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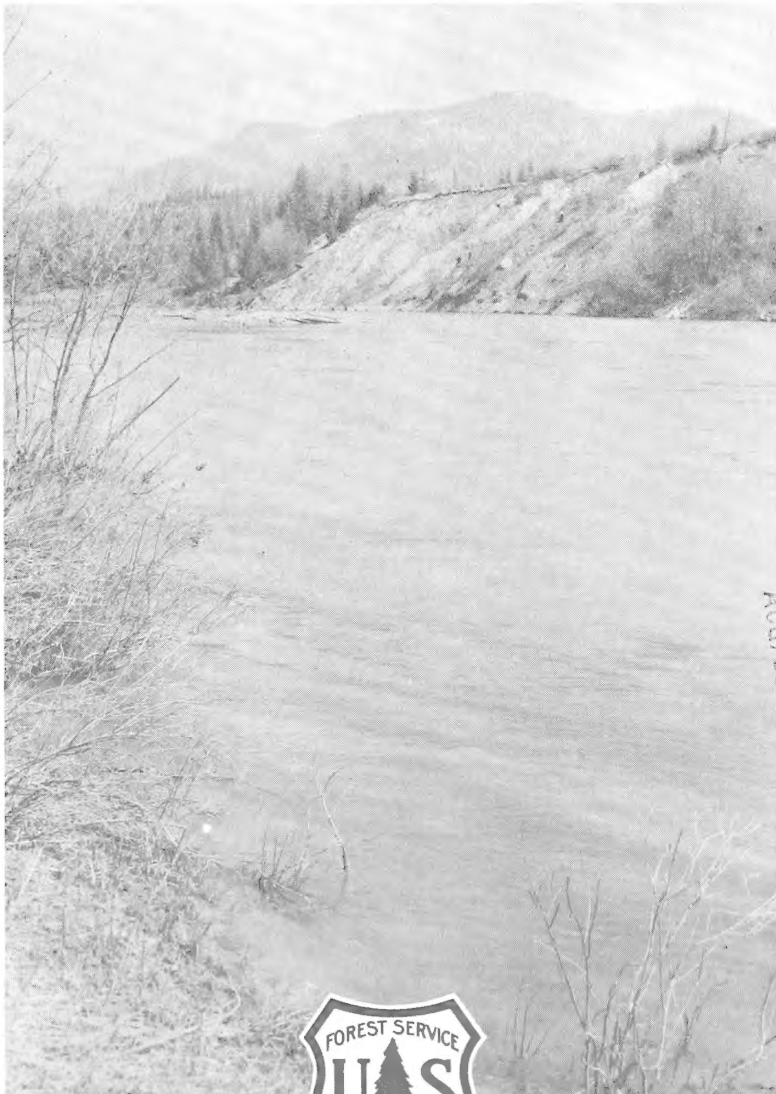

USDA Forest Service Research Paper INT-113
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
Ogden, Utah 84401

USDA Forest Service
Research Paper INT-113
December 1971

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ABSTRACT

The long-term average water yield of a watershed appears to be a good index to the magnitude of its expected peak flow. On the basis of this relation, tables are presented showing expected peak flows that are applicable to watersheds in Idaho and Montana west of the Continental Divide. Tabulated peak flows are for four different return periods: mean annual; 5; 10; and 20 years. Three examples are given to illustrate the tables' field application.

What is the 20-year flood potential of this watershed?

INTRODUCTION

Foresters and other land managers have long considered water an important product of forest lands. This product yields great benefits when its flow is orderly, timely, and is confined within the banks of a stream. On the other hand, water appearing as a flood is a potentially destructive force that land managers should consider when planning future forest operations.

The effects of clearcutting operations on the hydrologic regime of a watershed are complex, and the magnitude of these effects is highly variable. Nevertheless, we do know that a clearcut watershed yields more water (Hibbert 1967), and that the pattern of runoff distribution is changed, including an increase in base flow and peak flow (Bethlahmy 1971). Thus, foresters and other land managers who contemplate clearcutting operations should consider the associated problem of future changes in the hydrologic regime.

Our research has shown that on a unit area basis the long-term average water yield of a watershed is a good index to the magnitude of its expected peak flow. The greater the average yield per unit area, the greater the expected peak flow for period of record. This relation is readily perceived from table 1 that shows data for 11 rivers in Idaho which have good or excellent streamflow records (U.S. Department of Interior 1964). Notice the regular decrease in values of both average annual flow and associated peak flow. Although peak flow per unit area is related to unit drainage yield, any discussion of peak flow should include the element of chance. A record of many years of data will probably include greater peak flow values than a short record. Hence, a comparison of peak flows for different areas should be based not only on the watershed's average yields but also on the element of time; how long is the record, and how often can one expect a peak flow of a given magnitude? Such considerations are especially important to engineers and economists who are concerned with investments in structures having an economic life expectancy.

Table 1.--*Relation of peak flow to average annual flow for some Idaho rivers with good or excellent stream records*

River	Average annual flow	Peak flow[1]	Elevation of gage	Length of record	Watershed area
	[2]*C.f.s.m.*	[2]*C.f.s.m.*	[3]*Feet*	*Years*	*Sq.mi.*
Cub	4.24	36.86	5,320	21	19.4
Boundary	1.98	33.81	1,770	34	97
Mission	1.71	22.96	2,800	6	23
Clearwater (Kamiah)	1.68	21.24	1,162	54	4,850
Moyie (Eastport)	1.23	18.60	2,620	35	570
Yaak	1.20	15.80	1,850	8	766
Moyie (Eileen)	1.16	14.57	2,124	39	755
Big Lost River (Wild Horse)	.86	11.14	6,820	20	114
Robie	.50	10.32	4,960	14	15.8
Thomas Fork	.44	7.69	6,280	15	113
Bannock	.36	5.91	5,240	16	5.75

[1]Peak flow for period of record.
[2]Cubic feet per second per square mile.
[3]Above mean sea level.

Peak flows which can be expected in Idaho and Montana, in watersheds west of the Continental Divide, are listed in tables 2 and 3 for four different return periods. The selected return periods are: 2.33 years (usually termed the mean annual return period); 5; 10; and 20 years. In these tables, peak flow is a function of average water yield and an expected return period, and is expressed in units of cubic feet per second per square mile (c.f.s.m.). In table 2, average water yield (the independent variable) increases by selected increments in inches, and in table 3 by selected increments in c.f.s.m. These tables were constructed in accordance with the methods described in Appendix 1, and are based on sources of data listed in Appendix 2.

Table 2.--*Maximum peak flows (c.f.s.m.) for selected return periods for watersheds west of the Continental Divide in Idaho and Montana*

Average annual yield	Return period (years)			
	2.33	5.0	10	20
Inches	- - - - - *C.f.s.m.* - - - - -			
5.0	2.6105	3.2904	4.1589	5.2339
6.0	2.9845	3.7810	4.7295	5.9284
7.0	3.3984	4.3267	5.3577	6.6899
8.0	3.8526	4.9282	6.0433	7.5180
9.0	4.3465	5.5856	6.7854	8.4111
10.0	4.8791	6.2975	7.5818	9.3661
11.0	5.4484	7.0619	8.4294	10.3791
12.0	6.0520	7.8755	9.3240	11.4450
13.0	6.6866	8.7343	10.2609	12.5578
14.0	7.3487	9.6336	11.2345	13.7109
15.0	8.0341	10.5679	12.2388	14.8972
16.0	8.3787	11.5314	13.2676	16.1092
17.0	9.4580	12.5180	14.3145	17.3395
18.0	10.1875	13.5216	15.3730	18.5808
19.0	10.9229	14.5361	16.4370	19.8258
20.0	11.6600	15.5554	17.5005	21.0677
21.0	12.3948	16.5741	18.5581	22.3004
22.0	13.1236	17.5867	19.6047	23.5181
23.0	13.8431	18.5885	20.6356	24.7157
24.0	14.5503	19.5751	21.6467	25.8885
25.0	15.2426	20.5426	22.6346	27.0356
26.0	15.9176	21.4877	23.5963	28.1450
27.0	16.5736	22.4075	24.5291	29.2226
28.0	17.2089	23.2997	25.4313	30.2636
29.0	17.8224	24.1624	26.3011	31.2663
30.0	18.4131	24.9941	27.1375	32.2294
31.0	18.9804	25.7938	27.9398	33.1524
32.0	19.5239	26.5609	28.7075	34.0348
33.0	20.0434	27.2948	29.4406	34.8767
34.0	20.5390	27.9956	30.1391	35.6784
35.0	21.0108	28.6634	30.8036	36.4404
36.0	21.4592	29.2985	31.4345	37.1635
37.0	21.8846	29.9016	32.0326	37.8485
38.0	22.2876	30.4734	32.5988	38.4967
39.0	22.6689	31.0146	33.1341	39.1092
40.0	23.0291	31.5263	33.6394	39.6871
41.0	23.3690	32.0094	34.1159	40.2318
42.0	23.6893	32.4649	34.5648	40.7447
43.0	23.9910	32.8941	34.9873	41.2272
44.0	24.2747	33.2979	35.3845	41.6807
45.0	24.5413	33.6776	35.7575	42.1065
46.0	24.7917	34.0343	36.1077	42.5061
47.0	25.0266	34.3690	36.4361	42.8807
48.0	25.2469	34.6830	36.7440	43.2317
49.0	25.4532	34.9774	37.0323	43.5605
50.0	25.6465	35.2530	37.3022	43.8681

Table 3.--*Maximum peak flows (c.f.s.m.) for selected return periods for watersheds west of the Continental Divide in Idaho and Montana*

Average annual yield	Return period (years)			
	2.33	5.0	10	20
	- - - - - - - -	- - - *C.f.s.m.*	- - - - - -	- - - - - - - -
0.2	1.8989	2.3648	3.0639	3.8924
0.3	2.2982	2.8829	3.6801	4.6489
0.4	2.7664	3.4946	4.3972	5.5242
0.5	3.3070	4.2059	5.2192	6.5222
0.6	3.9216	5.0199	6.1472	7.6432
0.7	4.6092	5.9363	7.1786	8.8830
0.8	5.3663	6.9514	8.3073	10.2335
0.9	6.1871	8.0581	9.5239	11.6827
1.0	7.0638	9.2462	10.8160	13.2157
1.1	7.9868	10.5032	12.1695	14.8154
1.2	8.9455	11.8146	13.5689	16.4635
1.3	9.9289	13.1654	14.9980	18.1414
1.4	10.9259	14.5402	16.4414	19.8309
1.5	11.9261	15.9241	17.8839	21.5148
1.6	12.9196	17.3031	19.3120	23.1778
1.7	13.8976	18.6645	20.7135	24.8062
1.8	14.8526	19.9974	22.0783	26.3886
1.9	15.7782	21.2924	23.3978	27.9155
2.0	16.6694	22.5419	24.6652	29.3798
2.1	17.5222	23.7401	25.8756	30.7759
2.2	18.3339	24.8825	27.0254	32.1004
2.3	19.1026	25.9662	28.1124	33.3509
2.4	19.8273	26.9894	29.1358	34.5267
2.5	20.5079	27.9516	30.0954	35.6282
2.6	21.1447	28.8530	30.9921	36.6565
2.7	21.7386	29.6946	31.8274	37.6136
2.8	22.2908	30.4779	32.6033	38.5018
2.9	22.8030	31.2051	33.3222	39.3244
3.0	23.2768	31.8783	33.9867	40.0841
3.1	23.7143	32.5004	34.5997	40.7846
3.2	24.1173	33.0739	35.1642	41.4292
3.3	24.4881	33.6018	35.6830	42.0215
3.4	24.8286	34.0868	36.1592	42.5649
3.5	25.1407	34.5317	36.5957	43.0626
3.6	25.4267	34.9395	36.9952	43.5182
3.7	25.6882	35.3126	37.3605	43.9346
3.8	25.9273	35.6537	37.6942	44.3148
3.9	26.1454	35.9652	37.9987	44.6617
4.0	26.3445	36.2494	38.2765	44.9781
4.1	26.5259	36.5086	38.5295	45.2662
4.2	26.6911	36.7446	38.7599	45.5285
4.3	26.8415	36.9595	38.9696	45.7672
4.4	26.9784	37.1552	39.1604	45.9842
4.5	27.1028	37.3330	39.3338	46.1816
4.6	27.2159	37.4947	39.4913	46.3608
4.7	27.3186	37.6416	39.6344	46.5236

BETHLAHMY, NEDAVIA

1971. Maximum peak flows for selected return periods for watersheds west of the Continental Divide in Idaho and Montana, USDA Forest Serv. Res. Pap. INT-113, 12 p., illus.

Peak flow tables are presented that are applicable to watersheds in Idaho and Montana west of the Continental Divide. The tables show peak flows as a function of mean annual water yield, and are for four different return periods: mean annual; 5; 10; and 20 years. Three examples illustrate the practical use of the tables.

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A mountain stream at flood stage.

EXAMPLES FOR FIELD APPLICATION

Three examples are given to show how the tables can be used for field application.

EXAMPLE 1

Problem: A road will be built across the outlet of a 1.5-sq.-mi. drainage having an expected annual water yield of 40 inches. What is the maximum rate of flow the culvert should accommodate:

(a) if designed for a 20-year flood?
(b) if designed for a 50-year flood?

Solution:

(a) For an annual yield of 40 inches, table 2, col. 5, shows a peak flow of 39.69 c.f.s.m. Since the drainage area is 1.5 sq. mi., we can expect a 20-year flood of 59.53 c.f.s. (39.69 X 1.5).

(b) The tables do not show peak flows for return periods exceeding 20 years. Extrapolation is required, but this procedure is fraught with great uncertainty. In table 2, opposite an average 40-inch annual yield, we find the expected peak flows for the 10- and 20-year floods to be 33.64 and 39.69 c.f.s.m., respectively. Plot the paired values (year versus flow) on log-log paper, connect them with a straight line, and extend the line to the 50-year flood. The peak flow is 49.3 c.f.s.m. Inasmuch as the area is 1.5 sq. mi., the expected 50-year flood is 74 c.f.s. (49.3 X 1.5 = 74).

It must be understood that such extrapolation results in only approximate values.

EXAMPLE 2

Problem: A road crosses the outlet of a 40-acre watershed over a 12-inch corrugated metal culvert whose top is 1 foot below the road surface. Plans call for clearcutting the watershed that has an annual yield of 35 inches. After cutting we expect annual water yield to increase by 15 percent. Assuming a 20-year-design flood, will the presently located culvert accommodate the increased flow?

Solution:

The expected annual flow is 40.25 inches (35 inches X 1.15). In table 2, col. 5, interpolating for peak values between 40 and 41 inches, we obtain an expected peak flow of 39.82 c.f.s.m. Since the area involved is 40 acres, the expected peak flow is 2.49 c.f.s. ($39.82 \times \frac{40}{640}$). Using culvert discharge tables (e.g., Hendrickson 1957), we find that the presently installed culvert (use 1.0 percent slope and 0.025 roughness coefficient) will accommodate only 2.4 c.f.s. Because there is a present capacity of only 2.4 c.f.s., and the expected need is for 2.49 c.f.s., it appears that the road will probably be damaged by overflowing unless a larger culvert is installed or the surface of the road is raised to allow for ponding.

EXAMPLE 3

Problem: The annual water yield from a 5.0-sq.-mi. drainage is 40 inches. Plans call for clearcutting a 40-acre subwatershed. What are the present and expected peak flows at the outlet of the main drainage for a 10-year flood if the annual water yield of the clearcut area is expected to increase by 15 percent?

Solution:

Under present conditions (before cutting) the expected 10-year flood for the entire drainage is 168.20 c.f.s. In table 2, col. 4, opposite 40 inches, read 33.64 c.f.s.m. and multiply by 5.0 sq. mi., and for the 40-acre subwatershed it is 2.10 c.f.s. ($33.64 \times \frac{40}{640}$).

After cutting, the average yield from the clearcut 40-acre subwatershed will be 46.0 inches (40 X 1.15). In table 2, col. 4, we read a peak flow value of 36.11 c.f.s.m. Since the subwatershed is 40 acres, the peak flow is 2.26 c.f.s. ($36.11 \times \frac{40}{640}$).

On the clearcut area, the peak flow will increase by 0.16 c.f.s. (2.26 - 2.10). Add this value to the precutting peak flow for the entire drainage:

$$168.20 + 0.16 = 168.36 \text{ c.f.s.}$$

It is apparent that clearcutting the 40-acre subwatershed will not alter the peak flow of the main watershed in any significant way.

A raging mountain stream overflows a bridge.

DISCUSSION

The three examples illustrate how the tables may be used, and the practical significance of the effects of clearcutting operations. We once again remind the reader that the tabulated values are expressed in yield per unit area, and hence may be applied to watersheds of any size or at any elevation.

In illustrating the use of the tables, we used a potential water yield increase of 15 percent. Some readers may consider this figure as too conservative, because it is considerably smaller than figures reported in the literature. At Fraser, Colorado, for example, where 75 percent of the annual precipitation occurs as snow, a 40-percent commercial clearcut in strips yielded a first-year increase of 30 percent in annual streamflow (Goodell 1958). We used the figure 15 percent as an example, and not as a universal recommendation. In using the tables, the reader should consider the special circumstances applying to his case.

The tables may also be used to solve problems relating to channel stability, bank cutting, and stream level. However, because the characteristics of stream channels vary considerably from one segment to another, it is apparent that a particular problem may not have a unique solution. Nevertheless, the land manager may sometimes be particularly concerned with certain segments of a stream channel because they appear vulnerable to changes in the hydrologic regime. In such cases, it may be worthwhile to make the assumptions needed to perform the calculations and to determine the magnitude of changes that can be expected.

Limitations

Flood peaks reflect the complex interaction of many variables, and many formulas have been devised to account for the effects of these variables. In most cases, however, the land manager has only limited information about the magnitude of the important variables. For example, Rosa (1968) published water yield maps for Idaho, but maps of this sort are not available for even such basic variables as rainfall intensity or soils grouped according to their hydrologic properties.

The user of these tables is cautioned that the tabulated values are far from being definitive; they are only an approximation to give the land manager an idea of what may be expected. Mr. C. A. Thomas has observed[1] that the tabulated values may be too high for streams with a high base flow and are probably too low for streams with flashy run-off and low base flows.

The user should bear in mind that the tables will probably be applied to areas considerably smaller than those from which the tables were derived. Furthermore, flow data for the very small drainages cover only a brief span of time.

[1]Personal communication, on file at Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Moscow, Idaho.

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APPENDIX I

The published tables are based on the finding that peak flow is a function of mean water yield. The equation is:

$$\ln (P/A) = a+b\ [1.5708 - \text{arc tan } (\sinh F/A)] \qquad (1)$$

in which P, A, and F are, respectively, peak flow (c.f.s.), area (square miles), and mean flow (c.f.s.). The constant 1.5708 is the angle 90° expressed in radians.

Equation (1) is based on data found in Thomas, Broom, and Cummans (1963) and Bodhaine and Thomas (1964). Only those rivers were analyzed whose records indicated no diversions, impoundments, or poor data. The equation was derived as follows: For each streamflow record, the annual peak flow data were arranged in a descending order of magnitude. If N represents the total number of items in the series, and M_i is the ordered position in the series (i.e., $1,2 \ldots M_i \ldots N$), then the probability of occurrence (P_r) (or percent chance) for a peak flow equal to or smaller than that in ordered position M_i is

$$100 \text{ X } \frac{(M_i - 0.5)}{N}$$

This probability was calculated for each ordered position, and defined the plotting position of the associated peak flow on log-normal paper. A smooth line was drawn through the plotted data, but was not extended beyond the range of the plotted data. We then read the adjusted peak flows for the selected recurrence periods: 2.33; 5; 10; and 20 years. (The recurrence period is 100 divided by the probability of occurrence; e.g., if $P_r = 20$, $T_r = 5$.)

Data drawn from the smooth curves formed four new sets of data, one for each selected recurrence period. Each set of data was then analyzed to obtain the values of a and b in equation (1). We have listed below these values, as well as the correlation coefficient (R) relating the dependent and independent variables.

Recurrence period (Years)	*a*	*b*	*R*
2.33	3.3434	-1.9693	0.966
5	3.6653	-2.0440	.950
10	3.7141	-1.8908	.938
20	3.8733	-1.8324	.902

Values for tables 1 and 2 were calculated for selected values of mean flow *(F/A)* using the equation

$$\frac{P}{A} = e^{a+b[1.5708 - \text{arc tan } (\sinh \frac{F}{A})]} \qquad (2)$$

where e is 2.71828, base for Naperian logarithms.

APPENDIX II

Data for the following rivers were used to derive equation 1.

River No. (USGS)	River name and location	Length of record	Area	Mean elevation
		Years	*Sq.mi.*	*Feet*
	IDAHO			
12-3055	Boulder Creek near Leonia	37	53	4,980
12-3065	Moyie River at Eastport	36	570	4,870
12-3075	Moyie River at Eileen	40	755	4,710
12-4110	Coeur d'Alene River near Prichard	14	335	4,120
12-4130	Coeur d'Alene River at Enaville	26	895	3,610
13-3170	Salmon River at White Bird	53	13,550	6,720
13-3375	South Fork Clearwater River at Elk City	21	261	5,150
13-3390	Clearwater River at Kamiah	55	4,850	5,010
13-3405	North Fork Clearwater River at Bungalow Ranger Station	13	996	4,930
13-1200	Big Lost River at Wildhorse, near Chilly	21	114	8,540
13-1625	East Fork Jarbridge River near Three Creek	16	89	7,600
13-1850	Boise River near Twin Springs	54	830	6,350
13-1965	Bannock Creek near Idaho City	17	5.75	5,240
	WYOMING			
13-115	Pacific Creek near Moran	21	160	8,160
13-320	Bear Creek near Irwin	12	77.1	7,130
	MONTANA			
3505	Kootenai Creek near Stevensville	7	28.9	6,670
3560	Skyland Creek near Essex	6	8.09	5,920
3585	Middle Fork Flathead River near West Glacier	18	1,128	5,800
3590	South Fork Flathead River at Spotted Bear	10	958	6,130
3595	Spotted Bear River near Hungry Horse	8	184	5,960
3600	Twin Creek near Hungry Horse	8	47	5,300
3610	Sullivan Creek near Hungry Horse	9	71.3	5,510
3615	Graves Creek near Hungry Horse	9	27	5,430

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