Progress Report

HYDROGRAPH RISE TIMES

by

Songthara Om Kar

an Interim Report
Prepared for

Office of Water Resources Research
U.S. Department of the Interior
on the continuing investigation entitled:

"FLOODS FROM FOREST COMPARED TO THOSE FROM FARMLAND"

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ABSTRACT

HYDROGRAPH RISE TIMES

An exploratory study on "Floods from Forest Compared to Those from Farmland" was performed as an extension of a thorough study of Hydrograph Rise Times (Appendix). Fifty-one watersheds were classified, using as a criterion the watershed coverage, into four groups: forest, cultivated, grass, and desert. Equations for predicting rise times and ten-year flood peaks were derived in simple and multiple regression analyses by computer. The best equations obtained were used to study the effects of changing the watershed coverage on rise times and flood peaks by using two average watersheds. However, no conclusions concerning the trend of behavior of watersheds compared are warranted. Detailed information on watershed coverage and condition must be secured before any further work is to be performed.

ACKNOWLEDGMENTS

This is an interim report of continuing investigations of the "Floods from Forest Compared to Those from Farmland" being performed at Colorado State University. The data used was taken from the "Data Compilation for Small Watersheds" which was accomplished under the supervision of Dr. V. Yevjevich, Professor-in-Charge of the Hydrology Program.

This work was supported by funds provided to the Colorado State University Natural Resources Center by the Office of Water Resources Research, United States Department of the Interior.

Dr. Stephen C. Smith, formerly Director of the CSU Natural Resources Center, Dr. Bertram C. Goodell, Professor at Colorado State University and especially, Mr. Walter U. Garstka, Professor of Civil Engineering were consulted in the preparation of this interim report.

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LIST OF SYMBOLS

Symbol	Definition	Unit
A	Area	Square miles
F	Form factor	Dimensionless
H	Total fall	Feet
L	Length of main stream	Miles
L_c	Distance to centroid of area	Miles
P	Ten-year one-hour precipitation	Inch
q	Ten-year flood peak	Inch per hour
R_T	Relative rise time	Dimensionless
R^2	Coefficient of determination	Dimensionless
S_1, S_2	Stream slope	Feet per mile
S_{ey}	Standard error of estimates	Unit of independent variable
T_R, T_{R1}, T_{R2}	Rise time	Hours
T_M, T_{M1}, T_{M2}	Median rise time	Hours

PART ONE

Interim Report

HYDROGRAPH RISE TIMES

INTRODUCTION

Investigations of runoff from agricultural watersheds and effects of forest on stream flow have been extensive in the United States and other nations for over a century and are of increasing interest. Pertinent references to the general subject are: Kittredge (1)*, Garstka et al. (2), Hertzler (3), and Storey (4).

The title of the investigation would indicate it to be a general study. The subject is so vast that only a small clearly delineated aspect could be pursued within limitations of funds. Therefore, hydrograph rise times were investigated.

A very thorough study of rise times was performed as shown in the Appendix by Om Kar. Data used in this study are from the compilation to be released in September 1967, "Research Data Assembly for Small Watersheds - Part II", Engineering Research Center, Colorado State University, Fort Collins, Colorado.

The results of this analysis explained to some extent the complexity of small watershed responses due to the heterogeneity between individual small watersheds with respect to climate, geometric characteristics and other watershed factors.

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* Numbers in the parentheses refer to the references which appear at the end of the report.

Rise times within a watershed vary from about 0.3 to 3 times or more the median rise time. A single distribution of relative rise times, R_T , applicable to all watersheds investigated, has the following mathematical form:

$p(R_T)$ = probability density of R_T

$$p(R_T) = \frac{1}{-1.74\ R_T} e^{-\frac{(\ln R_T + 0.16)^2}{0.96}}$$

The median rise time T_M in hours for a humid watershed can be estimated reasonably from the following equation:

$$T_M = 0.86 + 0.25\ L_c - 0.65\ F ,$$

where L_c is the distance to centroid of area in miles and F is the dimensionless form factor.

The median rise time T_M in hours for an arid watershed can be estimated reasonably from the following equation:

$$T_M = 1.33 - 0.86\ S_2^{\frac{1}{2}} \times 10^{-1} - 0.093\ A \times 10^{-2}$$

where S_2 is the stream slope in feet per mile and A is the area in square miles.

The above equations for predicting median rise times are limited to watersheds subject to short duration storms.

This interim report is an extension of that analysis. The purpose is to study the effects of changing the watershed coverage on the hydrograph rise times and the ten-year flood peaks.

ANALYSIS OF DATA

The watershed coverage is used as a criterion for the classification of watersheds into four groups:

1. Forest, more than 21% of the watershed area forested,
2. Cultivated, more than 50% of the watershed area cultivated,
3. Grass, more than 50% of the watershed area covered by grass, and
4. Desert, more than 50% of the watersheds are desert.

Table 1* lists the percentage of area of watershed coverage as described in references (5, 6 and 7) of 51 watersheds used and their classification. Figure 1* shows the approximate location of the watersheds.

The area A, the length of main stream L, and the total fall H are used as independent variables in the simple and multiple regression analysis of hydrograph rise times. Two different measurements of rise times were used: T_{R1} and T_{R2}, Figure 2. The reasons are explained on page 28 of the Appendix.

For the analysis of ten-year flood peak, which was suggested by Visiting Professor, F. C. Bell (on leave from the University of New South Wales, Australia), the area A, the ten-year one-hour precipitation P, and the channel slope S_1 were selected. P was taken from the "Rainfall Frequency Atlas of the United States" (8).

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* All tables and figures are in the back of the report.

PRESENTATION OF RESULTS

The results of this extended analysis on hydrograph rise times and ten-year flood peak are shown in Tables 2 through 13. Each table contains simple regression equations and multiple regression equations with their respective coefficients of determination and standard errors of estimates.

DISCUSSION OF RESULTS

The examination of the results shows that there are several equations with very low coefficient of determination R^2 and high standard errors of estimates S_{ey}, and there are only few equations with high R^2 and low S_{ey}. This is an indication that more investigations are needed. The best equations derived in this study are shown in Tables 14 and 15. The equations selected are indicated by an asterisk at the right hand side of Table 2 through 13.

For purposes of comparison of floods from forested, cultivated, grass and desert watersheds, two average watersheds were computed. The averages of the watershed parameters used in the comparison were taken from Reference (9). The 51 watersheds studied are among those included in the 186 watersheds of Reference (9). Watershed A has the average watershed characteristics of the overall sample of 186 watersheds investigated, and watershed B has the average watershed characteristics of 61 watersheds smaller than one square mile.

The data of these watersheds are shown in Table 16. Average watershed A represents a larger watershed and average watershed B represents a smaller watershed.

These data are substituted into equations listed in Tables 14 and 15. Figures 3 and 4 show graphically the results. A range of values of plus and minus one standard error of the estimate are shown for each of the bars. This indicates graphically the 68% probability range of the predicted values.

The insufficiency of data on hand is illustrated by the examination of watersheds 5, 15 and 49 of Table 1. Watershed 5, shown to have approximately 53% of the area bare, 25% covered by the shrub, and 22% covered by grass, could be classified as desert or grass. Watershed 15, shown to have approximately 20% of the area idle, 30% covered by pasture, 27% cultivated, 21% forested and 2% impervious, could be classified as grass, cultivated or forested. Watershed 49, having 58% of the area covered by forest, is classified as forest but 22% is cultivated, 9% pasture, and 11% idle.

The unexpected result in Figure 3 of rise times for grass and cultivated watersheds could be due to the effect of soil and water conservation practices on land use.

The number of watersheds, although it is the minimum needed to permit exploratory analysis, is not adequate for a thorough statistical study. Specific information on infiltration for each watershed to be included in the analyses would be desirable.

SUMMARY AND RECOMMENDATION

Fifty-one watersheds taken from the "Research Data Assembly for Small Watersheds" were classified into four groups: forest, cultivated, grass and desert. Equations for predicting rise times and ten-year flood peaks were derived and tested by using average of parameters based on a total of 182 watersheds and 61 watersheds smaller than one square mile. The results indicate a general trend that the rise time is longest for forested watershed and less for others. The rise time for desert watershed is not indicative. In almost all cases the coefficient of determination indicates that a large amount of variance is not explained.

This is an exploratory study and no conclusions concerning the trend of behavior of watersheds compared are warranted.

Before any further work is to be performed on "Floods from Forest Compared to Those from Farmland" detailed information on soils, land use, ecological characteristics, stand-density of the vegetal cover and the extent of the application of soil and water conservation practices on watersheds, needs to be secured.

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TABLES

TABLE 1. DATA FOR CLASSIFICATION OF WATERSHEDS

Order	State	Watershed No.	Watershed Coverage (percentage of area) Bare* or Idle	Shrub	Grass or Pasture	Cultivated	Woodland or Forest	Impervious	Classification for this Analysis
1	Arizona	1-03-06-01	85*	15					Desert
2		1-03-06-02	75*	12	13				Desert
3		1-03-06-03	32*	23	45				Desert
4		1-03-06-04	75*	25					Desert
5		1-03-06-05	53*	25	22				Desert
6		1-03-06-06	80*		20				Desert
7		1-03-06-18	80*	20					Desert
8		1-03-06-19	50*	28	22				Desert
9	Colorado	1-06-06-105					100		Forest
10	Florida	1-09-16-01			65		20	15	Grass
11	Idaho	1-12-04-01			85	15			Grass
12	Illinois	1-13-11-03			14	83		3	Cultivated
13	Iowa	1-15-11-01			35	45	20		Cultivated
14	Mississippi	1-24-12-01	33		13	21	31	2	Forest
15		1-24-12-02	20		30	27	21	2	Grass
16		1-24-12-03	53		10	20	15	2	Grass
17		1-24-12-04	39		13	20	23	5	Forest
18		1-24-12-05	65		4	2	29		Grass
19		1-24-12-07	48		10	15	26	4	Grass
20		1-24-12-09	49		14	23	12	2	Grass

TABLE 1. DATA FOR CLASSIFICATION OF WATERSHEDS - Continued

Order	State	Watershed No.	Watershed Coverage (percentage of area) Bare* or Idle	Shrub	Grass or Pasture	Culti-vated	Woodland or Forest	Imper-vious	Classifi-cation for this Analysis
21		1-24-12-10	49		14	23	12	2	Grass
22	Nebraska	1-27-07-01			15	82		3	Cultivated
23		1-27-07-02			10	87		3	Cultivated
24		1-27-07-03			19	80		1	Cultivated
25		1-27-07-04			22	74		4	Cultivated
26	New Mexico	1-31-06-01	80*		20				Desert
27		1-31-09-01	85*	8	8				Desert
28		1-31-09-04	70*		30				Desert
29	Ohio	1-35-14-02			54	20	23	3	Forest
30		1-35-14-04			43	41	12	4	Cultivated
31		1-35-14-05			57	15	24	4	Forest
32		1-35-14-06			55	15	26	4	Forest
33		1-35-14-07			50	18	28	4	Forest
34		1-35-14-08			57	29	14		Grass
35		1-35-14-09			50	19	27	4	Forest
36		1-35-14-10	5		28	43	21	3	Cultivated
37		1-35-14-32			67	17	10	6	Grass
38	Oklahoma	1-36-08-01			100				Grass
39		1-36-08-02			100				Grass
40		1-36-08-03			100				Grass

TABLE 1. DATA FOR CLASSIFICATION OF WATERSHEDS - Continued

Order	State	Watershed No.	Watershed Coverage (percentage of area) Bare* or Idle	Shrub	Grass or Pasture	Culti-vated	Woodland of Forest	Imper-vious	Classifi-cation for this Analysis
41	Texas	1-43-08-01			100				Grass
42		1-43-09-01			28	69		3	Cultivated
43		1-43-09-02			24	73		3	Cultivated
44		1-43-09-05			17	78		5	Cultivated
45		1-43-09-06			30	65		5	Cultivated
46		1-43-09-07			41	57		2	Cultivated
47		1-43-09-08			31	68		1	Cultivated
48	↓	1-43-09-09			31	68		1	Cultivated
49	Virginia	1-46-18-07	11		9	22	58		Forest
50	Wisconsin	1-49-11-01			16	79		5	Cultivated
51	↓	1-49-11-02			13	81		6	Cultivated

TABLE 2. RISE TIME T_{M1} FOR FORESTED WATERSHEDS

Correlations	Class: Forest						
	Dependent Variable: Rise time, T_{M1} hours						
	Problem T_{M1}	Constant	Independent Variable			n = 9	
			A	L	H	R^2	S_{ey}
			Regression Coefficient				
Simple	1	1.56302	.02750			.3069	.4897
	2	1.21347		.15579		.3748	.4651
	3	1.64891			.00016	.0836	.5631
Multiple	4	1.27054	.00717	.12518		.3812	.4998
	5	1.43140	.02963		.00020	.4349	.4776
	6	1.18983		.14677	.00009	.4012	.4916
	7	1.34269	.02163	.04714	.00017	.4420	.5199

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

TABLE 3. RISE TIME T_{M2} FOR FORESTED WATERSHEDS

Correlations	Class: Forest						
	Dependent Variable: Rise time, T_{M2}, hours						
	Problem T_{M2}	Constant	Independent Variable			n = 9	
			A	L	H	R^2	S_{ey}
			Regression Coefficient				
Simple	1	1.08289	.00972			.0948	.3562
	2	.79042		.10474		.4183	.2855*
	3	1.04596			.00017	.2349	.3274
Multiple	4	.60176	-.02371	.20593		.5913	.2585
	5	.95995	.01172		.00018	.3705	.3208
	6	.75756		.09221	.00013	.5443	.2730
	7	.63009	-.01803	.17529	.00006	.6144	.2751

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 3.

TABLE 4. TEN-YEAR FLOOD PEAK q FOR FORESTED WATERSHEDS

Correlations	Problem q	Constant	A	P	S_1	R^2	S_{ey}
Class: Forest							
Dependent Variable: 10-Year Flood Peak, q, in./hr.							
			Independent Variable / Regression Coefficient			n = 8	
Simple	1	.82414	-.01858			.1545	.5558
Simple	2	.45361		.12730		.0102	.6014
Simple	3	.78152			-.00038	.0235	.5974
Multiple	4	-.06657	-.02740	.48234		.2665	.5671*
Multiple	5	1.01125	-.02323		-.00076	.2405	.5771
Multiple	6	1.02843		-.10733	-.00055	.0257	.6536
Multiple	7						

n = number of watersheds

A = area of the watershed, square miles

P = 10-year one-hour precipitation, inches

S_1 = channel slope, feet per mile

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 4.

TABLE 5 RISE TIME T_{M1} FOR CULTIVATED WATERSHEDS

Correlations	Problem T_{M1}	Constant	A	L	H	R^2	S_{ey}
Class: Cultivated							
Dependent Variable: Rise time, T_{M1}, hours							
			Independent Variable / Regression Coefficient			n = 17	
Simple	1	.68898	.14418			.8950	.3315*
	2	.56386		.19778		.4057	.7887
	3	.03576			.00960	.7510	.5105
Multiple	4	.67802	.14214	.00628		.8952	.3315
	5	.41943	.10679		.00341	.9293	.2815
	6	.02775		.04626	.00856	.7644	.5141
	7	.43065	.10933	-.01199	.00353	.9301	.2905

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 3.

TABLE 6 RISE TIME T_{M2} FOR CULTIVATED WATERSHEDS

Correlations	Problem T_{M2}	Constant	A	L	H	R^2	S_{ey}
	Class: Cultivated						
	Dependent Variable: Rise time, T_{M2}, hours						
			Independent Variable			n = 17	
			Regression Coefficient				
Simple	1	.55749	.10834			.8251	.3349
	2	.49856		.05212		.3100	.6651
	3	.04299			.00743	.7345	.4126
Multiple	4	.59050	.11448	-.01892		.8285	.3432
	5	.30779	.07370		.00316	.8732	.3349
	6	.04191		.00625	.00729	.7349	.4267
	7	.34264	.08161	-.03723	.00354	.8857	.2908

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

TABLE 7. TEN-YEAR FLOOD PEAK q FOR CULTIVATED WATERSHEDS

Correlations	Problem q	Constant	A	P	S_1	R^2	S_{ey}
	Class: Cultivated						
	Dependent Variable: 10-Year Flood Peak, q, in./hr.						
			Independent Variable			n = 16	
			Regression Coefficient				
Simple	1	1.95237	-.41144			.3766	.8192
	2	-2.33599		1.47138		.4128	.7951
	3	1.25460			.00295	.0168	1.0288
Multiple	4	-1.33429	-.33961	1.24227		.6593	.6285
	5	2.37286	-.48215		-.00496	.4130	.8250
	6	-4.95174		2.13582	.01341	.6756	.6133
	7	-3.44165	-.18808	1.76626	.00851	.7161	.5971*

n = number of watersheds

A = area of the watershed, square miles

P = 10-year one-hour precipitation, inches

S_1 = channel slope, feet per mile

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 4.

TABLE 8. RISE TIME T_{M1} FOR GRASS WATERSHEDS

Class: Grass

Dependent Variable: Rise time, T_{M1}, hours

Correlations	Problem T_{M1}	Constant	Independent Variable A	L	H	n = 13 R^2	S_{ey}
			Regression Coefficient				
Simple	1	.73218	.02215			.3032	.3262
Simple	2	.65582		.06730		.3646	.3115
Simple	3						
Multiple	4	.52966	-.05014	.20386		.4178	.3127
Multiple	5	.69597	.02253		.00020	.3068	.3412
Multiple	6	.58718		.06991	.00036	.3758	.3238
Multiple	7	.36976	-.06328	.24446	.00066	.4525	.3196

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

TABLE 9. RISE TIME T_{M2} FOR GRASS WATERSHEDS

Correlations	Class: Grass						
	Dependent Variable: Rise time, T_{M2}, hours						
	Problem T_{M2}	Constant	Independent Variable / Regression Coefficient			n = 13	
			A	L	H	R^2	S_{ey}
Simple	1	.52597	.02619			.5576	.2266
	2	.44052		.07795		.6431	.2036*
	3	.65244			.00011	.0014	.3405
Multiple	4	.33398	-.04234	.19326		.6930	.1980
	5	.44382	.02706		.00045	.5820	.2311
	6	.31875		.08258	.00063	.6896	.1991
	7	.11006	-.06074	.25012	.00092	.7825	.1757

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 3.

TABLE 10. TEN-YEAR FLOOD PEAK q FOR GRASS WATERSHEDS

Correlations	Problem q	Constant	A	P	S_1	R^2	S_{ey}
	Class: Grass						
	Dependent Variable: 10-Year Flood Peak, q, in./hr.						
			Independent Variable (Regression Coefficient)			n = 13	
Simple	1	1.59483	-.05110			.1508	1.1781
	2	-.10362		.60609		.0975	1.2145
	3	1.40561			-.00056	.0107	1.2716
Multiple	4	-.36448	-.06733	.87710		.3398	1.0895
	5	1.97253	-.06805		-.00169	.2333	1.1740
	6	-8.87459		3.70599	.00911	.4208	1.2145
	7	-6.93338	-.03947	3.12473	.00693	.4856	1.0137*

n = number of watersheds

A = area of the watershed, square miles

P = 10-year one-hour precipitation, inches

S_1 = channel slope, feet per mile

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 4.

TABLE 11. RISE TIME T_{M1} FOR DESERT WATERSHEDS

Correlations	Class: Desert						
	Dependent Variable: Rise time, T_{M1}, hours						
	Problem T_{M1}	Constant	Independent Variable			n = 12	
			A	L	H	R^2	S_{ey}
			Regression Coefficient				
Simple	1	.38780	-.00166			.0132	.1868
	2	.40715		-.00715		.0297	.1852
	3	.39099			-.00001	.0215	.1860
Multiple	4	.44394	.00676	-.02556		.0523	.1929
	5	.40092	-.00179		.00001	.0368	.1945
	6	.42629		-.00835	-.00001	.0609	.1921
	7	.48727	.00993	-.03582	-.00001	.1056	.1988(*)

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

(*) Although none of the equations are indicative, equation T_{M1} - 7 was used to plot the bar graph as shown by dotted lines on Fig. 3.

TABLE 12. RISE TIME T_{M2} FOR DESERT WATERSHEDS

Correlations	Problem T_{M2}	Constant	A	L	H	R^2	S_{ey}
Class: Desert							
Dependent Variable: Rise time, T_{M2}, hours							
			Independent Variable			n = 12	
			Regression Coefficient				
Simple	1	.32923	-.00065			.0024	.1716
Simple	2	.33926		-.00343		.0082	.1711
Simple	3	.34164			-.00001	.0461	.1678
Multiple	4						
Multiple	5	.34622	-.00083		-.00001	.0500	.1765
Multiple	6	.36224		-.00487	-.00001	.0622	.1754
Multiple	7	.41205	.00811	-.02731	-.00002	.0979	.1824

n = number of watersheds

A = area of the watershed, square miles

L = length of main stream, miles

H = total fall, feet

R^2 = coefficient of determination

S_{ey} = standard error of estimates

TABLE 13. TEN-YEAR FLOOD PEAK q FOR DESERT WATERSHEDS

Correlations	Problem q	Constant	Independent Variable A	Independent Variable P	Independent Variable S_1	R^2	S_{ey}
Class: Desert							
Dependent Variable: 10-Year Flood Peak, q, in./hr.						n = 12	
			Regression Coefficient				
Simple	1	1.06539	-.01303			.1416	.4175
Simple	2	.68758		.18946		.0140	.4475
Simple	3	.81819			.00111	.0835	.4314
Multiple	4	.58064	-.01412	.29981		.1755	.4313
Multiple	5	.93620	-.01099		.00073	.1746	.4315
Multiple	6	-.27327		.59382	.00185	.1832	.4314
Multiple	7	-.16386	-.01110	.59913	.00148	.2761	.4287*

n = number of watersheds

A = area of the watershed, square miles

P = 10-year one-hour precipitation, inches

S_1 = channel slope, feet per mile

R^2 = coefficient of determination

S_{ey} = standard error of estimates

* Equation selected for plotting bar graph shown in Figure 4.

TABLE 14. EQUATIONS FOR PREDICTION OF HYDROGRAPH RISE TIMES

Class	n	Problem No.	Correlation	Equation	R^2	S_{ey}	Predicted Rise Time, hours: Watershed A	Predicted Rise Time, hours: Watershed B
Forest	9	T_{M2}- 2	Simple	$T_M = 0.790 + 0.105\ L$	0.418	0.285	1.217	0.905
Cultivated	17	T_{M1}- 1	Simple	$T_M = 0.689 + 0.144\ A$	0.895	0.331	1.606	0.752
Grass	13	T_{M2}- 2	Simple	$T_M = 0.440 + 0.078\ L$	0.643	0.204	0.757	0.526
Desert	12			None				

TABLE 15. EQUATIONS FOR PREDICTION OF TEN-YEAR FLOOD PEAKS

Class	n	Problem No.	Corre-lation	Equation	R^2	S_{ey}	Predicted 10 Year Flood Peak, in./hr.	
							Water-shed A	Water-shed B
Forest	8	q-4	Multiple	$q = -0.066 - 0.027A + 0.482P$	0.267	0.567	0.726	0.886
Cultivated	16	q-7	Multiple	$q = -3.442 - 0.188A + 1.766P + 0.008S_1$	0.716	0.597	1.020	2.782
Grass	13	q-7	Multiple	$q = -6.933 - 0.039A + 3.125P + 0.007S_1$	0.486	1.014	0.797	1.558
Desert	12	q-7	Multiple	$q = -0.164 - 0.011A + 0.599P + 0.0015S_1$	0.276	0.429	1.334	1.512

TABLE 16. DATA FOR AVERAGE WATERSHEDS A AND B

Number of Watersheds	Category	Average Watershed	A sq. mi.	L mi.	H ft.	S ft./mi.	P in.
186	Overall sample	A	6.37	4.07	1013	250	2.0
61	Area less than 1 sq.mi.	B	0.44	1.10	358	325	2.0

A = area of the watershed

L = length of main stream

H = total fall

S = stream slope

P = ten-year one-hour precipitation

FIGURES

Figure 1. Approximate location of watersheds

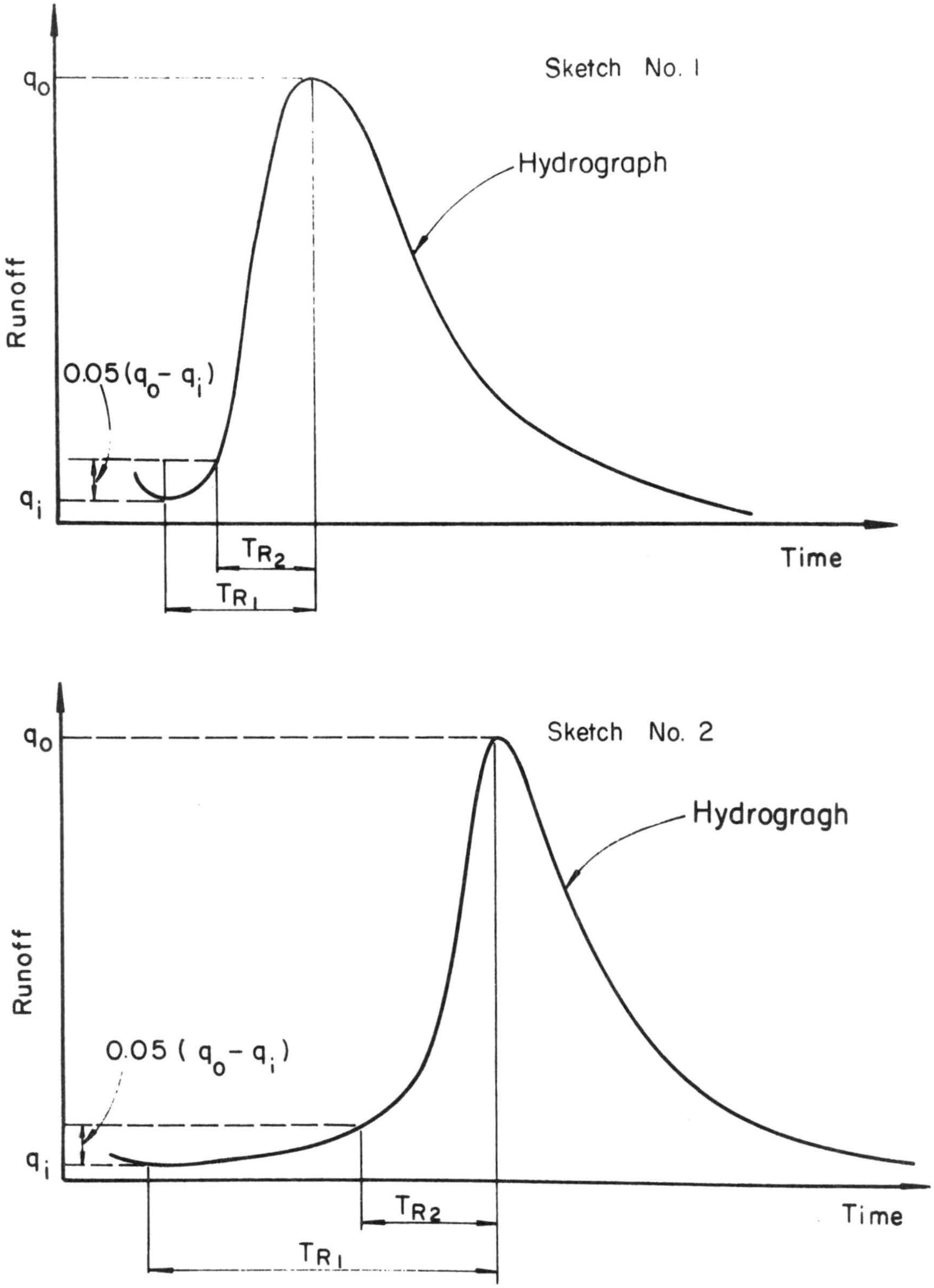

Figure 2. Rise time definitions

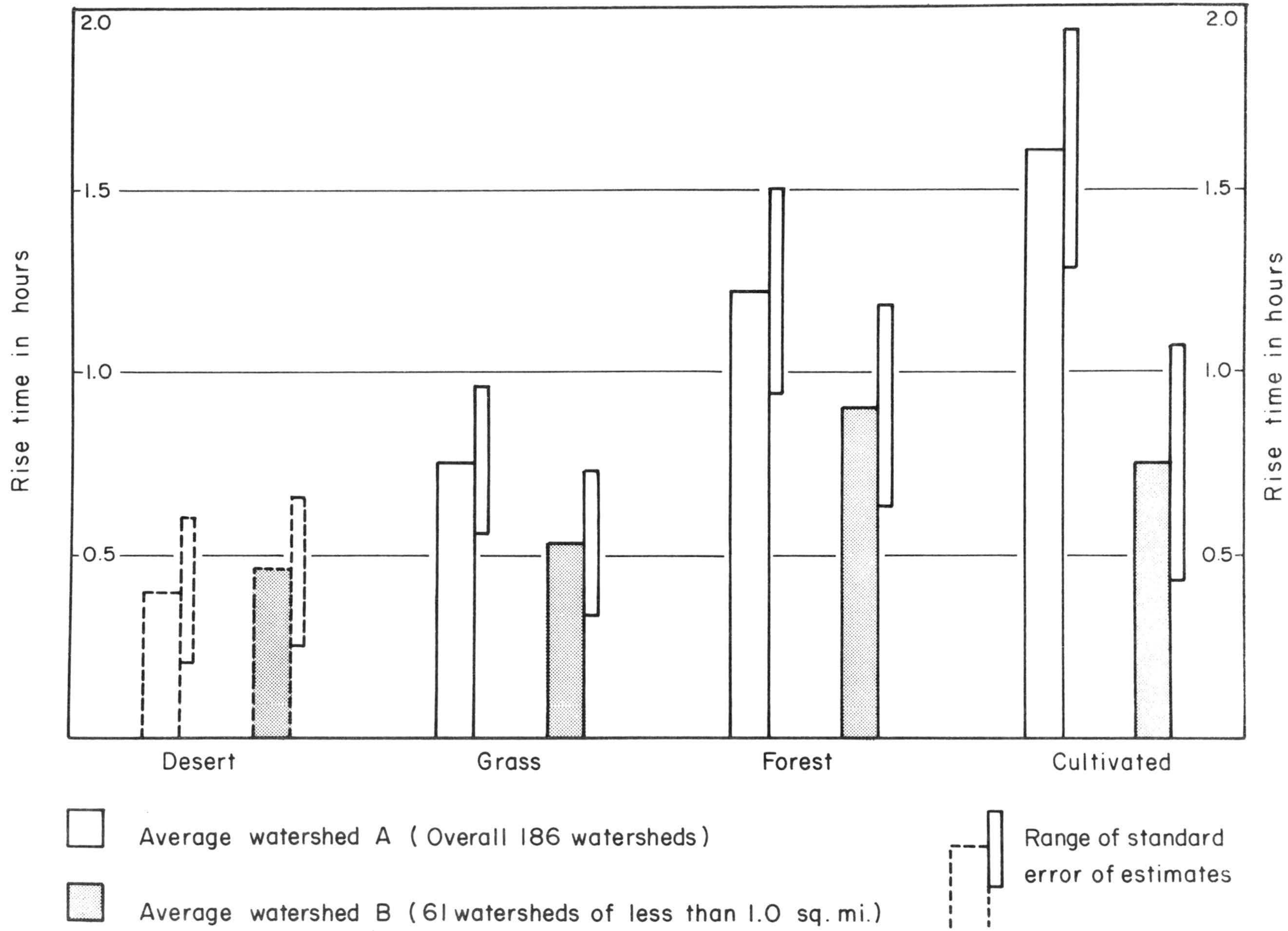

Figure 3. Comparison of hydrograph rise times predicted by formulae listed in table 14

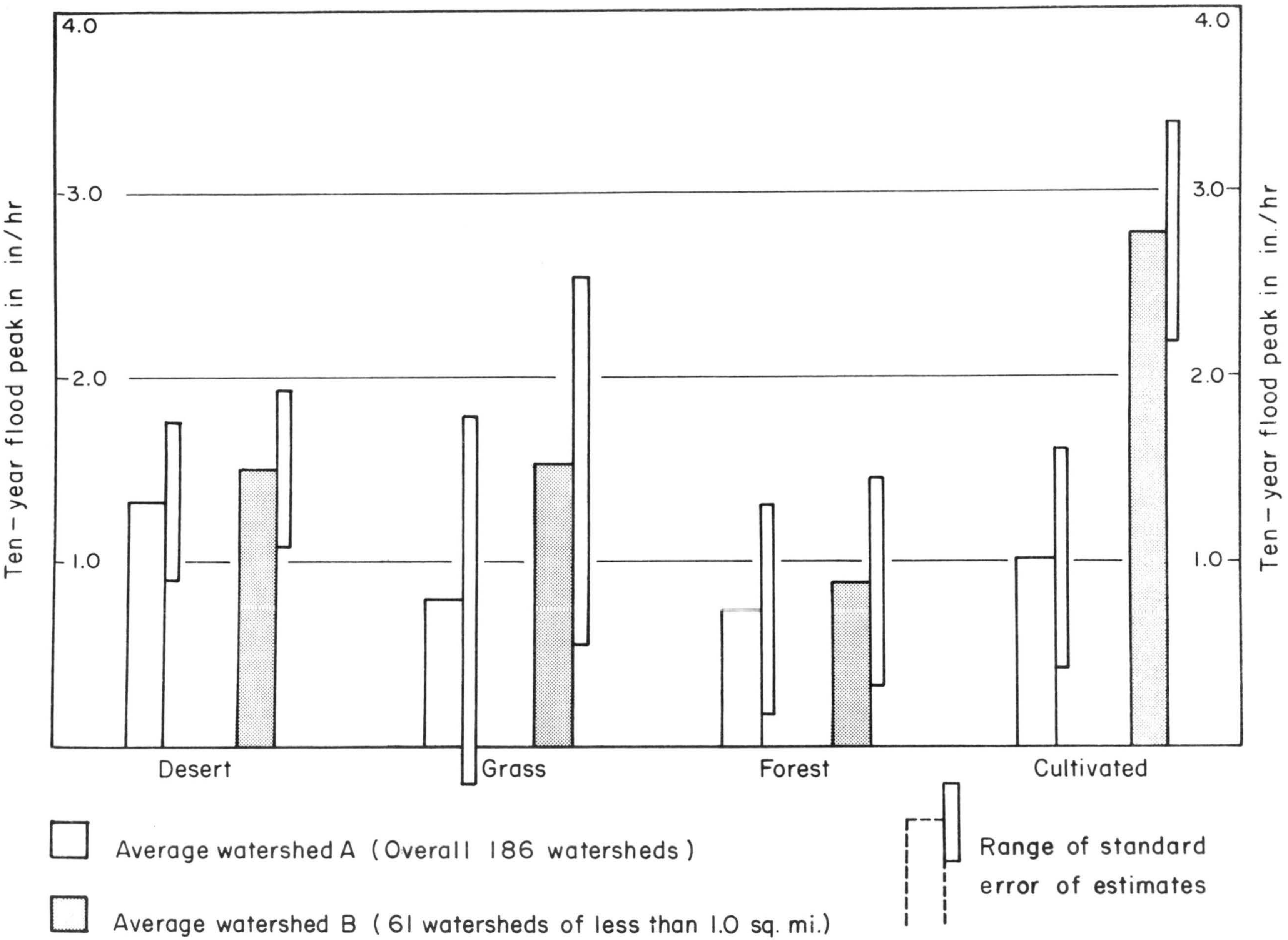

Figure 4. Comparison of ten-year flood peaks predicted by formulae listed in table 15

PART TWO

APPENDIX

Part Two is the 124-page thesis

HYDROGRAPH RISE TIMES

by Songthara Om Kar

in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering at Colorado State University.