of the TR-55 Model to Storms in Arid Climate Case Study: Upper Tabalah, The Kingdom of Saudi Arabia

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ABSTRACT. The U.S. Soil Conservation Service revised model (*TR-55*) is used to obtain peak discharges of the storms produced in Wadi Tabalah. *Tabular Hydrograph Method* is applied to simulate the values in order to compare them with the observed flood peak records. The model is found advantageous for computing practical watershed hydrograph parameters, such as losses, detention storages, time of concentration, considering some of the basic watershed and hydrologic parameters (size of basin, curve number, travel time and 24-hr rainfall depth) as input. Computational example is presented with the tabulated input values of seven observed storms. The findings are discussed in tabular and graphical forms, and compared with the historical records. The other model studies obtained through unit hydrograph and routing procedures by the author are compared with the model *TR-55* in order to draw conclusion about the practicality and applicability of the model under arid climate condition when the data is scarce and limited.

Introduction

A model called *Technical Release* (*TR-55*), was originally developed by the U.S. Soil Conservation Service (*SCS*) in the 1970's and was revised in June of 1986 and published by Wu, S. and Wu, J. (1987), is used in this study. The model incorporates current *SCS* procedures when the purpose is to assess the peak discharge hydrograph for drainage design. A simplified method is followed with two approaches, namely *Graphical and Tabular Methods,* as mentioned in the TR-55 manual (1986).

This paper discusses the history of the manual document as well as provides the information with an application to one of the representative basins under arid climate using observed storm records. The input/output features of the model can be shown, using the program's tabular hydrograph options in order to compare with other simulation programs which are already applied by the authors in their paper (Sorman *et al.* 1993). Therefore, the theory provided in this paper only covers the summary of the tabular method which is recommended for modelers to follow up in determining hydrographs for small areas.

The area chosen for this study is located at the upstream part of Wadi Tabalah which is the branch of Wadi Bishah. The wadi is situated on the eastern side of the escarpment with a drainage area of 170 km^2.

The area is controlled by a runoff recording station B413 and seven rainfall stations situated in and nearby the basin. Figure 1 shows the location of wadi and its sub-catchment with locations of rainfall and runoff stations.

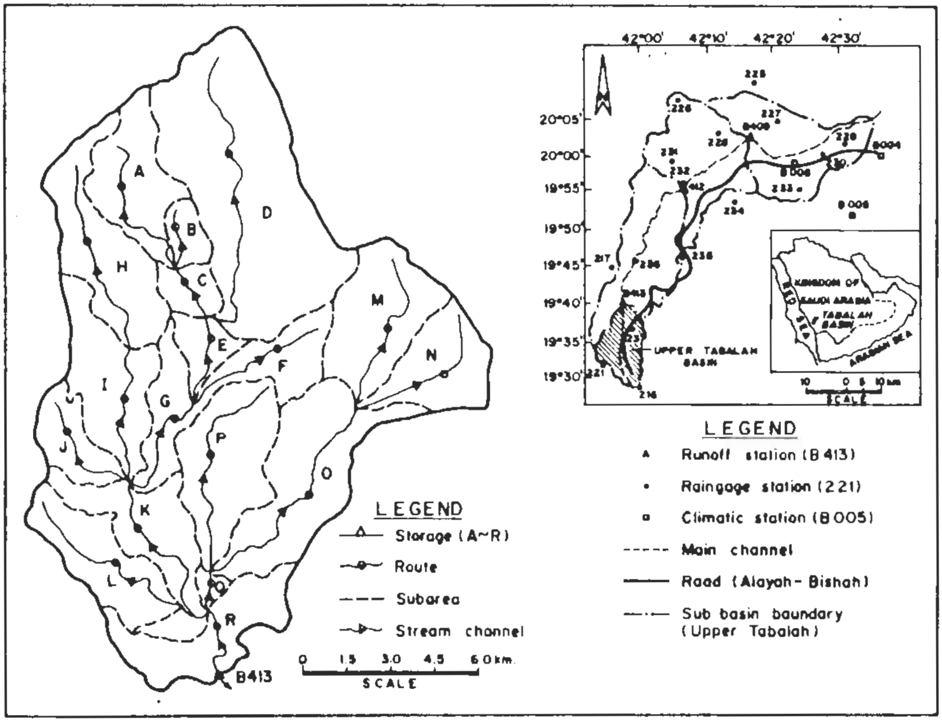

FIG. 1. Upper Tabalah basin and its sub-catchments.

History and Early Applications of the Method

For decades, the prediction of peak discharge has been based on the use of *Rational Method* and the U.S. Soil Conservation Service techniques. Recent advances in computational hydrology have led to re-evaluation of these techniques followed by Wu, S. and Wu, J. (1987), the adaptation of the mainframe programs (HEC-1, TR-20 or others) to personal computers. The purpose of this study is to review one of the latest developments of the peak discharge computation with application, so that the results obtained from the research can be compared with other similar model applications, such as excess rainfall (*XSRAIN*) and runoff-routing (*RORB*).

The use of early programs with mainframe, such as the *SCS-TR-20* and the Corps of Engineers, *HEC-1,* proved to be cumbersome and time consuming for simple works. The need for more cost effective methods became apparent. The model developed and revised by *SCS,* called as *Technical Release No. 55* (*TR-55*) has the advantage of computing watershed hydrology items, such as losses, time of concentration, detention storage and hydrograph estimates. The methods were developed based on a 24-hour storm and *SCS* type II rainfall distribution. The revised version of the model added the factor I_a/P to account for the effects that initial abstraction (I_a) and precipitation (P) have on both peak discharges and hydrographs. The *SCS* also added other types of rainfall distribution pattern.

The *Tabular Hydrograph Method* is the concern of this paper. It is applicable to basins with subarea, time of concentration T_c, between 0.1 and 2.0 hours and travel time T_t, of less than 3.0 hours. Drainage areas of the individual subareas should not differ by a factor of five or more, SCS - Technical Release (1986). Furthermore, the time to peak must be more accurate than that obtained by the use of the method. The method can be used to develop hydrographs for pre- and post-developed area analyses or to estimate peak discharges. It is an ideal method for small basins, where other models may prove to be too detailed. Further discussion about this is given by Glazner (1987) and Hromadka and McCuen (1987).

Computational Procedures of TR-55

The required model parameters are:

1 – Basin subdivision, if necessary.
2 – Size of the area.
3 – SCS curve number (CN) for each subarea.
4 – Time of concentation (T_c) for each subarea.
5 – Travel time (T_t) for each subarea.
6 – Rainfall distribution type (I, IA, II or III).
7 – The total 24-hr rainfall depth (P) for the selected return frequency (T_r).

Computational Example

The procedure for constructing a hydrograph can be summarized as:

1 – Calculate area (A), curve number (CN), precipitation depth (P), and time of concentration (T_c), as shown in Table 1 for all the storms studied.

2 – Calculate runoff depth (R) using $(P\text{-}0.2S)^2/(P + 0.8S)$ where storage $S = (1000/CN) - 10$.

3 – Ratio I_a/P is calculated as $0.2\ S/P$ to convert the hydrographs to m^3/sec/mm of runoff.

4 – Reach flow velocities are estimated to calculate travel time T_t = Reach length/ flow velocity.

5 – Use Option 1 and enter the aforementioned data to create the watershed file.

6 – Option 3 is run to compute the peak discharge for the file that was entered in step 5 using generated tabular hydrographs based on the travel time computed in step 4.

7 – Area and runoff is multiplied by the proper tabular hydrograph values to obtain hydrograph ordinates.

Following the procedure described above with the additional input values tabulated in Table 1 for each storm, the peak discharges are simulated in order to compare them with the observed records. The results are discussed more elaborately in the following section.

TABLE 1. Input/output data for TR-55 Model (Upper Tabalah B413).

Date			Precip.	Time of concent.	Curve no.	Intercept. precip.	I_a/p	Runoff depth	UH peak cms/inch	Simulated disch. Q_p	
D	M	Y	P (inch)	T_c (hrs)	CN	I_a (inch)	(–)	R (inch)	q_u	cms	m³/sec
25	01	85	1.15	0.20	77	0.597	0.519	0.09	361	2043	58.0
05	04	85	1.09	0.20	76	0.632	0.579	0.06	361	1376	39.0
10	04	85	0.232	0.15	96	0.083	0.359	0.04	764	1961	55.5
11	04	85	0.858	0.30	78	0.564	0.657	0.03	295	536	15.0
23	04	85	0.437	0.25	76	0.632	1.445	0.01	323	271	7.7
01	05	85	0.406	0.15	74	0.703	1.731	0.03	416	748	21.2
20	05	85	0.596	0.10	87	0.300	0.500	0.050 0.065	508	1285	36.3

$$Q_p \text{ (cms)} = \underset{\text{(cms/inch)}}{q_u} \times \underset{(\text{mi}^2)}{A} \times \underset{\text{(inch)}}{R}$$

cms/inch = cfs/mi²-inch

Discussion of Results

Rainfall-runoff data obtained for the study area through rainfall-runoff stations during the recording period 1985-87 are presented in Table 2. The storm and runoff hydrograph characteristics as well as duration, time lag, time base, and time to peak values are also tabulated. The runoff coefficients shown in the last column of Table 2 clearly indicate that the values vary between 3% and 10% for an area of 170 km² drainage size.

TABLE 2. Rainfall-runoff data in Upper Tabalah at B413.

Date	Precip. depth P (mm)	Direct runoff depth R (mm)	Observed peak disch Q_{DR} (m^3/sec)	Storm duration t_D (hr)	Time lag t_L (hr)	Time base t_B (hr)	Time to peak t_p (hr)	Runoff coeff. R_c (-)
25 Jan. 1985	29.21	2.03	58.0	7	1.5	10.0	5.0	0.069
05 Apr. 1985	27.13	2.95	38.8	6	1.5	25.0	3.0	0.109
10 Apr. 1985	5.89	1.14	61.0	1	0.5	6.2	1.6	0.194
11 Apr. 1985	21.79	0.66	16.6	4	1.8	9.0	3.8	0.030
23 Apr. 1985	11.10	0.30	6.2	5	4.0	8.0	9.0	0.027
01 May 1985	10.31	0.58	24.0	3.0	2.0	23.0	3.5	0.056
20 May 1985	15.14	1.65	35.2	2	2.0	24.0	2.5	0.109

In order to compare the input/output model parameters at the *TR-55* with the other models simulation studied recently by the authors (1993), the results of excess rainfall (*XSRAIN*), runoff-routing (*RORB*) and the model under study called *TR-55* are tabulated in Table 3. For example, in *XSRAIN* model studies, the unit hydrograph peak (q_{UH}), the curve number (CN) as well as the initial abstraction loss (I_a) are repetitive; similarly, initial loss abstraction (I_L) in the *RORB* model is closely related to the abstraction loss (I_a) in the *TR-55*. In addition, the time lag (T_L) in *XSRAIN* model is related to the time of concentration (T_c) in *TR-55*. Simple regression studies between the common variables in respective models as mentioned above provided us the correlation coefficients indicating that high correlation exists (such as 0.75 and 0.90) between curve numbers and initial abstraction losses of *XSRAIN* and *TR-55* respectively. Also the relationship between initial loss (I_L) of *RORB* model and abstraction loss (I_a) in *TR-55* is found in the range of 0.66.

Conclusion

The predicted peak discharges ($\hat{Q}_p$) using *TR-55* are compared with the simulated results of the other two models. The accuracy of prediction for the three models compared with the observed records is presented in Table 4. On the average, the minimum deviations in the discharge are obtained using *RORB* and *TR-55*. The simulated results have shown around 7-8% deviations from the observed which are considered to be acceptable. The selected models for predicting hydrograph peak discharges are proposed.

A typical storm hydrograph recorded on April 10, 1985 which has the highest peak among the others is presented in Fig. 2 with the isohyetal map and storm hyetograph.

TABLE 3. Input model parameters for XSRAIN, RORB and TR-55.

Date			Rainfall		XSRAIN(1)					RORB(1)				TR-55(2)			
			Depth	Duration	q_{UH}	t_L	CN	I_a	K_s	I_L	C_L	K_c	m	q_u	T_c	CN	I_a
D	M	Y	P (mm)	T_R (hr)	(m³/sec/mm)	(hr)	(−)	(mm)	(mm/hr)	(mm)	(mm/hr)			(m³/sec/mm)	(hr)		(mm)
25	01	85	29.2	7	31.0	1.5	80	13.2	1.17	24.8	7.6	1.20	0.79	26.4	0.20	77	15.2
05	04	85	27.1	6	11.5	1.5	81	11.9	0.97	5 / 13 — 18	6.7	1.84 / 1.78	0.84 / 0.84	26.4	0.20	76	16.0
10	04	85	5.9	1	26.0	0.5	98	1.0	0.08	0.8	3.6	2.03	0.73	55.8	0.15	96	2.1
11	04	85	21.8	4	24.4	1.8	84	9.7	1.30	14.3 / 2.4 — 16.7	0.30 / 0.01	0.01	0.70	21.5	0.30	78	14.3
23	04	85	11.1	5	9.1	4.0	87	7.6	0.43	10.0	6.3	3.43	0.60	23.6	0.25	76	16.0
01	05	85	10.3	3	31.1	2.0	90	5.6	0.53	10.5	4.2	3.54	0.69	30.4	0.15	74	17.9
20	05	85	15.1	2	14.7	2.0	89	6.4	1.25	14.4	1.0	2.43	0.75	37.2	0.10	87	7.6

(1)Sorman *et al.* (1993).
(2)Table 1, using TR-55.

TABLE 4. Model outputs and prediction errors in Q_p using different approaches.

Date			(SCS)		RORB		TR-55		Observed
			$\hat{Q}_p$	$\left(\frac{Q_{p_o}-\hat{Q}_p}{Q_{p_o}}\right)\times 100$	$\hat{Q}_p$	$\left(\frac{Q_{p_o}-\hat{Q}_p}{Q_{p_o}}\right)\times 100$	$\hat{Q}_p$	$\left(\frac{Q_{p_o}-\hat{Q}_p}{Q_{p_o}}\right)\times 100$	Q_{p_o}
D	M	Y	(m³/s)	(%)	(m³/s)	(%)	(m³/s)	(%)	(m³/s)
25	01	85	56.6	2%	50.6	13%	58	0%	58.0
05	04	85	37.9	15	38.9	0.3	39	0%	38.8
10	04	85	50.7	17	50.4	17	55.5	9	61.0
11	04	85	16.9	−2	16.8	−1.0	15	10	16.6
23	04	85	2.8	55	5.6	12.0	7.7	20	6.4
01	05	85	18.1	22	23.4	3.0	21.2	9.4	23.4
20	05	85	26.7	24	34.5	2.0	36.3	−3.1	35.2
Average				20%		7%		7.4%	

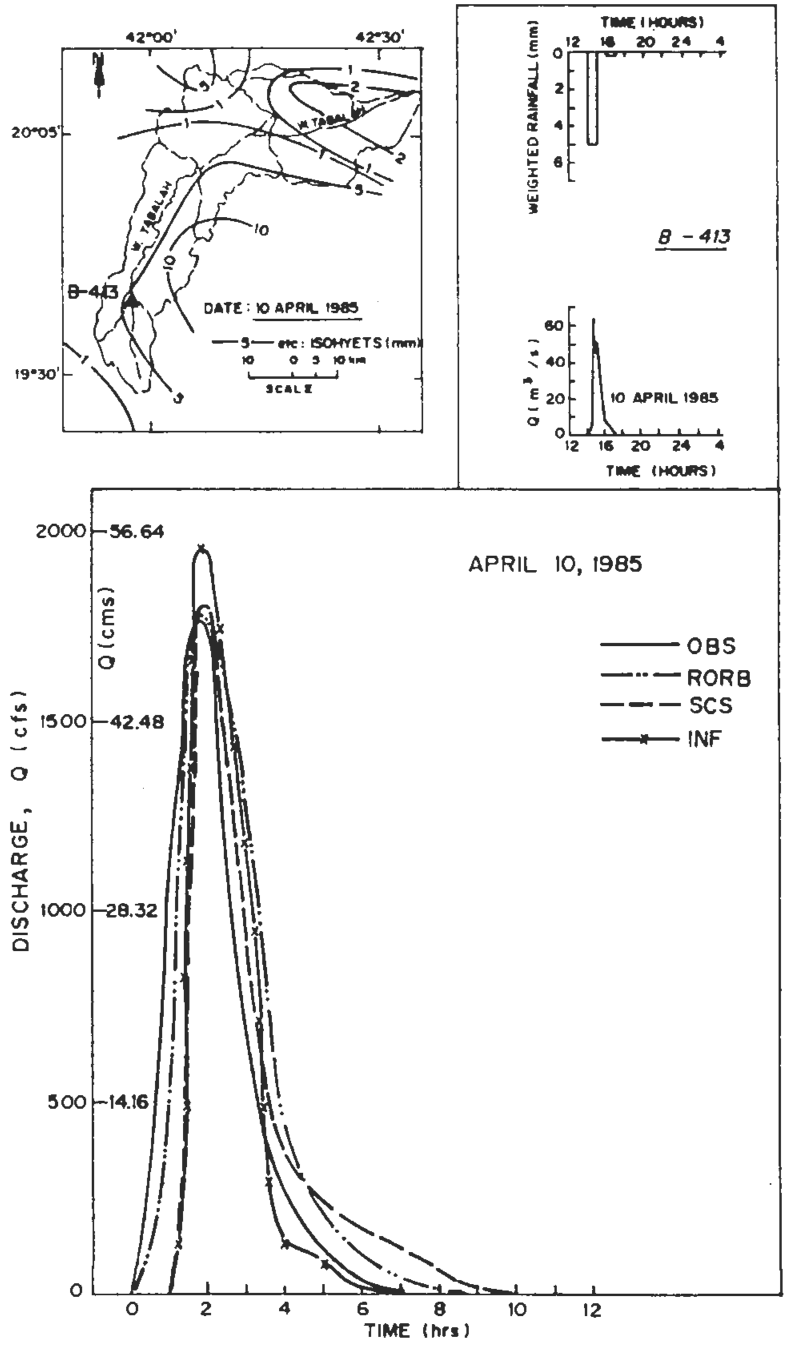

FIG. 2. Isohyetal map and the storm hydrograph for April 10, 1985.

The simulated hydrographs are plotted together with the observed values after comparison using the other models, namely *XSRAIN* (*SCS*, and *INF* versions) and *RORB*. For the given data, *TR-55* model predicted the discharge hydrograph peak to be 55.5 m^3/sec (1961 cms) for which the observed data was recorded as 61 m^3/sec.

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تطبيق النموذج الرياضي تي آر ٥٥ (TR-55) على العواصف المطيرة في المناطق الجافة دراسة حالة : تبالة العليا - المملكة العربية السعودية

علي أونال شورمان

قسم علوم وإدارة موارد المياه ، كلية الأرصاد والبيئة وزراعة المناطق الجافة

جامعة الملك عبد العزيز ، جـــدة ، المملكة العربية السعودية

المستخلص . تم تطبيق النموذج الرياضي المعد بوساطة جمعية خدمات التربة الأمريكية والمعروف تحت مسمى تي آر ٥٥ (TR-55) للحصول على تصريف مياه السيول الناجمة عن العواصف المطيرة في حوض وادي تبالة . وتم مقارنة النتائج الخاصة بتصريف السيول التي تم الحصول عليها من تطبيق النموذج الرياضي بالقيم الحقلية . أظهرت النتائج الفوائد التي يمكن الحصول عليها من العوامل الهيدرولوجية الممثلة لكمية الفاقد من سريان المياه وعامل التخزين أو الأوقات اللحظية ، مع الأخذ بعين الاعتبار خواص الأحواض المائية الممثلة في حجم الحوض ، أوقات السرعة وكمية الأمطار .

وقد تم تطبيق النموذج وإظهار النتائج في جداول وأشكال ومقارنتها مع القيم التي تم الحصول عليها في الحقل والطرق الأخرى ، حيث أدى الاستنتاج إلى إمكانية استخدام النموذج آنف الذكر للمناطق الصحراوية ، وخصوصًا في الحالات التي لا توجد بها معلومات تفصيلية .