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Use of Talbot Formula for Estimating Peak Discharge in Saudi Arabia

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ABSTRACT. The Ministry of Communication (MOC) of the Kingdom of Saudi Arabia uses a modified form of Talbot formula to calculate peak discharge to be used for design purposes for various regions of the Kingdom. This paper examines the applicability of this formula with results based on frequency analysis of available stream gaging data. The results showed that the use of this formula may give extremely high or low values of discharge in some cases. A modification of the formula has been suggested which may be used until enough stream gaging data are available.

1. Introduction

The estimation of peak discharge of various recurrence intervals is one of the most common problems faced by hydrologists and engineers when designing drainage and reservoir structures. This problem can be of two categories. First, the site is at or near a gaging station and the stream flow records are fairly complete and of sufficient length to be used to provide estimates of peak discharges by frequency analysis. Second, the site is not near a gaging station and no stream flow records are available. In this case, some empirical formulas are used to estimate the peak discharges.

In 1953, the Hydrological Division of the Ministry of Agriculture and Water started the preliminary work for establishing stream gaging stations around the Kingdom. By 1960 only seven stream flow recording stations were in operation. During the period of 1965 to 1969, the number of installed gages increased from seven to thirty five and by 1986 this number further increased to 103. But many of these gaging stations had to be closed after only a few years of operation due to various reasons. Therefore most of the stations have only a few years of record. Because of the non existence of sufficient stream flow records of the Kingdom, the Ministry of Communication had to rely on empirical formulas for the estimation of peak discharges in their design of highway bridges and culverts. This empirical formula is a modified version of Talbot formula and is still being used by the Ministry. However, later experience showed that the estimation of peak discharges using this version of the Talbot formula gave erratic results in some cases.

2. Objectives

The above experience of the Ministry of Communication led to the idea of reexamination of the modified Talbot formula with the stream flow records now available, and with the following objectives in mind :

1) Examination of the applicability of the Modified Talbot formula being used by the Ministry of Communications to calculate peak discharges from drainage basins, by comparing modified Talbot formula predictions with the results based on frequency analysis of stream gaging data from as many places as possible in the Kingdom of Saudi Arabia.

2) Suggest modification of this formula based on the analysis of actual data.

3. Method

3.1 Approach

Peak discharges of three different recurrence intervals (namely 25, 50 and 100 years) of the selected basins were calculated using the modified Talbot formula. Frequency analysis was performed to estimate peak discharges of the same recurrence intervals for the same selected basins. The results of the two methods were compared and a modification of the formula was suggested.

3.2 Modified Talbot Formula

The orginal Talbot formula estimates the required area of the drainage structure rather than peak discharge taking into consideration the coefficient of discharge and size of the drainage area. In 1971 and during the design of some feeder roads in the mid-North of the Kingdom, the consultant of the project Wilson Murrow[1] had suggested a modification of Talbot formula to suit that part of the Kingdom. The Wilson Murrow's report[1] neither gives any basis on which the original Talbot formula was modified nor the basis for the assumption of the different constants. While the first modification was developed using English units, current equations are in SI units. This modified Talbot formula is being used by MOC for all parts of the Kingdom without any further modification.

The modification was based on dividing the sizes of watersheds into four different categories, namely: Small, medium, large and regional. The areas less than 400 hectares are in the category of small watershed for which a separate type of equation is used. As the present study does not include any watershed of less than 400 hectares, the equation applied to small watershed has not been included in this paper. The following sections describe the modified Talbot formula developed by Wilson Murrow[1] for the next three different categories of watersheds based on areas, namely :

a) Medium watershed of size 400-1258 hectares
b) Large watersheds of size 1258-35944 hectares
c) Regional watersheds of size more than 35,944 hectares

The basic equation for peak discharge of the modified Talbot formula is of the form

$$Q = K\,C\,A^{n}\,R_f\,F_f \qquad (1)$$

where

Q = is the peak discharge in m^3/sec.
K = is a constant having values 0.558, 3.561 and 10.166 for medium, large and regional watersheds respectively.
C = is a coefficient of discharge which was suggested to be the summation of C_1, C_2 and C_3, where C_1 is the coefficient of terrain condition, C_2 is the coefficient of slope of drainage area, and C_3 is the coefficient of shape of drainage area. Table 1 shows the values of C_1, C_2 and C_3. (Wilson Murrow[1]).
A = is the drainage area in hectares.
n = is an exponent which depends on the size of the drainage area having values 0.75, 0.50 and 0.40, for medium, large and regional watersheds respectively.
R_f = is a rainfall factor which was suggested to be 1.5 for medium watershed and 1.4 for both large and regional watershed.
F_f = is a frequency factor depending on the desired storm frequency and are shown in Table 2 (Wilson Murrow[1]).

TABLE 1. Values of C_1, C_2 and C_3 used in Equation (1).

C_1	0.30	Mountainous area
	0.20	semi-mountainous
	0.10	low land
C_2	0.50	$S > 15\%$
	0.40	$10 < S < 15\%$
	0.30	$5\% < S < 10\%$
	0.25	$2\% < S < 5\%$
	0.20	$1\% < S < 2\%$
	0.15	$0.5\% < S < 1\%$
	0.10	$S < 0.5\%$
C_3	0.30	$W = L$
	0.20	$W = 0.4\,L$
	0.10	$W = 0.2\,L$

W = width, L = length, S = slope of drainage area.

3.3 Frequency Analysis and Probability Distribution

The primary objectives of frequency analysis are to determine the return periods of recorded events of known magnitude and then to estimate the magnitude of events

TABLE 2. Design storm frequency factor F_f

Frequency in years	F_f
5	0.60
10	0.80
25	1.00
50	1.20
100	1.40

for design return periods beyond the recorded range by probability distributions. Most of the probability distributions are empirical in nature. In most cases the selection of a distribution for hydrologic data is based on the hydrologist's sense, experience and verification of data. Many probability distributions have been found to be useful for hydrologic frequency analysis, but there is no best distribution for floods and there is no reason to expect that a single distribution will apply to all streams worldwide. Moreover, there is no general agreement among hydrologists as to which of the various distributions should be used. Studies by Al-Jebreen[2], Al-Turbak and Quraishi[3], Sorman and Abdulrazzak[4], Al-Nimer[5] and Shequra[6] showed that Extreme Value Type 1 (EV1), commonly called Gumbel Type 1 is the best suited distribution of floods for different regions of the Kingdom of Saudi Arabia. Therefore EV1 frequency analysis was used in the present study to compare the results of the modified Talbot formula.

4. Results and Discussion

4.1 Selection of Study Areas

Most of the stream gaging stations now in operation in the Kingdom have only a few years of record. But more reliable frequency study a large record (about 30 years) is necessary. However, assuming 90% confidence and 25% error level the number of sample size came to about 10. Therefore it was decided to select only those stations which have 10 or more years of record. After reviewing the hydrological records published by the Ministry of Agriculture and Water, it has been found that only 32 stations have 10 or more years of record. Table 3 shows these selected stations along with basic parameters.

A homogeneity test based on the Langbein test for regional flood frequency analysis practiced by the U.S. Geological Survey[7] showed that all 32 stations are homogeneous. The test result is shown in Fig. 1.

Peak discharges fof 25, 50 and 100 years return periods (Q_{25}, Q_{50} and Q_{100}) were obtained by Modified Talbot formula used by MOC (Eq. 1) and EV1 distribution. The results are shown in Table 4. For the purpose of comparison absolute percentage of deviation of Eq. 1 from EV1 results, that is [(Eq. 1-EV1) / (EV1)] × 100 for each station was obtained and shown in column 5 in Table 4. The comparison showed wide deviations. Out of 32 stations 20 showed higher (+ ve error), and 12 showed lower (– ve error) values than EV1 when Eq. 1 was used. Eight stations were exceptionally high and varied between 121 to 1220% higher (+ ve error) than EV1 values and five

TABLE 3. Selected basins' parameters.

Station no.	Size (ha)	Type of terrain	Slope	Width (km)	Length (km)	Elevation (m)	Years record	Region
A402	8000	Semi-Mountainous	0.028	5.5	12.5	2150	18	Abha
A403	228500	"	0.00596	30	75.5	1800	15	Abha
A404	14600	"	0.0149	8	18.5	2145	21	Abha
A405	44000	"	0.00675	11	40	1880	18	Abha
B402	1135000	"	0.00485	70	160	1280	22	Bisha
B404	1263000	"	0.0059	70	180	1080	21	Bisha
B405	127000	"	0.008	20	62	1290	17	Bisha
B406	1692000	"	0.00413	90	185	970	23	Bisha
B407	883000	"	0.0066	49	180	820	14	Bisha
B408	329000	"	0.0091	47	70	1360	13	Bisha
B409	829000	"	0.0038	41	200	1200	11	Bisha
B410	287500	"	0.0036	32	90	1280	11	Bisha
N401	560000	"	0.0210	65	77	1270	17	Najran
R401	167500	Mostly flat	0.0073	30	55	625	20	Riyadh
SA401	78400	Semi-	0.0297	15	50	430	16	Sabya
SA411	457600	Mountainous	0.0062	66	66	298	19	Sabya
SA414	135000	"	0.0283	40	35	150	10	Sabya
SA415	471300	"	0.0168	57	82.5	200	19	Sabya
SA417	100000	"	0.015	24	43	130	29	Sabya
SA418	120000	"	0.0560	24	50	178	11	Sabya
SA421	90000	"	0.00753	23	38	99	18	Sabya
J401	267100	"	0.025	34	78	100	20	Jeddah
J402	38300	"	0.0705	19	20	390	20	Jeddah
J403	450000	"	0.0108	48	95	8	18	Jeddah
J404	97000	"	0.00787	26	37	80	20	Jeddah
J408	89600	"	0.0120	26	35	495	20	Jeddah
J410	140600	"	0.0153	28	50	100	15	Jeddah
M404	3325000	"	0.0011	117	255	685	20	Medina
M405	304800	"	0.0052	40	78	845	18	Medina
TA401	23600	"	0.338	10	24	1525	24	Taif
TA403	372000	"	0.0110	58	65	1195	18	Taif
TA404	12000	"	0.0650	10	12	1750	22	Taif

stations were exceptionally low and varied between 53 to 73% lower (– ve error) than EV1 values. In general, with a few exception, stations from regions A, B, M, R and N gave higher, while the stations from regions SA and TA gave lower values when Modified Talbot formula (Eq. 1) was used. Out of six stations in region J three were higher and three were lower than the EV1 results. About half of the selected 32 stations had variations of more than ± 50%. The percentage deviation from EV1 values are summarized in Table 5.

Therefore, it was deemed necessary to try to adjust and modify (if possible) the present form of the Modified Talbot formula being used by MOC in the Kingdom of Saudi Arabia.

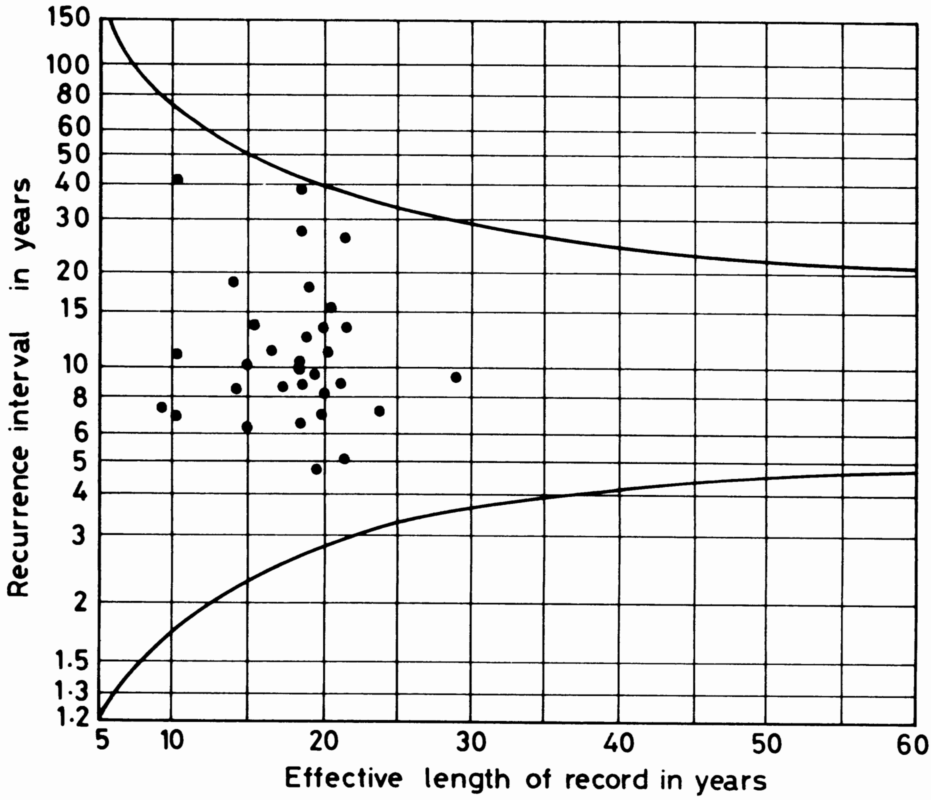

FIG. 1. Homogeneity test graph.

TABLE 4. Selected Basin's peak discharges (m^3/sec) calculated by modified Talbot formula and EV1 distribution.

Station no.	R.P. years	EV1	M. Talbot Eq. 1	% Error*	M. Talbot Eq. 2	% Error**
	25	279	293	+ 5	247	- 11
A 402	50	334	351	+ 5	294	- 12
	100	388	410	+ 6	342	- 12
	25	1337	1089	- 19	883	- 34
A 403	50	1597	1307	- 18	1054	- 34
	100	1855	1525	- 18	1224	- 34
	25	205	364	+ 78	305	+ 49
B 404	50	245	437	+ 78	364	+ 49
	100	285	510	+ 79	423	+ 48
	25	368	500	+ 36	415	+ 13
A 405	50	428	599	+ 40	494	+ 15
	100	489	699	+ 43	574	+ 17

TABLE 4. Contd.

Station no.	R.P. years	EV1	M. Talbot Eq. 1	% Error*	M. Talbot Eq. 2	% Error**
B 402	25	1876	1904	+ 2	1876	+2
	50	2225	2285	+ 3	2225	+ 2
	100	2572	2666	+ 4	2572	+ 4
B 404	25	349	2137	+ 512	–	–
	50	413	2565	+ 521	–	–
	100	476	2992	+ 529	–	–
B 405	25	593	801	+ 35	801	+ 35
	50	710	961	+ 35	961	+ 35
	100	827	1121	+ 36	1121	+ 36
B 406	25	963	2271	+ 136	–	–
	50	1125	2725	+ 142	–	–
	100	1286	3179	+ 148	–	–
B 407	25	1472	1650	+ 12	1650	+ 12
	50	1730	1980	+ 15	1980	+ 15
	100	1987	2310	+ 16	2310	+ 16
B 408	25	2472	1364	– 45	1364	– 45
	50	2971	1636	– 45	1636	– 45
	100	3465	1909	– 45	1909	– 45
B 409	25	1072	1337	+ 25	1337	+ 25
	50	1294	1604	+ 24	1604	+ 24
	100	1515	1871	+ 24	1871	+ 24
B 410	25	79	1037	+ 1213	–	–
	50	95	1245	+ 1211	–	–
	100	110	1452	+ 1220	–	–
J 401	25	2646	1385	– 32	1198	– 41
	50	2502	1661	– 34	1432	– 43
	100	2954	1938	– 34	1666	– 44
J 402	25	205	768	+ 275	–	–
	50	248	922	+ 272	–	–
	100	290	1076	+ 271	–	–
J 403	25	1964	1604	– 18	1384	– 30
	50	2333	1925	– 18	1655	– 29
	100	2700	2246	– 17	1925	– 29
J 404	25	504	844	+ 68	738	+ 46
	50	589	1012	+ 72	881	+ 50
	100	673	1181	+ 76	1025	+ 52
J 408	25	1897	896	– 53	782	– 59
	50	2275	1075	– 53	935	– 59
	100	2650	1255	– 53	1088	– 59
	25	170	1024	+ 502	–	–

TABLE 4. Contd.

Station no.	R.P. years	EV1	M. Talbot Eq. 1	% Error*	M. Talbot Eq. 2	% Error**
J 410	50	206	1229	+ 497	–	–
	100	241	1434	+495	–	–
M 404	25	311	2953	+ 850	–	–
	50	373	3544	+ 850	–	–
	100	434	4135	+ 853	–	–
M 405	25	348	1270	+ 265	–	–
	50	417	1524	+ 265	–	–
	100	484	1778	+ 267	–	–
N 401	25	1528	2052	+ 34	1512	– 1
	50	1815	2463	+ 36	1802	– 1
	100	2100	2873	+ 37	2089	– 1
R 401	25	533	742	+ 39	570	+ 7
	50	635	891	+ 40	679	+ 7
	100	736	1039	+ 41	787	+ 7
SA410	25	723	775	+ 7	1011	+ 40
	50	857	930	+ 9	1222	+ 43
	100	990	1085	+ 10	1435	+ 49
SA 411	25	4048	1700	– 58	2289	– 44
	50	4836	2040	– 58	2767	– 43
	100	5617	2380	– 58	3248	– 42
SA 414	25	1835	1204	– 34	1599	– 13
	50	2220	1444	– 35	1932	– 13
	100	2602	1685	– 35	2268	– 13
SA 415	25	1675	1716	+ 2	2312	+ 38
	50	1970	2059	+ 5	2794	+ 42
	100	2264	2402	+ 6	3279	+ 45
SA 417	25	3326	893	– 73	1172	– 65
	50	3981	1072	– 73	1417	– 64
	100	4631	1250	– 73	1663	– 64
SA 418	25	3185	1094	– 66	1447	– 55
	50	3690	1313	– 64	1750	– 53
	100	4192	1532	– 64	2054	– 51
SA 421	25	1171	795	– 32	1038	– 11
	50	1356	955	– 30	1257	– 7
	100	1539	1114	– 28	1475	– 4
TA 401	25	526	183	– 65	308	– 41
	50	638	219	– 66	375	– 41
	100	749	256	– 60	446	– 41
TA 403	25	2823	1644	– 42	3447	+ 22
	50	3416	1973	– 42	4213	+ 23
	100	4004	2302	– 43	4992	+ 25

TABLE 4. Contd.

Station no.	R.P. years	EV1	M. Talbot Eq. 1	% Error*	M. Talbot Eq. 2	% Error**
TA 404	25	185	422	+ 128	–	–
	50	227	506	+ 123	–	–
	100	268	591	+ 121	–	–

$* \frac{\text{Eq. 1} - \text{EV1}}{\text{EV1}} \times 100$ $** \frac{\text{Eq. 2} - \text{EV1}}{\text{EV1}} \times 100$

TABLE 5. Summary of percentage deviation of modified Talbot formula prediction from EV1 values.

Percentage deviation	Number of stations with	
	Eq. 1	Eq. 2*
0 to 25	6	5
+ 25 to + 50	4	5
+ 50 to + 75	1	–
+ 75 to 100	1	–
Over + 100	8	–
0 to – 25	2	5
– 25 to – 50	5	6
– 50 to – 75	5	3
Total	32	24*

* 8 stations with more than + 100% errors were not considered in modification with Eq. 2 of Talbot formula.

4.2 Further Modification of Talbot Formula

A total of 171 modifications were tested by using linear, non-linear and exponential multiple regression analysis. The modification included two additional variables (elevation of station E, and mean annual precipitation over the basin P) besides the variables given in the Modified Talbot formula. Unfortunately, no further satisfactory modification could be achieved. However, it was found that when eight stations (B404, B406, B410, M404, M405, J402, J410 and TA404) which showed exceptionally high values (over + 100%) were omitted, a somewhat reasonable further modification of Talbot formula (Eq. 1) was possible by the introduction of a certain power m as shown in Eq. 2. The omission was justified because variations of more than 100% may be due to some geological, topographical and sp climatological characters of the basin which need further investigation. For example the geological feature of the catchment area may be such that most of the water is lost by infiltration before it reaches the measuring station.

$$Q = (KC A^n R_f F_f)^m \tag{2}$$

Power m was calculated by computer program, based on least square method, for best fit curve passing through origin. The values of m varied with the geographical location of the area (that is region A, B, or J etc.). Table 6 shows the m values obtained for each region, and column 6 in Table 4 shows the discharges obtained using Eq. 2.

TABLE 6. m values of Eq. 2 for each geographical region.

Region	A	B	J	N	R	SA	TA
m	0.97	1.00	0.98	0.96	0.96	1.04	1.10

The improvement achieved by further modification and the summary of percentage deviation of Eq. 2 from EV1 results are sohwn in columns 6 and 7 in Table 4. Comparison of average absolute percentage deviation based on regional basis by Eq. 1 and Eq. 2 from EV1 results of peak discharges for return periods 25, 50 and 100 years are shown in Table 7. The overall percentage deviation are shown in the last line of the same table. The comparison shows some improvement. The results of Table 7 are also shown graphically in Fig. 2.

TABLE 7. Comparison of average absolute percentage of deviation of peak discharges for different returd periods (T).

Region	T = 25 years			T = 50 years			T = 100 years		
	Eq.* 1	Eq.** 1	Eq. 2	Eq.* 1	Eq.** 1	Eq. 2	Eq.* 1	Eq.** 1	Eq. 2
A	35	35	27	35	35	28	37	37	28
B	248	24	24	250	24	24	253	25	25
J	158	43	44	158	44	45	158	45	46
M	558	–	–	558	–	–	560	–	–
N	34	34	1	36	36	1	37	37	1
R	39	39	7	40	40	7	41	41	7
SA	39	39	38	39	39	38	39	39	38
TA	78	54	32	77	54	32	77	55	33
Over-all	149	37	31	149	37	31	151	38	32

* Includes all 32 stations.

** *Exclude 8 exceptional high stations.*

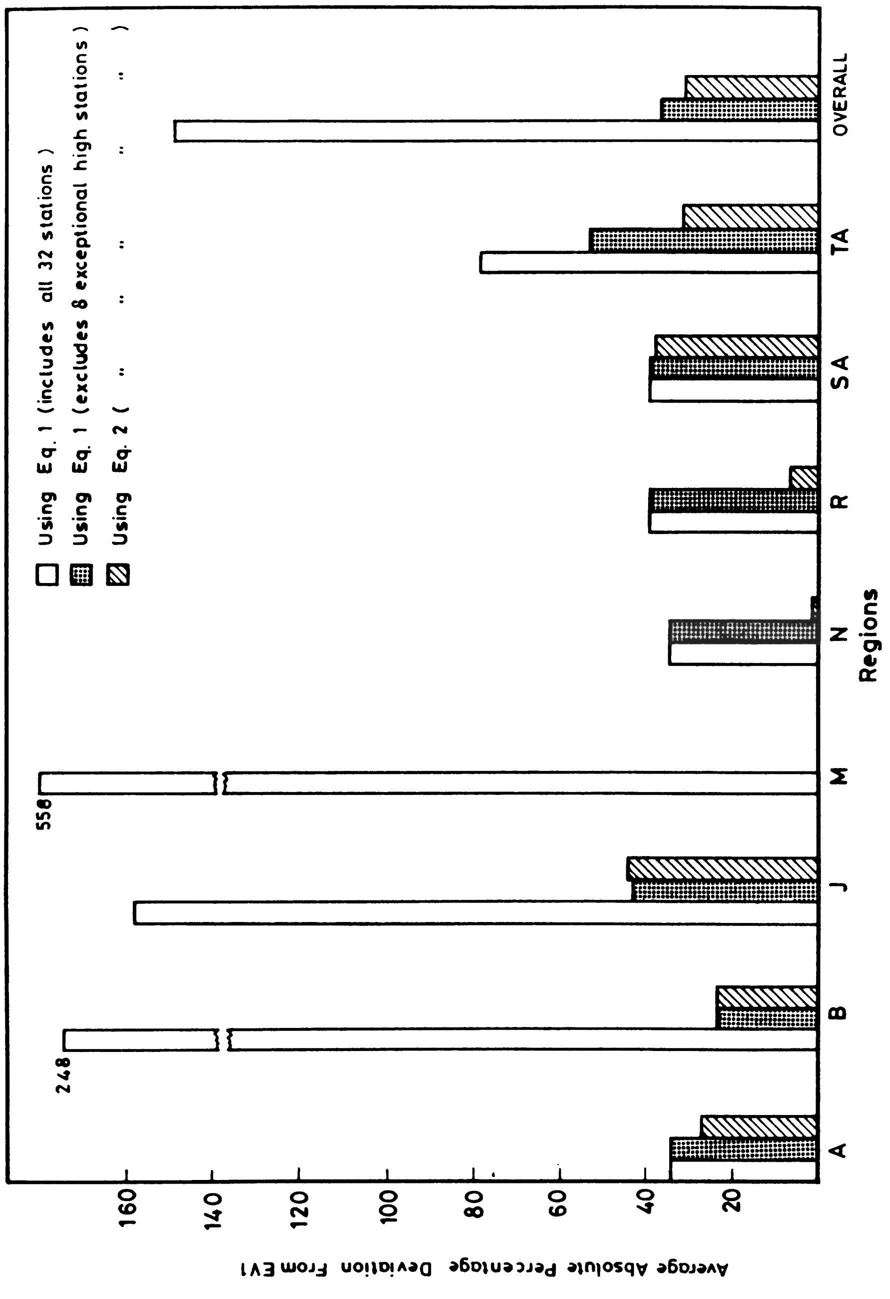

FIG. 2. Absolute percentage deviation from EV1 (T = 25 years).

5. Conclusion

Comparison of the results of the Modified Talbot formula (the one used by MOC at present) with EV1 results showed wide variation. Further 171 modifications using linear, non-linear and exponential multiple regression analysis were tested. It was found that the presently used modified Talbot formula (Eq. 1) raised to certain power m gave the best possible further modification (Eq. 2). The value of m varied depending upon the geographical location of the area. Comparison of the results of Tables 4, 5 and 7 shows some improvement but the results are not entirely satisfactory. Even with the further modification by Eq. 2 one can expect variation of ± 50% from the EV1 values. Eight stations which showed exceptional high values by Eq. 1 were not considered in further modification by Eq. 2. Therefore it is recommended that the modified Talbot formula presently in use by MOC be used with extreme caution, because it may give exceptionally high or low values in some cases. The eight stations which were omitted in the derivation of Eq. 2 should further be investigated to find the reason for so exceptioanally high variation. The modification suggested in Eq. 2 may be used until enough stream gaging data is available. The area of all the 32 stations tested in this report were in the category of large and regional watershed (none in the medium category). Therefore the modification suggested in this paper is only valid for large and regional watersheds of size more than 1258 hectares.

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استخـــدام معـــادلــة «تالبت» في تقــديـر ذروة التـدفــق في المملــكــة العربيــة السعوديــة

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المستخلص . تستخدم وزارة المواصلات في المملكة العربية السعودية صيغة مطورة لمعادلة «تالبت» في حساب ذروة تدفق السيول ، وذلك لاستخدامه في أغراض التصميم في عدة مناطق من المملكة . يقدم هذا البحث دراسة إمكانية تطبيق تلك الصيغة من المعادلة ، وذلك باستخدام نتائج التحليل الترددي لبيانات محطات رصد السيول . وقد أظهرت النتائج أن استخدام تلك الصيغة من المعادلة قد يعطي - في بعض الحالات - قيمًا عالية جدًا أو منخفضة جدًا للتصريف . هذا وقد تم اقتراح تطوير جديد لتلك المعادلة يمكن استخدامه إلى أن يتم الحصول على بيانات كافية عن تصريف السيول في المحطات المختلفة ، حيث يمكن في تلك الحالة الحصول على أفضل صيغة مطورة لمعادلة (تالبت) .