United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Research Station**

General Technical
Report RMRS-GTR-228

A Synthesis of Post-Fire Road Treatments for BAER Teams: Methods, Treatment Effectiveness, and Decisionmaking Tools for Rehabilitation

Randy B. Foltz, Peter R. Robichaud, and Hakjun Rhee

A SUMMARY OF
KNOWLEDGE FROM THE
**Joint
Fire Science
Program**

Foltz, Randy B.; Robichaud, Peter R.; Rhee, Hakjun. 2009. **A synthesis of post-fire road treatments for BAER teams: methods, treatment effectiveness, and decisionmaking tools for rehabilitation.** Gen. Tech. Rep. RMRS-GTR-228 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 152 p.

ABSTRACT

We synthesized post-fire road treatment information to assist BAER specialists in making road rehabilitation decisions. We developed a questionnaire; conducted 30 interviews of BAER team engineers and hydrologists; acquired and analyzed gray literature and other relevant publications; and reviewed road rehabilitation procedures and analysis tools. Post-fire road treatments are implemented if the values at risk warrant the treatment and based on regional characteristics, including the timing of first damaging storm and window of implementation. Post-fire peak flow estimation is important when selecting road treatments. Interview results indicate that USGS methods are used for larger watersheds (>5 mi^2) and NRCS Curve Number methods are used for smaller watersheds (<5 mi^2). These methods are not parameterized and validated for post-fire conditions. Many BAER team members used their own rules to determine parameter values for USGS regression and NRCS CN methods; therefore, there is no consistent way to estimate post-fire peak flow. Many BAER road treatments for individual stream crossings were prescribed based on road/culvert surveys, without considering capacities of existing road structure and increased post-fire peak flow. For all regions, rolling dips/water bars, culvert upgrading, and ditch cleaning/armoring are the most frequently used road treatments. For Forest Service Regions 1 and 4, culvert upgrading is preferred, especially for fish-bearing streams. For Forest Service Region 3, culvert removal with temporary road closure and warning signs is preferred. Except for culverts, insufficient data is available on other road treatments to estimate their capacity and to evaluate their effectiveness.

Keywords: wildfire, BEAR, burned area, emergency response, peak flow, roads

THE AUTHORS

Randy B. Foltz is a Research Engineer with the Rocky Mountain Research Station's Soil and Water Engineering Research Work Unit and is stationed at the Forestry Sciences Laboratory, Moscow, ID.

Peter R. Robichaud is a Research Engineer with the Rocky Mountain Research Station's Soil and Water Engineering Research Work Unit and is stationed at the Forestry Sciences Laboratory, Moscow, ID.

Hakjun Rhee is a Post-Doctoral Research Associate with the Biological Systems Engineering at Washington State University, Pullman, WA.

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and series number.

Fort Collins Service Center

Telephone (970) 498-1392
FAX (970) 498-1122
E-mail rschneider@fs.fed.us
Web site http://www.fs.fed.us/rm/publications
Mailing address Publications Distribution
Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, CO 80526

Rocky Mountain Research Station
240 W. Prospect Road
Fort Collins, Colorado 80526

ACKNOWLEDGMENTS

Funding for the project was provided by the Joint Fire Science Program (project number 06-3-4-03). We gratefully acknowledge the contributions of the following Forest Service BAER team members for their interviews: Norman Ambos, Melvin Bennett, Greg Bevenger, Mike Bradshaw, Thomas Clifford, Mike Dixon, Thomas Durston, Richard Edwards, Robert Faust, Nick Gerhardt, Terry Hardy, Ben Hipple, Alex Janicki, Richard Jones, Greg Kuyumjian, John Lane, Rusty LeBlanc, Robert Lefevre, Grant Loomis, Gary Miller, Carolyn Napper, Gregory Napper, Kathy Nelson, Mark Nienow, Mike Parenti, Rick Patten, Dean Sirucek, Mark Story, Bo Stuart, and John Thornton. We also acknowledge the contributions of the following personnel for their review of this report: Greg Bevenger, Nick Gerhardt, Richard Hawkins, Greg Kuyumjian, and Bruce Sims.

CONTENTS

Introduction

Wildland fires can cause extreme changes in the landscape that can drastically influence surface runoff and sediment transportation. Removal of the forest duff layer causes increased runoff and subsequent increases in peak flow and sediment transport. These increased flows can impact forest resources and infrastructures. Roads are one of the most impacted forest infrastructures. They are designed to divert water to desired locations and prevent washouts. Post-fire flows often exceed design capacity, requiring that many structures be treated following fires. For example, culverts sized for unburned forest conditions are often unable to pass the new, higher flows and are replaced with larger ones. Nationwide road structure replacement costs in the 1990s were about 20 percent of the total post-fire rehabilitation expense (Robichaud and others 2000).

Problem Statement

Watersheds with satisfactory hydrologic conditions (greater than 75% of the ground covered with vegetation and litter) and adequate rainfall sustain stream baseflow conditions for much or all of the year and produce little sediment and erosion. Fire consumes accumulated forest floor material and vegetation, altering infiltration by exposing soils to raindrop impact or creating water repellent soil conditions, thus reducing soil moisture content. Runoff plot studies show that, when severe fire produces hydrologic conditions that are poor (less than 10% of the ground surface covered with plants and litter), surface runoff can increase more than 70% and erosion can increase by three orders of magnitude (DeBano and others 1998; Robichaud 2005).

In the post-fire environment, road drainage features must accommodate flows under these changed and variable conditions to prevent failure. Road structures designed for the unburned forest condition are often unable to accommodate increased runoff, sediment, and debris following fire. BAER teams estimate post-fire increases in stream flows and make judgments on the ability of existing road structures to accommodate these new flow regimes. If necessary, treatments are prescribed to address user safety and road infrastructure investment, as well as to prevent disruption of use or unacceptable degradation of critical natural and cultural resources.

BAER team members use a variety of tools to estimate the post-fire increase in runoff and sediment. These vary from local expertise to computer models. This synthesis of commonly used post-fire assessment tools and road treatments will aid BAER team members in responding to the tight time frames allotted for rehabilitation decisions.

Study Objectives

The overall goal of this study was to develop a resource for BAER teams to assist them in making post-fire road rehabilitation decisions. We synthesized the most useful post-fire analysis tools for use in determining the required capacity of road structures and guidelines and procedures for prescribing road treatments after wildfire. Our specific objectives were to: (1) develop a questionnaire to acquire qualitative and quantitative information on post-fire road rehabilitation; (2) conduct interviews of BAER team engineers and hydrologists to define specific needs of BAER specialists with respect to post-fire road rehabilitation; (3) analyze gray literature and conduct additional literature review of relevant publications based on needs identified from interview results; (4) review and synthesize road rehabilitation procedures and analysis tools that would be most useful to BAER teams (specific tools of interest include those that estimate post-fire runoff and sediment flows and road structure capacities); (5) design an easily navigable post-fire road guide to access during rehabilitation responses (this included both on-line and hard copy resources); and (6) transfer information through workshops and presentations to agencies involved in post-fire road rehabilitation. This report summarizes our accomplishment of the study objectives.

Methods

This study includes U.S. Forest Service BAER projects in the Western continental United States (Regions 1 through 6). We began by requesting Burned Area Report (FS-2500-8) forms and monitoring reports from the Regional headquarters and Forest Supervisors' offices. We developed interview questionnaires and interviewed BAER specialists regarding their experiences with post-fire rehabilitation. We also analyzed gray and peer-reviewed literature acquired from the interviews and literature search. We then reviewed and synthesized quantitative and qualitative information on procedures for prescribing road treatments after wildfire, estimating post-fire runoff and sediment, and determining road treatments.

Burned Area Report Data

The U.S. Forest Service Burned Area Report form contains the fire name and watershed location and the size, suppression cost, vegetation, soils, geology, length of stream channels, and roads and trails affected by the fire. The watershed description includes areas in low, moderate, and high burn severity categories and the area of water repellent soil. Erosion hazard ratings and estimates of erosion and sediment potential are included. Additionally, hydrologic design factors are included, such as estimated vegetation recovery, design chance of success, design storm recurrence interval, storm duration, storm magnitude, design flow, reduction in infiltration, and post-fire runoff flow. Values at risk are described and the probability of success for hillslope, channel, and road treatments are estimated. Cost estimates of no action (loss) versus cost of selected alternatives are identified, as well as BAER funds requested and other matching funds.

Interview Survey

We developed interview forms (Appendix A) after modification of the survey form from a previous study (Robichaud and others 2000). We used the forms to record information during interviews with BAER team members. Questions were designed to elicit opinions regarding the interviewees' experiences with the treatments used on their forests and other fires. The interview survey was comprised of three parts: (1) hydrologic design factor questions of Burned Area reports (e.g., how they estimated post-fire runoff and sediment); (2) road treatment questions (e.g., frequent-used road treatments); and (3) aftermath road treatment questions (e.g., success and failure of the prescribed treatments). Prior to conducting interviews, we requested information such as Burned Area Report forms and post-fire monitoring reports to familiarize the interviewer with the various fires and treatments used. We conducted onsite interviews because much of the supporting data were located in the interviewees' offices and could be retrieved during the interviews. We attempted to ask questions that would allow for ranking results because much of the information was qualitative.

Analysis Methods

We analyzed interview survey results using Microsoft Excel™. We gave ranked information results a value from one to three with the first ranking receiving three points; the second two points; and the third one point. We evaluated runoff, peak flow, and sediment yield estimation methods used by BAER teams and described their benefits/drawbacks based on the comments of BAER interviewees, scientific literature, and the judgment of the proposal's PI and Co-PI as suggested by the JFSP (Joint Fire Sciences Program). Examples of the different estimation methods from BAER reports were provided and we grouped qualitative answers and comments so as to draw meaningful inferences.

Results and Discussion

Overview of Data Collected

We categorized collected data into the following: (1) Burned Area Reports (FS 2500-8) acquired from Regional BAER coordinators, (2) published literature from a literature review/search, (3) interview results from BAER specialists, and (4) gray literature and unpublished data from interviewed BAER specialists. The published literature can be found in the references. A list of gray literature and unpublished data can be found in Appendix B.

Interview Survey

We interviewed a total of 30 BAER specialists. We visited a total of 28 BAER specialist offices to conduct interviews face-to-face and acquire any gray literature and monitoring reports while interviewing them. Two BAER specialists were interviewed by phone due to schedule conflicts. Interviewed BAER specialists were mostly hydrologists (45%), engineers (22%), and soil scientists (20%) (table 1). Thus, we had a representative sample of specialists involved in post-fire runoff and sediment estimation methods and road treatment recommendations. The experience of the interviewed BAER specialists ranged from 6 to over 30 years.

Table 1—Background of interviewed BAER specialists by Regions.

		Region					
Background	**Overall**	**1**	**2**	**3**	**4**	**5**	**6**
	- - - - - - - - - - - - - - - - % - - - - - - - - - - - - - - -						
Hydrology	45	67	100	33	43	25	75
Engineering	22			17	29	38	25
Soil	20	33		17	14	25	
Natural resource	7			17	14		
Forestry	3			17			
Road management	3					13	
No. of BAER interviewee responses	30	6	1	6	7	8	2

Hydrologic design factor

The Burned Area Report contains a section titled “Hydrologic Design Factors,” which lists the factors used to estimate the need for post-fire treatments. The following section summarizes the interviewee’s methodology used to complete this section. For each of the factors, we will discuss the most popular methods, comprising 80% of the responses. All responses are listed in each table.

For **estimated vegetation recovery period**, most of interviewed BAER specialists used “professional judgment” (42%) or consulted with local botanists, ecologists, soil scientists, or hydrologists (39%) (table 2). It was unclear what method the consulted specialists used. Research results (8%) and "2 to 3 years" (8%) were the next popular responses.

For **design chance of success**, most BAER specialists (78%) used professional judgment (table 3). The interviewed BAER specialists without hydrology or engineering backgrounds consulted with hydrologists (13%). It was unclear what method the consulted hydrologists used.

For **equivalent design recurrence interval**, there was no clear preference and the most frequent answer was "consult w/hydrologist" (36%). It was unclear what method the consulted hydrologist used. Fixed values of 10 years (14%) and 25 years (14%) were the next most common replies (table 4).

For **design storm duration**, there was no clear preference and the most frequent answer was "consult w/hydrologist" (44%). It was unclear what method the consulted hydrologist used. One-hour duration (17%), various duration depending on damaging storm (13%), and 30-minute duration (12%) were the next most common replies (table 5). Damaging storm is further discussed in the *Damaging Storm* section.

For **design storm magnitude**, a majority of the interviewees with a hydrology background used NOAA Atlas (46%), and those without a hydrology background consulted with hydrologists (40%) (table 6). It was unclear what method the consulted hydrologist used. A small number of BAER specialists used other methods, such as Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Daly 2007) and CLIGEN (USDA ARS and Forest Service 2008). Also, one interviewee specifically identified that, for watershed less than 5 mi^2, the damaging storm is a 5-minute duration, 6-inch/hour intensity, convective storm in Regions 2 and 3. In Colorado, the damaging storm is a 2-year return period, 24-hour duration, 0.1-inch/hour intensity convective storm in July or August.

Estimated reduction in infiltration was mostly estimated from soil burn severity (USDA Forest Service 2007) maps (46%) or measured in the field (29%) (table 7).

To estimate **design flow** (pre-fire peak flow), most of the interviewed BAER specialists used the USGS Regression (50%), Curve Number (18%), or consulted with a hydrologist (18%) (table 8). It was unclear what method the consulted hydrologist used. To estimate **adjusted design flow** (post-fire peak flow), most of interviewed BAER specialists used the USGS Regression (43%), Curve Number (28%), Rule of Thumb by Kuyumjian (pers. comm., 2007 USDA Forest Service; 7%) and TR55 (USDA NRCSb 2005; 7%) (table 8). Detailed information about each method is discussed in the *Post-fire Runoff and Erosion Estimation* section.

Road treatment

The BAER FS-2500-8 form contains a section that describes the BAER team's road treatment recommendations. The following section summarizes the interviewees' preferred road treatments.

Rolling dips/water bars/cross drain, culvert upgrading, ditch cleaning, armoring, culvert removal, and trash racks constituted 80% of the most frequently used road treatments. All responses are shown in table 9. The rolling dips/water bars/cross drain treatment was used most frequently throughout the Regions. Culvert upgrading was used mainly in Regions 1, 4, and 6 where fish habitat protection is a high priority. Culvert removal was used often in Region 3 where flash flooding is common. Trash racks were used in Regions 3 and 5, and culvert riser was used only in Region 5.

Table 2—Estimated vegetation recovery period used by BAER specialists.

Estimated vegetation recovery period	%
Professional judgment	42
Consult w/botanist, ecologist, soil scientist, and hydrologist	39
Research results	8
2-3 years	8
3-5 years	3
No. of BAER interviewee responses	19

Table 3—Design chance of success used by BAER specialists.

Design chance of success	%
Professional judgment	78
Consult w/hydrologist	13
80%	4
Risk table[a]	4
No. of BAER interviewee responses	23

[a] Schmidt (1987) as shown in table 10.

Table 4—Equivalent design recurrence interval used by BAER specialists.

Equivalent design recurrence interval	%
Consult w/hydrologist	36
10 years	14
25 years	14
5 years	9
100 years	9
Values at risk	9
Professional judgment	9
No. of BAER interviewee responses	22

Table 5—Design storm duration used by BAER specialists.

Design storm duration	%
Consult w/hydrologist	44
1 hour	17
Depend on damaging storm	13
30 minutes	12
15 minutes	6
Less than 6 hours	4
Professional judgment	4
No. of BAER interviewee responses	23

Table 6—Design storm magnitude used by BAER specialists.

Design storm magnitude	%
NOAA Atlas	46
Consult w/hydrologist	40
PRISM[a]	8
Past experience	4
CLIGEN[b]	2
No. of BAER interviewee responses	25

[a] Daly (2007).

[b] USDA Agricultural Research Service and Forest Service (2008).

Table 7—Estimated reduction in infiltration used by BAER specialists.

Estimated reduction in infiltration	%
Soil burned severity maps	46
Field measurement[a]	29
Consult w/soil scientist	10
Previous studies	6
Back-calculation[b]	5
Professional judgment	3
40% for high/moderate burned area	2
No. of BAER interviewee responses	22

[a] Infiltrometers were used.

[b] Back-calculate from design flow and adjusted design flow.

Table 8—Pre- and post-fire peak flow estimation methods used by BAER specialists.

Pre-fire peak flow estimation method	%	Post-fire peak flow estimation method	%
USGS Regression	50	USGS Regression	43
Curve Number	18	Curve Number	28
Consult w/hydrologist	18	Rule of Thumb	7
TR55	7	TR55	7
No runoff/flow	4	Consult w/hydrologist	7
Professional judgment	4	WEPP	5
		FERGI	2
		WATBAL	2
No. of BAER interviewee responses	28	No. of BAER interviewee responses	30

Table 9—Frequently recommended road treatments by BAER specialists by Region.

	Region						
Method	**Overall**	**1**	**2**	**3**	**4**	**5**	**6**
	- -- - - - - - - - - - - - - - % - - - - - - - - - - - - - -						
Rolling dip/water bar/cross drain	29	29		27	30	19	42
Culvert upgrading	20	33			48		17
Ditch—cleaning, armoring	16	25		14	13	17	
Culvert removal	10	6		36			25
Debris/trash rack	6			9		19	
Armored ford crossing	5		33	5	4	6	8
Culvert riser	5					19	
Storm patrol	3		50	9			
Culvert overflow bypass	2				4	6	
Hazard/warning sign	1	2	17				
Flared inlet	1					6	
Channel debris cleaning	1					6	
Culvert inlet/outlet armoring	1	2					
Additional relief culvert	1	2			3		
Outsloping road	1					3	
Fillslope armoring	1						8
No. of BAER interviewee responses	30	8	1	6	5	8	2

To calculate the treatment cost, BAER specialists consulted with engineers, followed regional cost guides, and modified and used the cost of previous years. Often, 3% yearly interest was applied to the cost from the previous year. Some BAER specialists added a 20 to 25% emergency factor and a 35% overhead fee. Indefinite Delivery Indefinite Quantity (IDIQ) contracts were favored by some BAER specialists. IDIQs are contracts that provide for an indefinite quantity of supplies or services during a fixed period of time (Office of Federal Procurement Policy 2008).

Road treatment effectiveness monitoring

To evaluate the prescribed road treatments, monitoring reports and any follow up records are needed; however, most interviewed BAER specialists did not have these reports or records. A limited number of monitoring reports were acquired during the interviews. Most monitoring reports contained pictures and a description of the BAER treatments; however, they did not provide enough information to evaluate whether road treatments achieved their desired post-fire erosion mitigation.

Post-Fire Road Rehabilitation Procedures

When prescribing post-fire rehabilitation treatments, most BAER specialists followed similar procedures. Many BAER interviewees highlighted important aspects of these BAER procedures. The most notable comment was that prescribing road treatments differed among Regions because climates differed. The following is a list of post-fire road rehabilitation procedures identified by BAER specialists as useful in determining road recommendations.

Values at risk

BAER treatments are prescribed, prioritized, and implemented, depending on the values (e.g., life, safety, property) and/or resources (natural or cultural) that are at risk due to the burned condition of the forest. If there are no values or resources at risk, no BAER treatment is needed. A recent publication (Calkin and others 2007) provides a reliable and repeatable method to access values at risk.

Damaging storm

A damaging storm is a precipitation event that will likely threaten human lives or cause damage to property or road structures within the burned-over watershed or downstream values. A damaging storm can be a convective storm, summer thunderstorm, or rain-on-snow event, depending on the Region. A damaging storm is a (1) rain-on-snow event during spring snowmelt for mid- to high-elevation areas; (2) convective storm from May to September for the majority of other areas; and (3) winter frontal storm for portions of Regions 5 and 6.

Our interviews with the BAER team members indicated that while they had a clear understanding of what constituted a damaging storm, the term “design storm” was often used interchangeably with “damaging storm.” A design storm is a storm event associated with a specified return period and is used as the basis for the design of stormwater-management systems. Both terms appear to be useful in BAER work, but we suggest a clear distinction be made between the two terms.

Window of implementation

The window of implementation should be carefully considered during the BAER assessment. The amount of time the BAER implementation team has before a damaging storm will most likely affect the burned watersheds. Therefore, the assessment team should determine the number of treatments that can be implemented, then prioritize the treatments based on values at risk. This is especially important for the southwestern United States, where fire season is usually from May to July and convective storms follow shortly thereafter. Ideally, the BAER treatments would be implemented within 3 to 4 weeks after the treatments are approved by the Washington Office. Any administrative help to speed up the BAER implementation is useful, such as:

- pre-ordering and stockpiling the necessary materials (such as warning signs);
- contracting implementation equipment and associated personnel using Indefinite Delivery/Indefinite Quantity (IDIQ) contracts; or
- developing close communication between assessment and implementation teams.

Probability of success

The probability of treatment success is closely related to the values at risk. If the values at risk are high, high probability of treatment success should be considered. The BAER treatment choice is determined by post-fire runoff, which is generated by precipitation events after wildland fires. Therefore, predicted precipitation events are crucial to the successful treatment selection. Future precipitation events can be estimated by using previous weather data, such as NOAA Atlas (NOAA 2008) or PRISM (Daly 2007). The probability of treatment success should consider the design storm (i.e., future precipitation events), design life of the treatments, and the recovery period following the fire. To calculate the chance of success of the treatment, Table 10 can be used.

Table 10—Calculated risk table (recurrence interval in years) (Schmidt 1987).

		Risk – Percent chance																		
Success		95	90	85	80	75	70	65	**60**	55	50	45	40	35	30	25	20	15	10	5
Failure		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Design life (years)	1	20	10	7	5	4	4	3	3	3	2	2	2	2	2	2	2	2	2	2
	2	40	20	13	10	8	6	5	5	4	4	4	3	3	2	2	2	2	2	2
	3	59	29	19	14	11	9	8	7	6	5	4	4	3	3	3	2	2	2	2
	4	78	39	25	19	15	12	10	8	7	7	6	5	4	4	4	3	3	2	2
	5	98	48	32	23	18	15	13	10	9	8	7	6	6	5	4	4	3	3	2
	6	117	58	38	28	22	17	15	12	11	10	8	7	7	6	5	4	4	3	2
	7	136	67	44	32	25	20	17	14	12	11	9	8	7	6	6	5	5	4	3
	8	156	77	50	37	28	23	20	16	14	12	11	9	8	7	7	5	5	4	3
	9	175	86	56	41	32	26	22	18	16	13	12	10	9	8	7	6	5	4	4
	10	195	96	63	46	35	29	24	20	17	15	13	11	10	9	8	7	6	5	4
	11	214	104	69	50	39	31	27	22	19	16	14	13	11	10	9	7	6	5	4
	12	234	114	75	55	42	34	29	24	21	18	16	14	12	10	9	8	7	6	5
	13	254	124	81	59	46	37	31	26	22	19	17	15	13	11	10	9	7	6	5
	14	273	133	86	64	49	40	34	28	24	21	18	16	14	12	11	9	8	7	5
	15	293	143	93	68	53	43	36	30	26	22	19	17	15	13	12	10	8	7	6
	16	312	152	99	73	56	45	38	32	27	24	20	18	16	14	12	10	9	8	6
	17	332	162	105	77	60	48	40	34	29	25	22	19	17	15	13	11	9	8	6
	18	351	171	111	82	63	51	43	36	31	26	23	20	18	15	14	12	10	8	7
	19	371	181	117	86	67	54	45	38	32	28	24	21	19	16	14	12	11	9	7
	20	390	190	123	91	**70**	57	47	40	34	29	26	22	20	17	15	13	11	9	8
	25	488	238	154	113	88	71	59	50	42	36	32	28	25	22	19	16	14	11	9
	30	585	285	185	135	105	85	71	60	51	44	38	33	29	25	22	19	16	14	11
	35	683	333	216	157	122	99	82	70	59	51	45	39	34	30	26	23	19	16	12
	40	780	380	247	180	140	113	94	79	68	58	51	44	39	34	29	25	22	18	14
	45	878	428	277	202	157	127	105	89	76	66	57	50	43	38	33	28	24	20	15
	50	975	475	308	225	174	141	117	99	85	73	63	55	48	43	37	32	27	22	17
	60	1170	570	370	269	209	169	140	118	101	87	76	66	58	50	44	38	32	27	20
	70	1365	665	431	314	244	197	163	138	118	101	89	77	67	59	51	44	37	31	24
	80	1560	760	493	359	279	225	186	157	134	116	101	88	77	67	58	51	43	35	27
	90	1755	855	554	404	313	253	209	177	151	130	113	99	86	75	66	57	48	40	31
	100	1950	950	616	449	348	281	233	196	168	145	126	110	96	84	73	63	53	44	34

Example 1:	If a culvert through a road is to last for 20 years with a 25% chance of failure (or 75% chance of success), the culvert should be designed for the 70-year flood recurrence event. Failure in this context means that the recurrence interval flood is equaled or exceeded at least once during the specific design life. The culvert may or may not physically fail or be washed out.
Example 2:	The same culvert above is used for post-fire condition in which 7-year post-fire flood is equal to 70-year pre-fire flood. Post-fire condition will last for only 3 years; therefore, the design life will be 3 years. Then percent chance of success decreased from 75% to 60% if the existing culvert is used for post-fire condition.

Post-fire runoff increase

Post-fire runoff increase is estimated based on the design storm. Each BAER team used their preferred method. The interview survey showed that a majority of BAER specialists use the following methods, ranked from high to low (table 8): (1) USGS Regression, (2) Curve Number, (3) Rule of Thumb by Kuyumjian, (4) Water Erosion Prediction Project (WEPP) Model, and (5) Fire-Enhanced Runoff and Gully Initiation (FERGI) Model. Detailed information on each method is found in the *Post-fire Runoff and Sediment Estimation* section.

Capacity of existing road structures

If existing road structures can handle the increased post-fire peak flow, no further treatment is needed. However, in some cases, the existing road structures can not handle the increased flow, and they should be removed or upgraded if the values at risk warrant the expected expense. Also, many BAER specialists recommended considering a bulking factor to account for the debris and sediment delivered with increased runoff from the burned upland area. Typical bulking factors range from 0.1 to 0.25. Limited information exists on road structure capacities, and estimates must be made using on-site measurements and calculations. Road structures, such as culverts and rolling dips/water bars, are further discussed in the *BAER Road Treatments*, *Culvert Sizing*, and *Rolling Dip/Water Bar* sections.

Choosing a road treatment

Post-fire road treatments should be implemented after considering the factors discussed previously. The interview survey showed that BAER specialists use the following treatments, ranked from high to low (table 9): (1) rolling dips/water bars/cross drain, (2) culvert upgrading, (3) ditch cleaning and armoring, and (4) culvert removal.

Post-Fire Runoff and Erosion Estimation

To prescribe road treatments, it is essential to determine whether the existing drainage structure can handle the post-fire runoff increase. Extensive literature indicates that streamflow increases after fires through a combination of the hydrologic processes summarized in table 11.

There is a general consensus that post-fire streamflow can increase, often with orders of magnitude larger than pre-fire events, especially for watersheds of high and moderate burn severity. Burned watersheds can yield runoff that quickly produces flash floods. The largest post-fire peak flow often occurs in smaller watersheds. Bigio and Cannon (2001) reported that specific discharges were the greatest from relatively smaller watersheds (<0.4 mi^2) with an average

Table 11—Changes in hydrologic processes caused by wildfires (Neary and others 2005).

Hydrologic process	Type of change	Specific effect
Interception	Reduced	Moisture storage smaller Greater runoff in small storms Increased water yield
Litter and duff storage of water	Reduced	Less water stored Overland flow increased
Transpiration	Temporary elimination	Streamflow increased Soil moisture increased
Infiltration	Reduced	Overland flow increased Stormflow increased
Stream flow	Changed	Increased in most ecosystems Decreased in snow systems Decreased on fog-drip systems
Baseflow	Changed	Decreased (less infiltration) Increased (less evaporation) Summer low flows (+ and –)
Stormflow	Increased	Volume greater Peakflows larger Time to peakflow shorter Flashflood frequency greater Flood levels higher Stream erosive power increased
Snow accumulation	Changed	Fires <10 ac, increased snowpack Fires >10 ac, decreased snowpack Snowmelt rates increased Evaporation and sublimation greater

discharge of 17,700 cfsm (cfs mi^{-2}) or 28 cfs $acre^{-1}$, while discharges from the next larger sized watersheds (0.4 mi^2 to 4 mi^2) averaged 2,100 cfsm. Increased post-fire flow may transport debris that was produced by the fire. Often, the post-fire peak flow is a combination of water flow and debris, called bulking. Road treatments should be prescribed and implemented if existing drainage structures can not handle the post-fire runoff increase.

BAER specialists have been using several methods to estimate post-fire runoff: USGS Regression, Curve Number, Rule of Thumb by Kuyumjian, ERMiT, FERGI, and WATBAL. The following is a discussion of each of these methods.

USGS Regression method

The USGS Regression method is the most commonly used post-fire runoff estimation method by BAER team members (43%; table 8).

The Department of Interior U.S. Geological Survey (USGS) has developed a method to estimate magnitude and frequency of floods of both gaged and ungaged streams. The flood-frequency relations at gaged and ungaged sites were developed for various hydrologic regions based on their stream gage records, basin characteristics, and numerous studies throughout the United States. These flood-frequency relations are often called and expressed as a form of "USGS regression equations," since a regression analysis was used to develop the flood frequency relations.

Input Requirements

To use the USGS Regression method, the following information is required:

- USGS Regression equations for the areas of interests (burned sites);
- gauged data from the watersheds of interests (if any);
- basin characteristics, such as the drainage area, elevation, precipitation, free water-surface evaporation, latitude, longitude, forest and herbaceous cover, high elevation area, channel slope, soil storage capacity and permeability, and minimum and maximum January temperatures (the actual required basin characteristics vary depending on the hydrologic regions. Fortunately, not all of these characteristics are required for a single region.);
- design storm intensity, duration, and recurrence interval;
- size of high soil burn severity areas; and
- water repellency and surface runoff increase of high/moderate soil burn severity area, which should be determined by users.

Program Availability

USGS Regression equation methods have been incorporated into StreamStats (USGS 2007), which is a web-based tool used to obtain streamflow information. StreamStats are available for many states and are being implemented for the others (fig. 1). Users can access StreamStat online (http://water.usgs.gov/osw/streamstats/index.html) and estimate peak flow at a given location.

How to Use

The following steps are used to apply the USGS Regression method for estimation of post-fire peak flow:

1. Find the USGS Regression equations for the area of interest

2. Collect the basin characteristics of burned areas

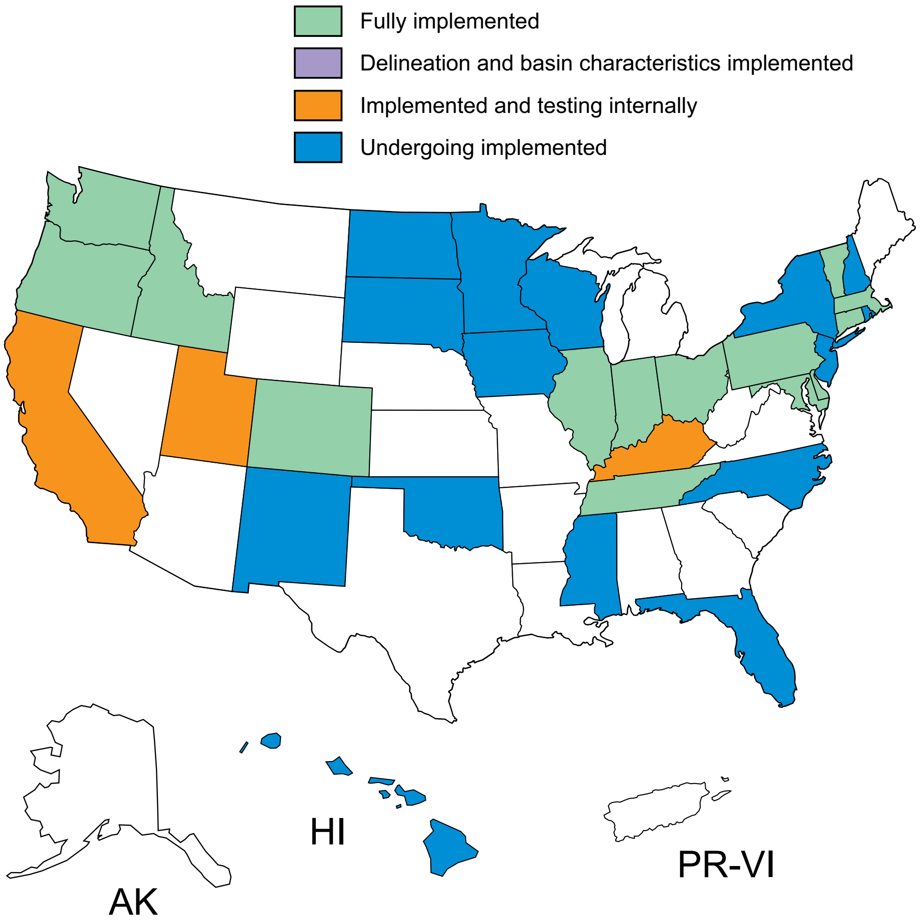


Figure 1—Availability of StreamStats for the U.S. (USGS 2007).

3. Collect information about the burned area, such as percentage of high and moderate soil burn severity areas

4. Determine design/damaging storm, including storm intensity, duration, and recurrence interval

5. Estimate pre-fire runoff assuming no fires and unburned area for the area of interest

6. Determine the percent runoff increase for high and moderate soil burn severity area compared to pre-fire runoff (a difficult step, as described below)

7. Determine *modifier* that is defined as a ratio of post-fire to pre-fire runoff and calculated as follows:

$$modifier = 1 + \frac{Percent\ runoff\ increase}{100\%} \times \frac{(A_H + A_M)}{A_T} \qquad \text{(Eq. 1)}$$

where

A_H = high burn severity area within the watershed (acre or mi^2);
A_M = moderate burn severity area within the watershed (acre or mi^2), and;
A_T = total watershed area (acre or mi^2).

8. Estimate post-fire runoff by multiplying the modifier and pre-fire runoff

Discussion

Since there are very limited studies and guidelines to determine the modifier or the percent runoff increase for high and moderate burn severity, BAER team members often rely on simple rules of their own. For example, some Region 1 BAER specialists used 100% runoff increase (double the runoff amount) for high/moderate soil burn severity areas in the first year of the fire, such as the 2006 Derby Fire (Story and others 2006). Also, they assumed 1/3 and 1/6 soil water repellency with a 10-fold surface runoff increase for high soil burn severity areas for the same year and for 1 year after the 2000 Skalkaho/Valley Complex Fires in Montana (2007 USDA Forest Service).

Some BAER team members in Region 1 skipped steps 6 through 8 and used a USGS Water-Resources Investigations Report (Parrett and others 2004) to estimate post-fire peak flow for their burned areas. This report provided post-fire runoff responses 1 year after a fire in three burned areas in Montana (Canyon Ferry, Ashland, and Bitterroot fires). Once the BAER team members chose a design storm and a station with a drainage area similar in size to their burned area, they could determine the matching post-fire peak flow for their burned areas. However, the report by Parrett and others (2004) did not provide information about the size of burned areas and burn intensities within watersheds. Care should be taken when using a USGS report to estimate post-fire peak flow for burned areas when more detailed burned area conditions are unavailable.

Advantages

The following were advantages to applying the USGS regression method for post-fire runoff and erosion estimation. The USGS Regression method:

- is applicable for estimating both pre- and post-fire peak flow;
- estimates peak flow, regardless of the storm duration and intensity;
- is appropriate for larger watersheds, which are greater than 5 mi^2;
- does not usually require detailed watershed information, such as soil and topography;
- is more accurate if gaged data is used from the watershed of interest;
- is applicable to longer duration events, and snowmelt runoff events.

Disadvantages

The following were disadvantages to applying the USGS regression method for post-fire runoff and erosion estimation.

- It does not estimate erosion.
- It does not consider post-fire debris flow/torrent.
- The user must find the appropriate USGS Regression equations for the watershed in the pre-fire condition.
- The user must find the appropriate USGS Regression equations for the watershed in the post-fire condition (if any).
- The user must determine the modifier, or the soil water repellency and post-fire runoff increase, for high and moderate burn severity areas.
- It uses only English units.

Example

> The Bitterroot National Forest had Skalkaho/Valley Complex Fires in 2000, and had a 10-yr, 24-hour storm event on 1 September 2001. It was

Table 12—Comparison of observed and estimated peak flows using USGS regression method from 10-year, 24-hour storm event 1 year after the 2000 Skalkaho/Valley Complex Fires in the Bitterroot National Forest, Montana (2002 USDA Forest Service).

Watershed (Creek)	Area	% high burn	2001 observed Q_{10}	Estimated Q_{10}		
				Unburned[a]	2000 burned[b]	2001 burned[c]
	(acres)		- - - - - - - - - - - - - - - -(cfs)- - - - - - - - - - - - - - - -			
Medicine Tree	4918	30	307	102	173	122[d]
Doran	4064	70	574	86	226	126
Lyman	3975	15	485	84	113	92
Laird	6222	60	613	125	300	175
Reimel (entire)	6154	30	210	150	255	180
Maynard	3395	60	377	89	214	125
Reimel	5050	30	187	126	214	151
Camp	5299	10	103	132	163	141
Cameron	21,844	20	282	381	559	432
Warm Spring	6712	20	312	134	197	152

[a] from Omang (1992)

[b] Assumed that high soil burn severity areas are 1/3 water repellency with a 10-fold increase in surface runoff

[c] Assumed that high soil burn severity areas are 1/6 water repellency with a 10-fold increase in surface runoff

[d] Estimated Medicine Tree Creek Q_{10} in 2001
= (% high burn)×(unburned Q_{10})×(1/6 water repellency)×(10-fold runoff increase)
+ (100% – % high burn)×(unburned Q_{10})
= (30%)×(102 cfs)×(1/6)×(10) + (100% – 70%)×(102 cfs)
= 122 cfs

assumed that 1/3 of the high soil burn severity areas had soil water repellency and a 10-fold increase in surface runoff. USGS Regression method (Omang 1992) was used to calculate peak flows in the unburned condition. Observed and estimated peak flows are provided in table 12.

Plotting percent of high soil burn severity area and observed post-fire peak flow showed that they are somewhat related (r^2=0.47) (fig. 2). Figure 3 shows that observed post-fire peak flow does not match estimated post-fire peak flow, assuming 1/6 soil water repellency with a 10-fold increase in surface runoff for high soil burn severity areas. Better soil water repellency effects should be developed and moderate soil burn severity areas should be considered for inclusion in the estimation.

Detailed information about how to use the USGS Regression methods can be found in Appendix C.

Curve Number methods

The NRCS Curve Number methods are the second most commonly used post-fire runoff estimation method by BAER team members (30%; table 8).

The Curve Number method was developed by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), to estimate runoff depth. It considers rainfall, soils, cover type, treatment/conservation practices, hydrologic conditions, and topography (slope steepness). Users have to choose a Curve Number (CN) based on cover type, treatment, hydrologic conditions, and Hydrologic Soil Group to estimate runoff and peak flow; therefore, the Curve Number is the single most important parameter in this method.

Figure 2—High burn severity area and observed post-fire peak flow (10-year, 24-hour) from the 2000 Skalkaho/Valley Complex Fires in the Bitterroot National Forest, Montana (2002 USDA Forest Service).

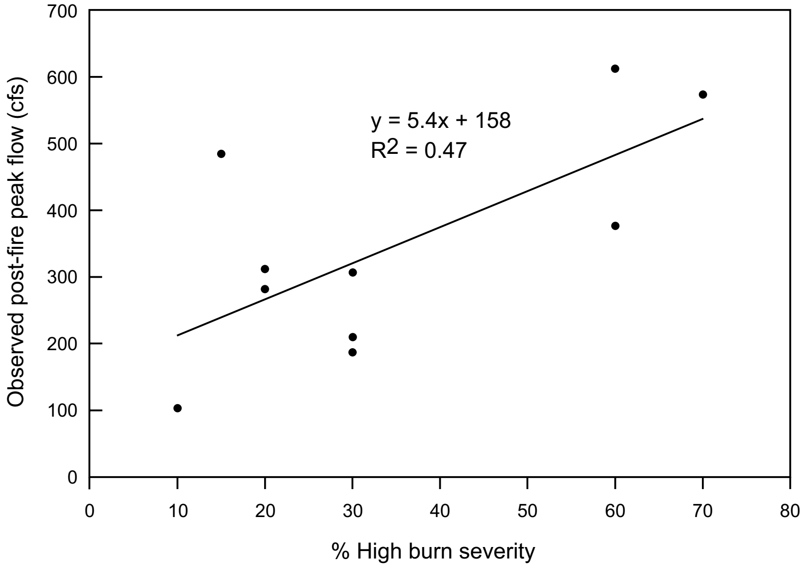
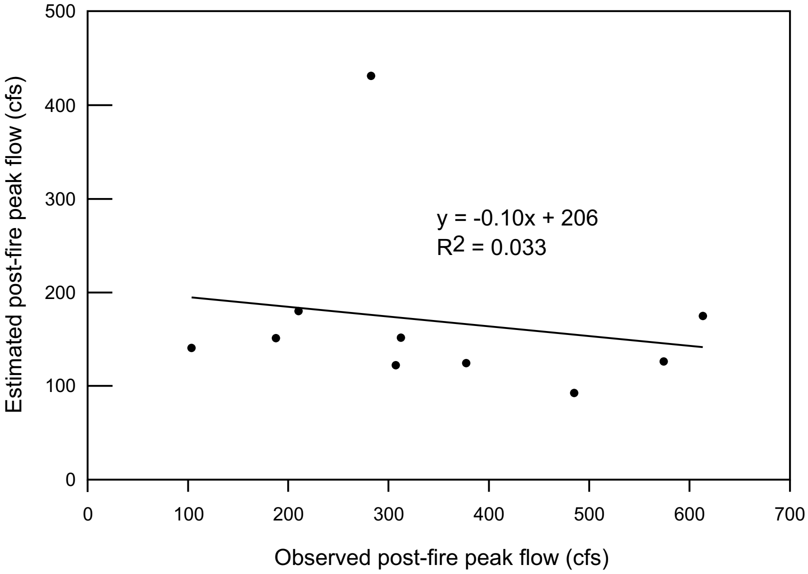


Figure 3—Observed and estimated post-fire peak flow (10-year, 24-hour) from the 2000 Skalkaho/Valley Complex Fires in the Bitterroot National Forest, Montana (2002 USDA Forest Service). Estimated post-fire peak flow does not match observed flow.



Input Requirements

To use NRCS Curve Number methods, the following information is required (USDA SCS 1991):

- drainage area in ft^2, mi^2, or acres;
- rainfall amount for a storm duration of 24 hours, with a given recurrence interval;
- Hydrologic Soil Groups (table 13) in which the watershed soil is classified;
- average watershed slope in percent;
- flow length the longest flow path, from the watershed divide to the outlet, in feet; and
- pre-fire and post-fire runoff Curve Numbers.

Table 13—Description of NRCS Hydrologic Soil Group (USDA SCS 1991).

Group	Description	Minimum infiltration rate (inch h^{-1})
A	Low runoff potential and high infiltration rates, and consists chiefly of sands and gravels.	Greater than 0.30
B	Moderate infiltration rates, and have moderately fine to moderately coarse texture.	0.15 to 0.30
C	Low infiltration rates, and consists chiefly of soils having a layer that impedes downward movement of water and soils of moderately fine to fine texture.	0.05 to 0.15
D	High runoff potential and very low infiltration rates, and consists mainly of clay soils, soils with a permanent high water table, or shallow soils over nearly impervious material.	Less than 0.05

Program Availability

There are two Curve Number methods that BAER teams frequently use—WILDCAT4, (Hawkins and Greenberg 1990) an MS DOS program, and FIRE HYDRO (Cerrelli 2005), an EXCEL spreadsheet. The WILDCAT4 is a storm runoff/hydrograph model that uses triangular unit hydrographs. The WILDCAT4 model requires the following information:

- name of the watershed;
- average land slope (%) and the length of the longest channel (ft) or time of concentration (hr);
- area (acre) of Hydrologic Response Unit (HRU), which is an area having a consistent hydrologic response;
- CN of HRU;
- storm duration (hrs);
- storm rainfall depth (inches); and
- storm distribution type, either SCS Type II (fig. 4), Farmer-Fletcher (for central and north-central Utah; Farmer and Fletcher 1972), uniform, custom, or generic.

If a ‘Generic’ distribution is chosen, the following information is needed:

- the minimum and maximum storm intensities (as a percent of the mean storm intensity) and
- the timing of the peak flow intensity (as a percent of the storm duration).

The WILDCAT4 should be applied to watersheds of 5 mi^2 or less. The WILDCAT4 main menu, watershed data, storm data, and summary output screens are shown in figures 5 through 8.

WILDCAT4 is easy to use. However, the user has to specify the CN of pre- and post-fire conditions and the program runs in DOS. WILDCAT5, a Windows version of the WILDCAT program, is in development and will be released in the near future (Hawkins, pers. comm. 2008 Univ. of AZ).

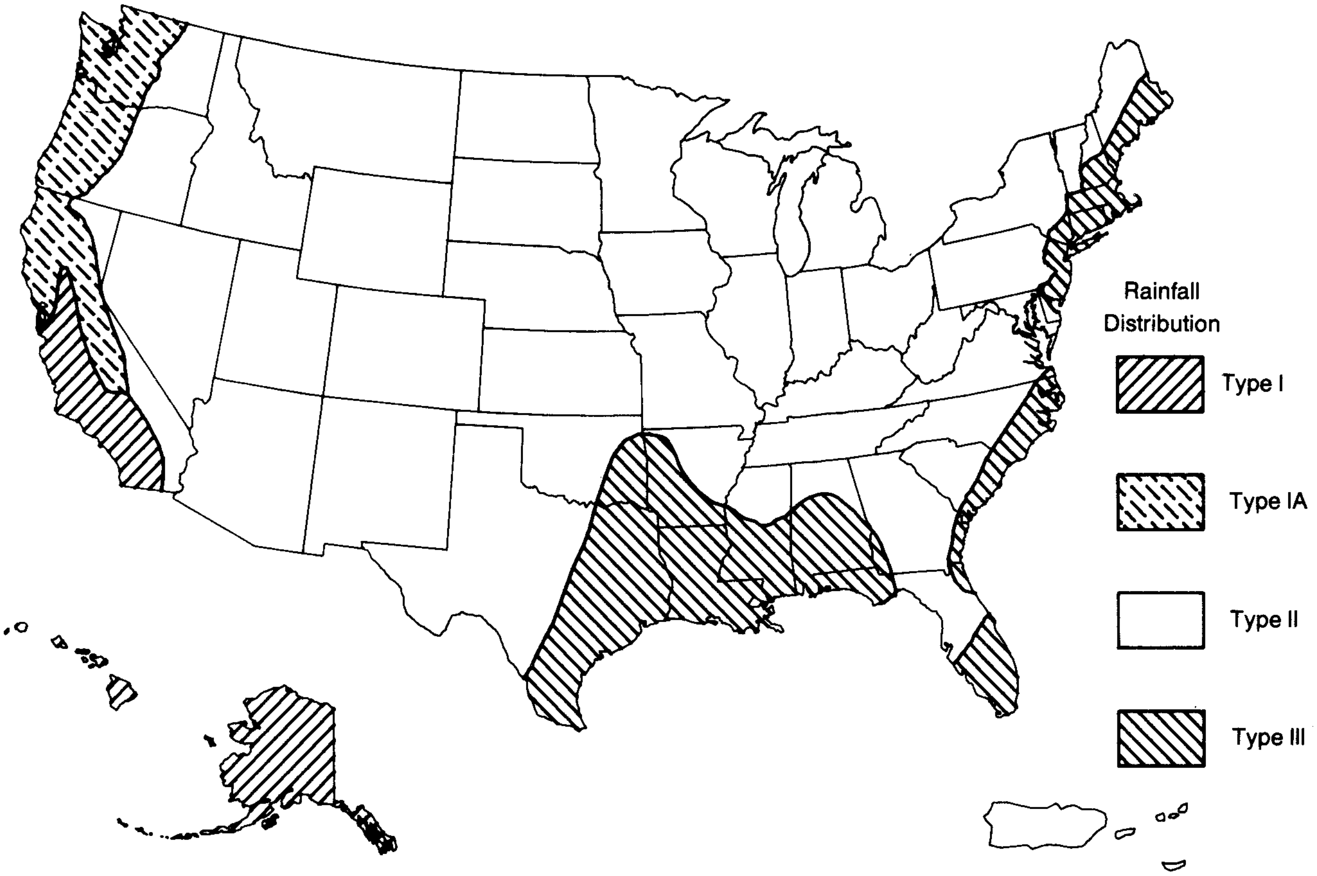
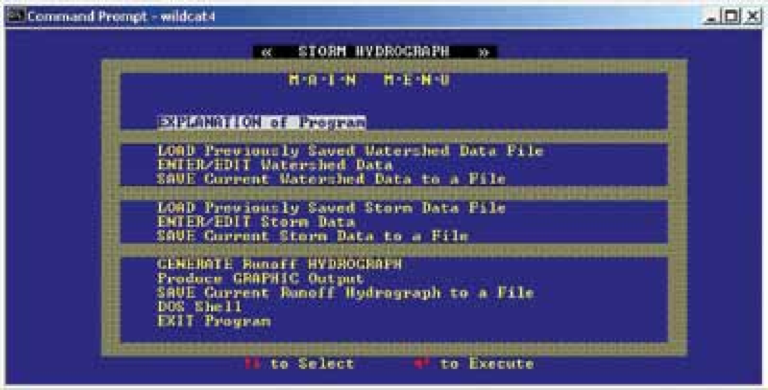
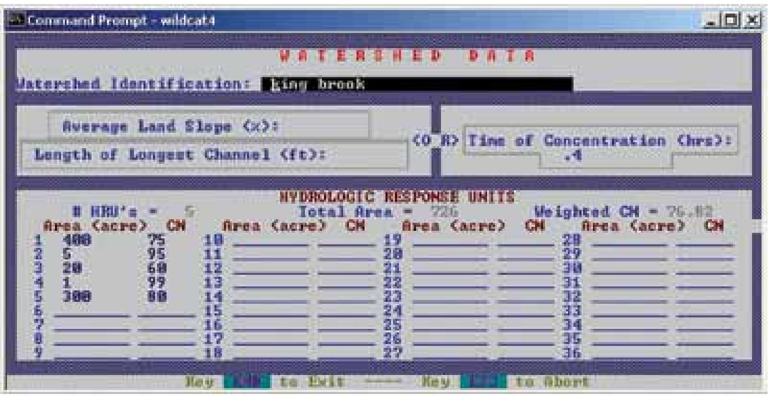


Figure 4—Approximate geographic boundaries for SCS rainfall distributions (USDA SCS 1991).



```
«   STORM HYDROGRAPH   »
    M·A·I·N  M·E·N·U

EXPLANATION of Program

LOAD Previously Saved Watershed Data File
ENTER/EDIT Watershed Data
SAVE Current Watershed Data to a File

LOAD Previously Saved Storm Data File
ENTER/EDIT Storm Data
SAVE Current Storm Data to a File

GENERATE Runoff HYDROGRAPH
Produce GRAPHIC Output
SAVE Current Runoff Hydrograph to a File
DOS Shell
EXIT Program

      ↑↓ to Select        ↵ to Execute
```

Figure 5—WILDCAT4 main menu screen.

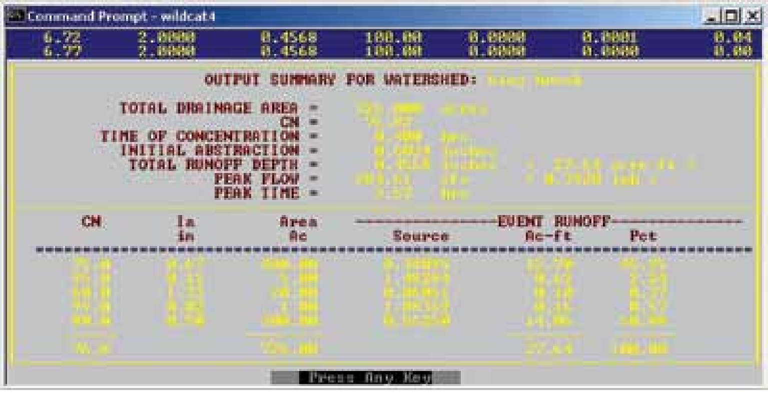


```
                       W A T E R S H E D   D A T A
Watershed Identification: king brook

   Average Land Slope (%):
 Length of Longest Channel (ft):        <O R> Time of Concentration (hrs):
                                                      .4

                       HYDROLOGIC RESPONSE UNITS
    # HRU's =   5          Total Area =  726         Weighted CN = 76.82
  Area (acre)  CN   Area (acre)  CN   Area (acre)  CN   Area (acre)  CN
1  400        75   10 ____  ____   19 ____  ____   28 ____  ____
2  5          95   11 ____  ____   20 ____  ____   29 ____  ____
3  20         60   12 ____  ____   21 ____  ____   30 ____  ____
4  1          99   13 ____  ____   22 ____  ____   31 ____  ____
5  300        80   14 ____  ____   23 ____  ____   32 ____  ____
6 ____      ____   15 ____  ____   24 ____  ____   33 ____  ____
7 ____      ____   16 ____  ____   25 ____  ____   34 ____  ____
8 ____      ____   17 ____  ____   26 ____  ____   35 ____  ____
9 ____      ____   18 ____  ____   27 ____  ____   36 ____  ____
            Key      to Exit  -----  Key      to Abort
```

Figure 6—WILDCAT4 watershed data screen.

```
                         S T O R M     D A T A
Storm Identification:

Storm Duration (hours)   6           Storm Distribution     5
                                     1=SCS Type II    2=Parmer-Fletcher
Storm Rainfall (inches)   2          3=Uniform    4=Custom    5=Generic

              GENERIC STORM DISTRIBUTION CHARACTERSITCS

      Minimum Storm Intensity (% of mean)                  10
      Maximum Storm Intensity (% of mean)                  500
      Time of Maximum Intensity (% of storm duration)      50

             Key        to Exit  -----  Key        to Abort
```

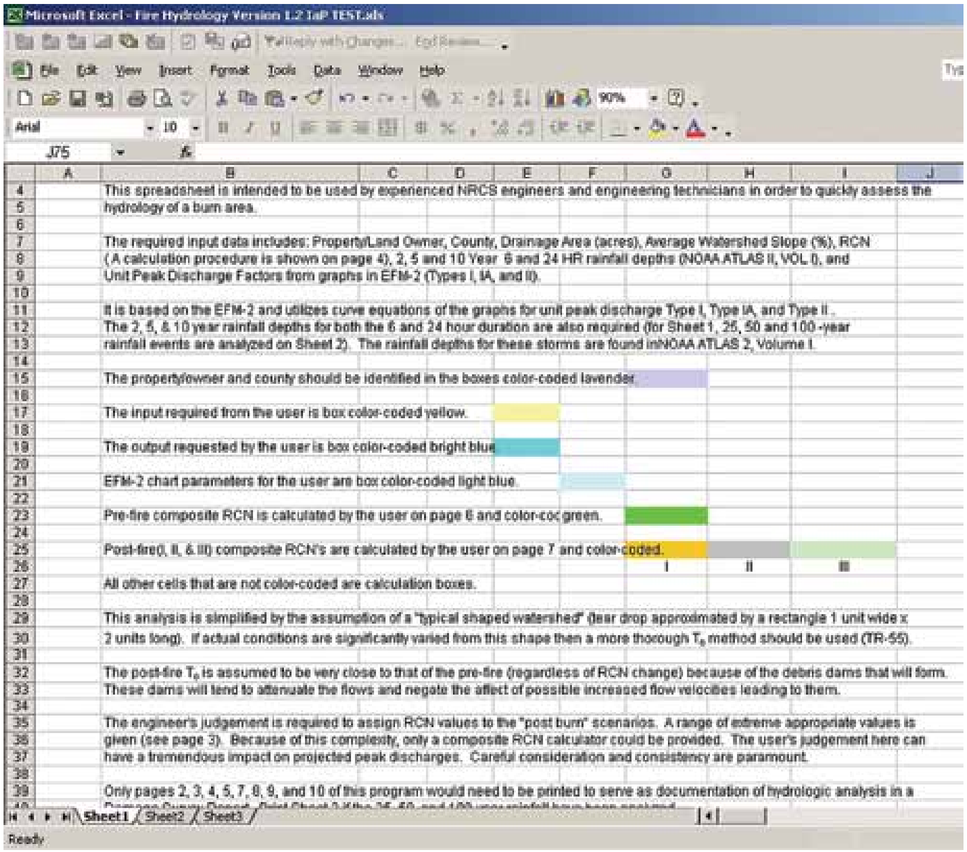
Figure 7—WILDCAT4 storm data screen.



```
  6.72       2.0000       0.4568      100.00      0.0000       0.0001          0.04
  6.77       2.0000       0.4568      100.00      0.0000       0.0000          0.00

                    OUTPUT SUMMARY FOR WATERSHED:

           TOTAL DRAINAGE AREA =
                            CN =
        TIME OF CONCENTRATION =
          INITIAL ABSTRACTION =
           TOTAL RUNOFF DEPTH =
                    PEAK FLOW =
                    PEAK TIME =

     CN          Ia          Area     ---------------EVENT RUNOFF---------------
                 in           Ac            Source         Ac-ft        Pct
  ===========================================================================

                         Press Any Key
```

Figure 8—WILDCAT 4 summary output screen.

Cerrelli (2005) developed a spreadsheet, called FIRE HYDRO, to assist NRCS and Forest Service personnel in estimating design peak flows for the burned areas of Montana. The FIRE HYDRO is a peak flow analysis tool for the 2-, 5-, 10-, 25-, 50-, and 100-year, 24-hour rainfall runoff events for the pre- and post-fire conditions. The required input data includes the following: drainage area (acre); average watershed slope (%); CN; and 2- to 100-year, 6- and 24-hour rainfall depths that are available from the NOAA web site (2008). The 6- and 24-hour rainfall depths are required to determine the SCS rainfall distribution type (Type I, IA, II, or III) (fig. 4). Most of Region 1, including Montana, has Type II, which produce the highest peak flow among the SCS rainfall distribution types. The FIRE HYDRO spreadsheets are shown in figures 9 through 11. Cerrelli (2005) assumed that the runoff Curve Numbers of *bare soil* cover type or *poor* hydrologic condition were used for post-fire conditions. However, there is no clear guideline to choose post-fire runoff Curve Numbers. The FIRE HYDRO is applicable for 24-hour rainfall events only, and is not applicable for short duration rainfall events such as a 1-hour storm or less.



This spreadsheet is intended to be used by experienced NRCS engineers and engineering technicians in order to quickly assess the hydrology of a burn area.

The required input data includes: Property/Land Owner, County, Drainage Area (acres), Average Watershed Slope (%), RCN (A calculation procedure is shown on page 4), 2, 5 and 10 Year 6 and 24 HR rainfall depths (NOAA ATLAS II, VOL I), and Unit Peak Discharge Factors from graphs in EFM-2 (Types I, IA, and II).

It is based on the EFM-2 and utilizes curve equations of the graphs for unit peak discharge Type I, Type IA, and Type II. The 2, 5, & 10 year rainfall depths for both the 6 and 24 hour duration are also required (for Sheet 1, 25, 50 and 100-year rainfall events are analyzed on Sheet 2). The rainfall depths for these storms are found inNOAA ATLAS 2, Volume I.

The property/owner and county should be identified in the boxes color-coded lavender.

The input required from the user is box color-coded yellow.

The output requested by the user is box color-coded bright blue

EFM-2 chart parameters for the user are box color-coded light blue.

Pre-fire composite RCN is calculated by the user on page 6 and color-coc green.

Post-fire(I, II, & III) composite RCN's are calculated by the user on page 7 and color-coded.

I II III

All other cells that are not color-coded are calculation boxes.

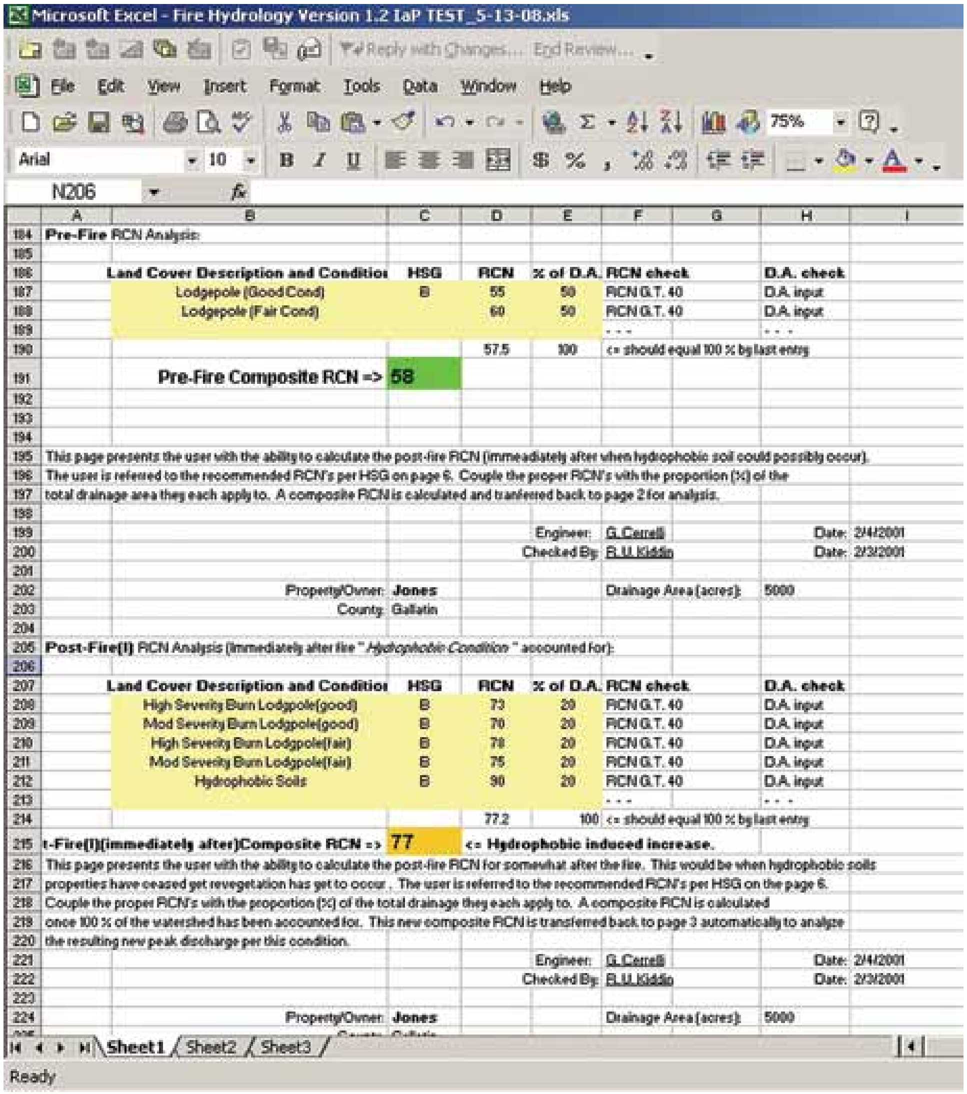
This analysis is simplified by the assumption of a "typical shaped watershed" (tear drop approximated by a rectangle 1 unit wide x 2 units long). If actual conditions are significantly varied from this shape then a more thorough T_c method should be used (TR-55).

The post-fire T_c is assumed to be very close to that of the pre-fire (regardless of RCN change) because of the debris dams that will form. These dams will tend to attenuate the flows and negate the affect of possible increased flow velocities leading to them.

The engineer's judgement is required to assign RCN values to the "post burn" scenarios. A range of extreme appropriate values is given (see page 3). Because of this complexity, only a composite RCN calculator could be provided. The user's judgement here can have a tremendous impact on projected peak discharges. Careful consideration and consistency are paramount.

Only pages 2, 3, 4, 5, 7, 8, 9, and 10 of this program would need to be printed to serve as documentation of hydrologic analysis in a

Figure 9—Explanatory section of FIRE HYDRO (Cerrelli 2005), an EXCEL spreadsheet to assist to estimate peak flows for the burned areas of Montana.



Pre-Fire RCN Analysis:

Land Cover Description and Conditio	HSG	RCN	% of D.A.	RCN check	D.A. check
Lodgepole (Good Cond)	B	55	50	RCN G.T. 40	D.A. input
Lodgepole (Fair Cond)		60	50	RCN G.T. 40	D.A. input
				- - -	- - -
		57.5	100	<= should equal 100 % by last entry	

Pre-Fire Composite RCN => 58

This page presents the user with the ability to calculate the post-fire RCN (immeadiately after when hydrophobic soil could possibly occur). The user is referred to the recommended RCN's per HSG on page 6. Couple the proper RCN's with the proportion (%) of the total drainage area they each apply to. A composite RCN is calculated and tranfered back to page 2 for analysis.

Engineer: G.Cerrelli Date: 2/4/2001
Checked By: R.U.Kiddin Date: 2/3/2001

Property/Owner: **Jones** Drainage Area (acres): 5000
County: Gallatin

Post-Fire(I) RCN Analysis (immediately after fire "*Hydrophobic Condition*" accounted for):

Land Cover Description and Conditio	HSG	RCN	% of D.A.	RCN check	D.A. check
High Severity Burn Lodgpole(good)	B	73	20	RCN G.T. 40	D.A. input
Mod Severity Burn Lodgpole(good)	B	70	20	RCN G.T. 40	D.A. input
High Severity Burn Lodgpole(fair)	B	78	20	RCN G.T. 40	D.A. input
Mod Severity Burn Lodgpole(fair)	B	75	20	RCN G.T. 40	D.A. input
Hydrophobic Soils	B	90	20	RCN G.T. 40	D.A. input
				- - -	- - -
		77.2	100	<= should equal 100 % by last entry	

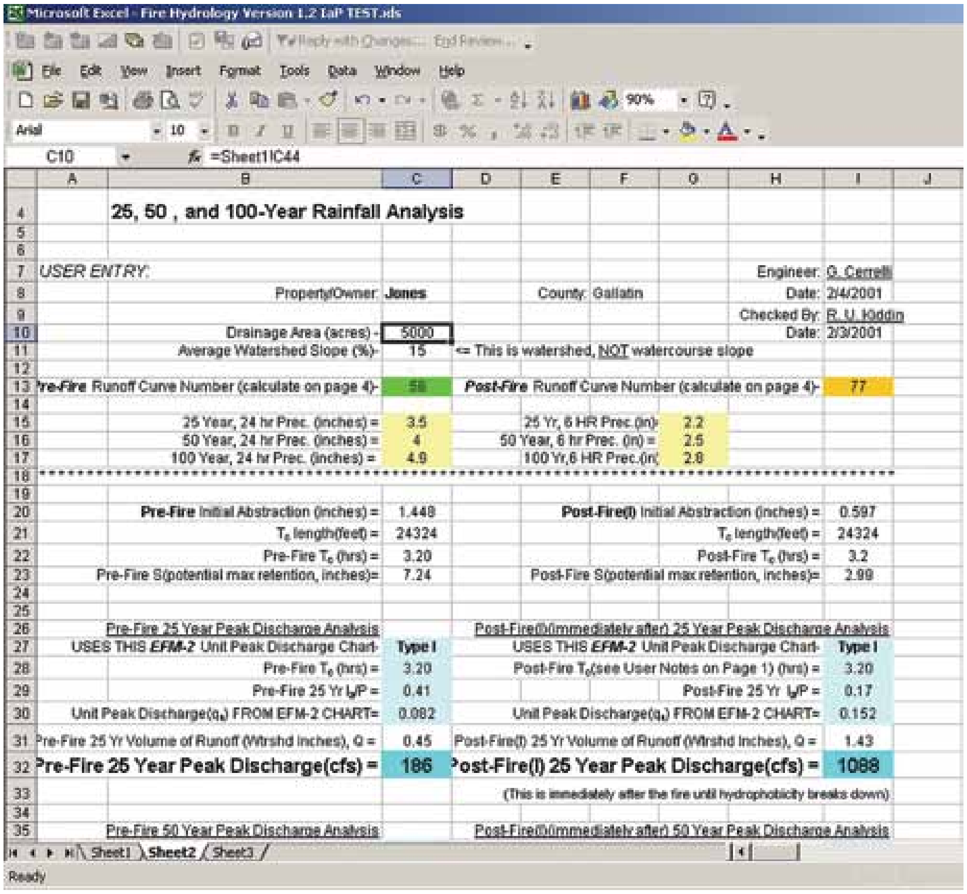
t-Fire(I)(immediately after)Composite RCN => 77 <= Hydrophobic induced increase.

This page presents the user with the ability to calculate the post-fire RCN for somewhat after the fire. This would be when hydrophobic soils properties have ceased yet revegetation has yet to occur. The user is referred to the recommended RCN's per HSG on the page 6. Couple the proper RCN's with the proportion (%) of the total drainage they each apply to. A composite RCN is calculated once 100 % of the watershed has been accounted for. This new composite RCN is transferred back to page 3 automatically to analyze the resulting new peak discharge per this condition.

Engineer: G.Cerrelli Date: 2/4/2001
Checked By: R.U.Kiddin Date: 2/3/2001

Property/Owner: **Jones** Drainage Area (acres): 5000

Figure 10—Runoff Curve Number (CN) section of FIRE HYDRO (Cerrelli 2005), an EXCEL spreadsheet to assist to estimate peak flows for the burned areas of Montana.



	A–B	C	D–F	G	H	I
4	25, 50 , and 100-Year Rainfall Analysis					
5						
6						
7	USER ENTRY:				Engineer:	G. Cerrelli
8	Property/Owner:	Jones	County: Gallatin		Date:	2/4/2001
9					Checked By:	R. U. Kiddin
10	Drainage Area (acres) -	5000			Date:	2/3/2001
11	Average Watershed Slope (%)-	15	<= This is watershed, NOT watercourse slope			
12						
13	**Pre-Fire** Runoff Curve Number (calculate on page 4)-	58	***Post-Fire*** Runoff Curve Number (calculate on page 4)-			77
14						
15	25 Year, 24 hr Prec. (inches) =	3.5	25 Yr, 6 HR Prec.(in)=	2.2		
16	50 Year, 24 hr Prec. (inches) =	4	50 Year, 6 hr Prec. (in) =	2.5		
17	100 Year, 24 hr Prec. (inches) =	4.9	100 Yr,6 HR Prec.(in(	2.8		
18	**					
19						
20	**Pre-Fire** Initial Abstraction (inches) =	1.448			**Post-Fire(I)** Initial Abstraction (inches) =	0.597
21	T_c length(feet) =	24324			T_c length(feet) =	24324
22	Pre-Fire T_c (hrs) =	3.20			Post-Fire T_c (hrs) =	3.2
23	Pre-Fire S(potential max retention, inches)=	7.24			Post-Fire S(potential max retention, inches)=	2.99
24						
25						
26	Pre-Fire 25 Year Peak Discharge Analysis		Post-Fire(I)(immediately after) 25 Year Peak Discharge Analysis			
27	USES THIS ***EFM-2*** Unit Peak Discharge Chart-	**Type I**	USES THIS ***EFM-2*** Unit Peak Discharge Chart-			**Type I**
28	Pre-Fire T_c (hrs) =	3.20	Post-Fire T_c(see User Notes on Page 1) (hrs) =			3.20
29	Pre-Fire 25 Yr I_a/P =	0.41			Post-Fire 25 Yr I_a/P =	0.17
30	Unit Peak Discharge(q_u) FROM EFM-2 CHART=	0.082	Unit Peak Discharge(q_u) FROM EFM-2 CHART=			0.152
31	Pre-Fire 25 Yr Volume of Runoff (Wtrshd Inches), Q =	0.45	Post-Fire(I) 25 Yr Volume of Runoff (Wtrshd Inches), Q =			1.43
32	**Pre-Fire 25 Year Peak Discharge(cfs) =**	**186**	**Post-Fire(I) 25 Year Peak Discharge(cfs) =**			**1088**
33			(This is immediately after the fire until hydrophobicity breaks down)			
34						
35	Pre-Fire 50 Year Peak Discharge Analysis		Post-Fire(I)(immediately after) 50 Year Peak Discharge Analysis			

Figure 11—Input and output section showing pre-fire and post-fire peak flow of FIRE HYDRO (Cerrelli 2005), an EXCEL spreadsheet to assist to estimate peak flows for the burned areas of Montana. The 5,000 acre drainage area had a pre-fire 25-year peak flow of 186 cfs with a CN of 58 and post-fire peak flow of 1,088 cfs with a CN of 77, calculated from figure 9.

Discussion

There are limited numbers of studies that provide post-fire runoff Curve Numbers. Springer and Hawkins (2005) attempted to provide a guideline to choosing post-fire runoff Curve Numbers based on the 2000 Cerro Grande Fire in New Mexico, and concluded that "*the post-fire trends in CN and peak flows are not readily explained and will be a topic of future research.*"

Livingston and others (2005) provided a guideline to choose the post-fire runoff numbers with a range of values as seen in table 14. They used computed CNs and compared pre-and post-fire CNs for 31 small (0.12 to 2.5 mi^2) subbasins in the Los Alamos area, New Mexico, and 24 small (0.11 to 2.3 mi^2) subbasins affected by the 2002 Long Mesa Fire at Mesa Verde National Park, Colorado. To classify the soil burn severity of the whole watershed/basin, they used Wildfire Hydrologic Impact (WHI), based on the percentage of high and moderate soil burn severity (table 15 and fig. 12) and a general relation between pre- and post-fire CN ratio (fig. 13). Post-fire runoff CN can be estimated using

Table 14—Post-fire curve numbers (CNs) for various burn severities (Livingston and others 2005).

Soil burn severity	Estimated CN
Unburned	55 to 75
Low	80 to 83
Moderate, without water repellent soils	87
Moderate, with water repellent soils	89
High, without water repellent soils	92
High, with water repellent soils	95

Table 15—Variations in Wildfire Hydrologic Impact (WHI) classification due to high soil burn severity (Livingston and others 2005).

Percentage of subbasins with a high soil burn severity	Wildfire Hydrologic Impact classification
0-6	Low
7-48	Moderate
49-80	Severe

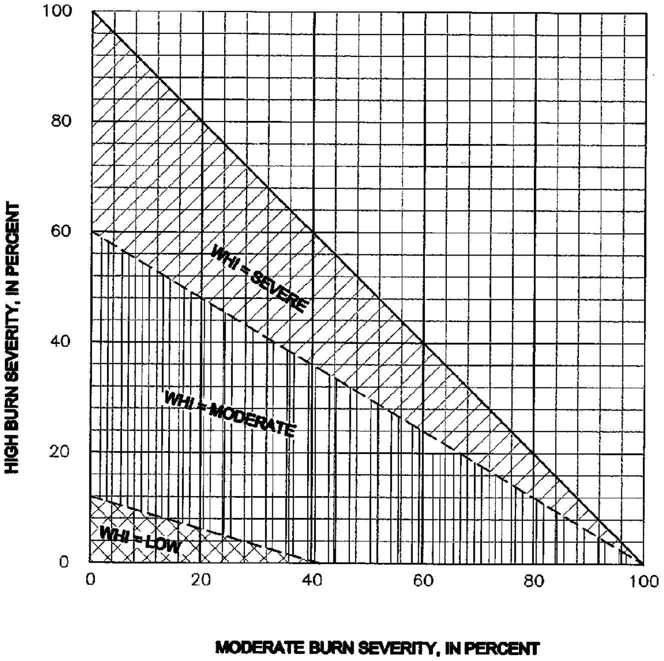


Figure 12—Wildfire Hydrologic Impact (WHI) for small burned subbasins as a function of soil burn severity (Livingston and others 2005).

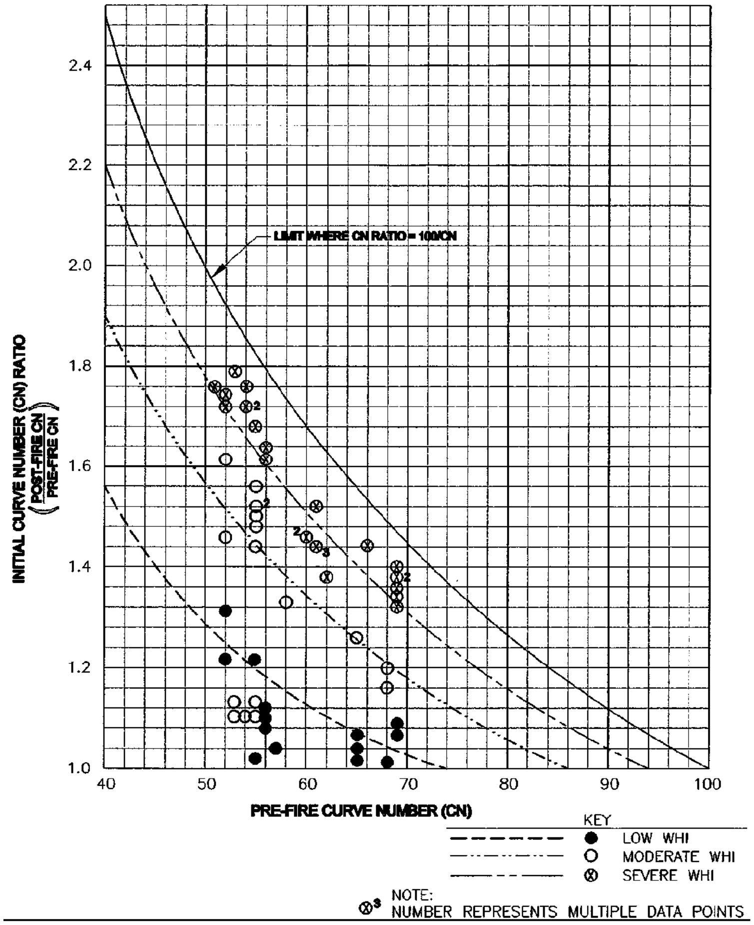


Figure 13—General relation between pre- and initial post-fire curve number (CN) ratio for indicated Wildfire Hydrologic Impact (Livingston and others 2005).

Table 16—Post-fire Curve Numbers (CNs) for various burn severities based on the Bitterroot National Forest, Montana (Cerrelli 2005).

Soil burn severity	Sub-category	Estimated CN
High[a]	HSG[b] A	64
	HSG B	78
	HSG C	85
	HSG D	88
Moderate		Use cover type[c] in Fair condition
Low and Unburned	North and East facing slopes	Use cover type in Good condition
	South and West facing slopes	Use cover type between Fair and Good conditions
Any	Water repellent soils	94[d]

[a] High burn severity areas were assumed to have attained at least 30% ground cover consisting of vegetation, duff, thick ash, or woody debris by June of the following year after the fire, and the CN values were from three Montana NRCS engineers with hydrologic evaluation experience.

[b] Hydrologic Soil Group in table 13.

[c] From table D.2 and D.3 in Appendix D.

[d] Rule of thumb by Montana NRCS.

figure 13 if pre-fire CN is known. Pre-fire CN should be determined by users using various sources such as table D.2 and D.3 in Appendix D. Their study results are applicable to the Los Alamos area and other areas in the southwest with similar pre-fire CN values and hydrology; however, they are less applicable to areas with different pre-fire rainfall and runoff characteristics.

An experienced BAER team member in Region 1 suggested using a CN of 90 to 95 for high soil burn severity without water repellent soils and 93 to 98 for high soil burn severity with water repellent soils (2003 USDA Forest Service). The Livingston CN values are within the range suggested by Story.

Cerrelli (2005) provided a guideline to select post-fire CN based on burn severity and hydrologic soil grouping specific to the Bitterroot National Forest wildfires (table 16). He did not find appropriate CNs in his initial search of the literature for CN values for burned areas in southwestern Montana. Consequently, Montana NRCS engineers created a guideline based on the existing NRCS CN/land use table (e.g., table D.2 and D.3). However, no gaging or calibrating took place to verify or improve this guideline. The 2-year to 5-year, 24-hour storm events occurred in the following spring and summer. Runoff from these storm events did not cause failure of the BAER treatments assessed and implemented using this CN guideline (Cerrelli 2005).

Since there are very limited studies and guidelines for choosing CNs for post-fire conditions, BAER team members often use simple rules of their own. Details on these rules are found in the *NRCS CN Methods* section. For example, in the Salt Creek BAER Hydrology Special Report (Higginson and Jarnecke 2007), they used the following rules to determine post-fire CNs.

- High burn severity CN = pre-fire CN + 15
- Moderate burn severity CN = pre-fire CN + 10
- Low burn severity CN = pre-fire CN + 5
- Maximum CN value is 100

Once the user has determined CNs for each HRU within a watershed, the problem arises of how to combine them. CNs and runoff depth are not linearly related (Grove and others 1998). A weighted average of all CNs in a watershed is commonly used to reduce the number of calculations, which is an assumption that CNs and runoff are linearly related. The underestimation of runoff using weighted average CNs is most severe for wide CN ranges, as would occur in watersheds containing low and high severity burns. Low CN values and low precipitation depths, as would occur in unburned southwestern watersheds, would result in underestimation of runoff. Therefore, care should be exercised when applying weighted average CNs.

Another approach is to use distributed CNs in a GIS application. However, White (1988) and Stuebe and Johnson (1990) reported that using distributed CNs resulted in as much as 100 percent higher runoff than using weighted average CNs.

The preferred method to estimate runoff from watersheds with different CNs is to combine runoff amounts from each HRU.

Advantages

The following were advantages to applying the NRCS CN methods for post-fire runoff and erosion estimation.

- NRCS CN methods are applicable for input to methods that calculate peak flow.
- Two CN methods and models (WILDCAT4 and FIRE HYDRO) are available for post-fire application.
- WILDCAT4 considers shorter-duration storms (e.g., 15-minute) to 24-hour storm duration, which is adequate for the regions where the damaging storm is short duration, such as 15 or 30 minutes.

Disadvantages

The following were disadvantages to applying the NRCS CN methods for post-fire runoff and erosion estimation.

- NRCS CN methods do not estimate erosion.
- NRCS CN methods do not consider post-fire debris flow/torrent.
- NRCS CN methods are applicable to smaller watersheds, which are less than 5 mi^2.
- The FIRE HYDRO method only considers 24-hour storm duration.
- The user must determine pre-fire and post-fire CN that is a sensitive parameter; therefore, the estimated peak flow is subjective to users.
- There are no guidelines to determine post-fire CN except in Regions 1 and 3.
- There is difficulty in combining runoff from areas of different CNs within a watershed. Instead, users interchangeably use a weighted average of all CNs in a watershed.
- The NRCS CN methods will likely underestimate runoff when applying weighted average of CNs for high burn severity area in arid weather conditions.
- The NRCS CN methods use English units only.

Example

The Blackerby Fire on the Nez Perce National Forest near Grangeville, Idaho, occurred in August 2005. On 19 May 2006 a 0.79-inch precipitation event with a 30-minute duration occurred over a portion of the burned area. The precipitation event was equivalent to a 25-year, 30-minute storm event as determined from the NOAA Atlas 2 (Miller and others 1973b).

The NRCS CN flood flow model results used in the BAER analysis (using FIRE HYDRO) were for a 25-year return event and based on the assumption of limited soil and vegetation regeneration during the first year after the fire. The observed flood discharge value was 71 cfs, or 56 cfsm (cfs mi^{-2}). This observed flood discharge was half that of predicted flow. Additionally, the observed debris flow discharge was 620 cfs, or 492 cfsm, indicating that debris flow discharge was nearly an order of magnitude greater than the flood discharge. Details of the results can be found in the *NRCS CN Methods* section.

Detailed information on how to use the NRCS Curve Number methods can be found in Appendix D.

Rule of Thumb by Kuyumjian

The Rule of Thumb by Kuyumjian has been used by Region 3 BAER team members, or about 7% of BAER interviewees (table 8).

Experienced BAER team members often use their own rule of thumb, which they developed based on their experience and post-fire monitoring/observation and works well within certain regions. An experienced BAER hydrologist (Kuyumjian, pers. comm. 2007 USDA Forest Service) suggested using the following rule of thumb, which requires a minimal amount of input information.

Input Requirements

To use the Rule of Thumb by Kuyumjian, the following information is required:

- area of high and moderate soil burn severity and
- anticipated precipitation amount from a damaging storm.

How to Use

There are two steps to apply the Rule of Thumb by Kuyumjian for estimating post-fire peak flow:

1. Determine the design/damaging storm, including storm intensity, duration, and recurrence interval.
2. Estimate the post-fire peak flow (Q_p) using the following relationship:

$$Q_p = 300 \times A_s \times I \times 1.25 \qquad \text{(Eq. 2)}$$

where

Q_p = peak flow in cfs;
I = precipitation intensity in inch/hour;
A_s = size of high and moderate burn severity area in mi^2; and
1.25 = bulking factor.

Discussion

The Rule of Thumb by Kuyumjian is similar to the rainfall-discharge relation that was determined for 31 data pairs in 2001 and 17 data pairs in 2002 from seven sub-watersheds in the Rendija Canyon watershed after the 2000 Cerro Grande Fire (Moody and others 2007). About 82% of the Rendija Canyon watershed was severely burned. Their analysis was based on the change in the normalized burn ratio (ΔNBR; Key and Benson 2006), which incorporates reflectance measurements from Landsat imagery and was designed to measure the fire effects on vegetation and soil characteristics. Watersheds with 581 ± 5% can be categorized as high or moderate-high burn severity (Cocke and others 2005; Key and Benson 2006). The rainfall-discharge relation was:

$$Q_u^{peak} = b \cdot \left(I_{30} - I_{30}^{thresh} \right) \qquad \text{(Eq. 3)}$$

where

Q_u^{peak} = peak flow per unit area (inch h^{-1});
b = unit-less constant;
I_{30} = 30 minutes rainfall intensity (inch h^{-1}); and
I_{30}^{thresh} = the largest value of I_{30} below which no surface flow occurs (inch h^{-1}).

Moody and others (2007) reported b and I_{30}^{thresh} values as shown in table 17. The rainfall-discharge relation can be used to compare the Rule of Thumb by Kuyumjian. Using combined b and I_{30}^{thresh} values from table 17, assuming I_{30} »8.5 mm h^{-1} (0.33 inch h^{-1}) and the entire drainage area was high severity burn area, equation 3 can be reduced to:

$$Q^{peak} = 303 \text{ x } A_s \text{ x } I_{30} \qquad \text{(Eq. 4)}$$

This is very close to the rule of thumb by Kuyumjian without the bulking factor of 1.25.

Table 17—*b* and I_{30}^{thresh} values in the rainfall-discharge relation from the Rendija Canyon watershed after the 2000 Cerro Grande Fire, New Mexico (Moody and others 2007).

Year	b	I_{30}^{thresh}	r^2	p
		(mm h^{-1})		
2001	0.50	7.6	0.73	<0.001
2002	0.43	11.1	0.52	0.001
2001 and 2002[a]	0.47	8.5	0.63	<0.001

[a] The values of *b* and I_{30}^{thresh} in 2001 and 2002 are not significantly different. Therefore, they were combined.

Advantages

The following were advantages to applying the Rule of Thumb by Kuyumjian for post-fire runoff and erosion estimation. The Rule of Thumb by Kuyumjian:

- is applicable for estimating post-fire peak flow;
- is a simple and quick approximation;
- does not need to determine parameter values; and
- considers bulking factor for post-fire debris flow/torrent.

Disadvantages

The following were disadvantages to applying the rule of thumb by Kuyumjian for post-fire runoff and erosion estimation. The Rule of Thumb by Kuyumjian:

- does not estimate erosion;
- is only applicable for short-duration (1 hour or less) high intensity (greater than 0.5 inches) storms;
- is not applicable for estimating peak flow from snowmelt or rain-on-snow or frozen ground;
- currently evaluated only for Region 3; and
- uses English units only.

Example

Approximately 4.8 mi^2 of the Rendija Canyon watershed was burned by the 2000 Cerro Grande Fire: 82% at high severity, 10% at moderate severity, 6% at low severity, and 2% was unburned (Gallaher and Koch 2004). Seven subwatersheds were monitored for rainfall intensity and discharge in 2001 and 2002 (Moody and others 2007). Four subwatersheds had 581 ± 5% of ΔNBR value that was considered high or moderate-high burn severity (Cocke and others 2005; Key and Benson 2006).

Assuming the entire drainage area was high severity burn area, peak flow per unit drainage area (cfs mi^{-2}) can be calculated based on rainfall intensity that is greater than 0.5 inches. The Rule of Thumb by Kuyumjian estimated less than half (47%) of the peak flows were within ± 50% of observed values (table 18), which can be from uncertainty associated with discharge and rainfall intensity measurements or natural variation that the rule of thumb cannot consider.

Table 18—Comparison of observed and estimated peak flow using the Rule of Thumb by Kuyumjian from various rainfall intensities (>0.5 inch h^{-1}) for 2001 in four high severity burn subwatersheds of Rendija Canyon after the 2000 Cerro Grande Fire, New Mexico (Moody and others 2007).

			Peak flow per unit drainage area	
Watershed	Date	Rainfall intensity I_{30}	Observed	Estimated by Rule of Thumb[a]
		(inch h^{-1})	- - - - -(cfs mi^{-2})- - - - -	
3	2 Jul	2.07	686	622
3	13 Jul	0.88	151	263
3	9 Aug	1.50	405	449
9	2 Jul	0.90	41	269
9	26 Jul	1.45	777	435
9	9 Aug	0.59	28	177
9	11 Aug	0.90	154	270
11	2 Jul	1.69	461	508
11	26 Jul	1.30	333	389
11	11 Aug	1.28	333	384
13	2 Jul	0.65	65	195
13	2 Jul	1.13	182	339
13	2 Jul	1.10	43	331
13	11 Jul	0.73	39	219
13	11 Aug	1.28	264	384

[a] Bulking factor is not considered only to compare observed peak flow.

TR-55

Seven of the BAER team members used TR-55 to calculate post-fire runoff increase (table 8).

The TR-55 requires the runoff Curve Number (CN) as an input parameter; therefore, it can be considered as a Curve Number method. The TR-55 was released as a simplified procedure to calculate the storm runoff volume, peakflow rate, hydrograph, and storage volume for storm water management structures in small watersheds in urban areas, assuming the NRCS Type II rainfall distribution for all calculations (USDA SCS 1975). Later, a major revision was made to improve the model by adding three more rainfall distributions (Type I, IA, and III; fig. 4), programming the computations, and estimating time of concentration using split separate flow phases (USDA SCS 1986).

Input Requirements

Required input data is as follows (USDA NRCS 2005b):

- identification data;
- dimensionless unit hydrograph;
- storm data;
- rainfall distribution;
- area;
- Runoff Curve Number (CN); and
- time of concentration details.

Program Availability

The current version of TR-55 computer model is WinTR-55, which was revised and completely rewritten. It uses the TR-20 model (USDA NRCS 2005a), a NRCS storm event surface water hydrologic model applied at a watershed scale, as the driving engine for all the hydrograph procedures (USDA NRCS 2005b).

WinTR-55 is a single-event, rainfall-runoff hydrologic model for small watersheds with multiple sub-areas that are homogeneous. It generates hydrographs from urban and agricultural areas and the generated hydrographs are routed downstream through channels or reservoirs.

Discussion

WinTR-55 model can be run in either English or Metric units. The WINTR-55 model and related documents are available at the NRCS web site http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html.

WinTR-55 model requires input data shown in table 19. For its applications on the BAER road treatments, the TR-55 should be run once for pre-fire watershed conditions and again for post-fire conditions.

Advantages

The following were advantages to applying the WinTR-55 for post-fire runoff and erosion estimation. WinTR55:

- is applicable for estimating peak flow;
- estimates time to peak;
- is applicable to larger watersheds, which are less than 25 mi^2; and
- uses both English and metric units.

Table 19—WinTR-55 variables and their ranges (USDA NRCSb 2005).

Variable	Range
Minimum area	No absolute minimum area. The user should carefully examine results from sub-area less than 1 acre.
Maximum area	25 mi^2 (6,500 ha)
Number of sub-watersheds	1 to 10
Time of concentration for any sub-area	0.1 hour $\le T_c \le$ 10 hour
Number of reaches	0 to 10
Type of reaches	Channel or structure
Reach routing	Muskingum–Cunge
Structure routing	Storage–indication
Structure types	Pipe or weir
Structural trial sizes	1 to 3
Rainfall depth	Default or user-defined 0 to 50 inches (0 to 1,270 mm)
Rainfall distributions	NRCS Type I, IA, II, III (fig. 4), NM60, NM65, NM70, NM75, or user-defined
Rainfall duration	24-hour
Dimensionless unit hydrograph	Standard peak rate factor 484, or user-defined

Disadvantages

The following were disadvantages to applying the WinTR-55 for post-fire runoff and erosion estimation. WinTR55:

- does not estimate erosion;
- does not consider post-fire debris flow/torrent;
- only considers 24-hour storm duration, so it is not applicable to the regions where the damaging storm duration is much shorter, such as 15 or 30 minutes;
- requires the user to determine pre-fire and post-fire CN that is a sensitive parameter, so the estimated peak flow is subjective to users; and
- does not provide guidelines to determine post-fire CN, except for Regions 1 and 3.

Example

The TR-55 model was used to estimate post-fire peak flows on the 2002 Bullock fire. Table 20 shows the analysis that was conducted. The “2-year post-fire equivalent” displays the corresponding flood level expected from a typical 2-year storm event.

Water Erosion Prediction Project (WEPP) Model: Erosion Risk Management Tool (ERMiT)

The ERMiT (Robichaud and others 2006, 2007), a FS WEPP Interface, has been used by the BAER team members (5%; table 8), primarily from Region 4.

The WEPP model was developed by an interagency group of scientists from the U.S. Department of Agriculture’s Agricultural Research Service, Forest Service, and Soil Conservation Service (currently Natural Resources Conservation Service); U.S. Department of Interior Bureau of Land Management; U.S. Geological Survey; and several university cooperators. The WEPP model predicts soil erosion and sediment delivery by water using stochastic weather

Table 20—Hydrological analysis 2-year, post-fire equivalent flood level using TR-55 for the 2002 Bullock Fire in the Coronado National Forest, Arizona (Lefevre and others 2002).

Site name	2-year post-fire equiv		Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
			-cfs-					
Bear Canyon: main canyon at highway		Pre	89	220	326	**535**[a]	668	847
	25	Post	**445**[a]	734	944	1,336	1,566	1,849
Bear Canyon: west canyon at highway		Pre	9	21	31	**50**	62	81
	25	Post	**38**	62	79	111	130	158
Willow Canyon summer home area at crossing		Pre	1	5	10	**27**	41	63
	25	Post	**18**	49	74	123	155	197
Rose Canyon campground at lower crossing		Pre	2	**9**	16	44	68	111
	5	Post	**10**	34	62	123	163	227
Barnum Rock at highway		Pre	0	1	2	6	9	**13**
	100+	Post	**17**	28	36	50	58	69
Sollers at highway		Pre	0	1	2	6	9	**15**
	100	Post	**12**	22	29	44	52	66
Sollers West at highway		Pre	0	2	3	8	12	**19**
	100	Post	**22**	36	45	63	74	90
Slide Area at highway		Pre	0	1	2	5	**8**	12
	50	Post	**9**	16	21	31	37	46
Slide Area West at highway		Pre	0	1	1	4	**6**	9
	50	Post	**5**	9	12	18	21	27
Incinerator Ridge East at highway		Pre	0	1	1	3	4	**6**
	100	Post	**7**	10	13	18	21	25
Incinerator Ridge at highway		Pre	0	1	1	4	**6**	9
	50	Post	**5**	10	13	20	24	31
Bear Willow summer home area		Pre	0	0	1	2	3	**4**
	100+	Post	**7**	11	13	17	20	23
Control Road at Green Springs		Pre	1	2	5	12	17	**26**
	100	Post	**30**	48	61	84	98	118
Marble Peak at Mine entrance		Pre	11	31	52	81	**102**	136
	50	Post	**103**	158	204	262	301	360
Lone Wolf Ranch at Eastern property line		Pre	15	35	**55**	83	103	135
	10	Post	**55**	93	128	173	202	246

[a] Bold numbers represent similar peakflows. For example, a 2-year post-fire, peakflow (445 cfs) is equivalent to a 25-year, pre-fire peakflow (535 cfs).

generation, infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics (Flanagan and Livingston 1995). The Forest Service WEPP (FS WEPP) Interfaces were developed by the U.S. Forest Service's Rocky Mountain Research Station, Soil and Water Engineering Research Work Unit, Moscow, Idaho (Elliot 2007). They are user-friendly, online tools for various forest applications, and consist of the following individual interfaces:

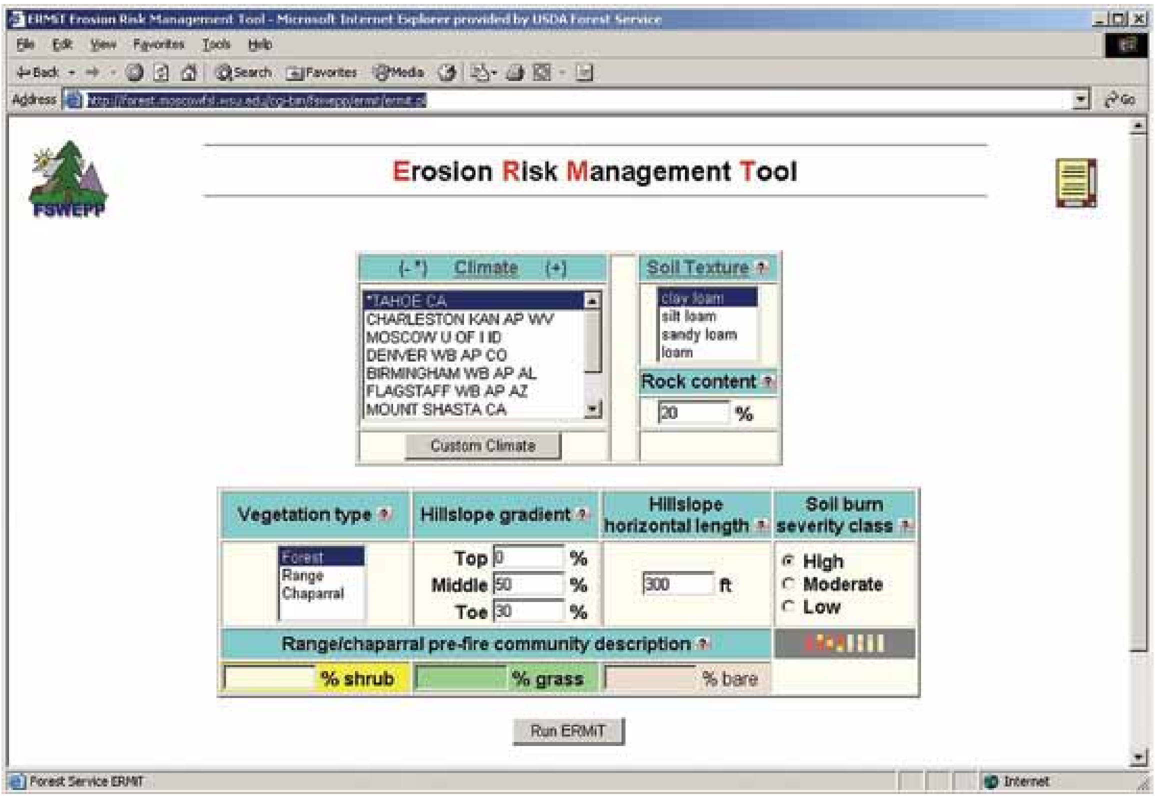
- Cross Drain: Predicts sediment yield from a road segment across a buffer.
- Rock:Clime: Creates and downloads a WEPP climate file.
- WEPP:Road: Predicts erosion from insloped or outsloped forest roads.

- WEPP:Road Batch: Predicts erosion from multiple insloped or outsloped forest roads.
- Disturbed WEPP: Predicts erosion from rangeland, forestland, and forest skid trails.
- Erosion Risk Management Tool (ERMiT): Predicts the probability associated with a given amount of soil erosion in each of 5 years following wildfire, and estimates effectiveness of various hillslope treatments.
- WEPP FuME (Fuel Management): Predicts soil erosion associated with fuel management practices, including prescribed fire, thinning, and a road network, and compares that prediction with erosion from wildfire.

Input Requirements

To use the ERMiT, the following information is required (fig. 14):

- climate
- soil texture, chosen among clay loam, silt loam, sandy loam, and loam
- rock content
- vegetation type, chosen among forest, range, and chaparral
- range/chaparral pre-fire community description, which can be defined by users if "range" or "chaparral" is selected for vegetation type
- hillslope gradient, which consists of top gradient, middle gradient, and toe gradient (the top and toe gradients each represent 10% of the hillslope length and the middle gradient represents 80% of the hillslope length)
- hillslope horizontal length
- soil burn severity, chosen among high, moderate, and low.



Address: http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl

Climate: *TAHOE CA; CHARLESTON KAN AP WV; MOSCOW U OF I ID; DENVER WB AP CO; BIRMINGHAM WB AP AL; FLAGSTAFF WB AP AZ; MOUNT SHASTA CA

Soil Texture: clay loam; silt loam; sandy loam; loam

Rock content: 20 %

Vegetation type: Forest; Range; Chaparral

Top 0 %
Middle 50 %
Toe 30 %

300 ft

● High
○ Moderate
○ Low

% shrub
% grass
% bare

Figure 14—ERMiT input screen (http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl).

Program Availability

The ERMiT is run from the web site (http://forest.moscowfsl.wsu.edu/fswepp/). Users can type and choose input information, and run ERMiT. The ERMiT reports rainfall event rankings and characteristics (including runoff), the exceedance probability associated with sediment delivery, and mitigation treatment comparisons (e.g., untreated, seeding, mulching with application rate of 0.5, 1, 1.5, and 2 ton/acre, erosion barriers, and contour-felled logs/straw wattles) (fig. 15).

Advantages

The following were advantages to applying the ERMiT for post-fire runoff and erosion estimation. ERMIT:

- is applicable for estimating post-fire erosion up to 5 years after the fire;
- identifies the damaging storm, which is often a short duration (less than 1 hour), high intensity storm;
- provides various outputs, such as the exceedance probability;
- is suitable for evaluating the effectiveness of various hillslope treatments (e.g., seeding, mulching, erosion barriers, and contour-felled logs/straw wattles);
- is user-friendly, easy to use, and on-line accessible;
- is process-based (i.e., applicable to any part of the United States and to other countries as long as the required climate information is available); and
- uses both English and metric units.

Disadvantages

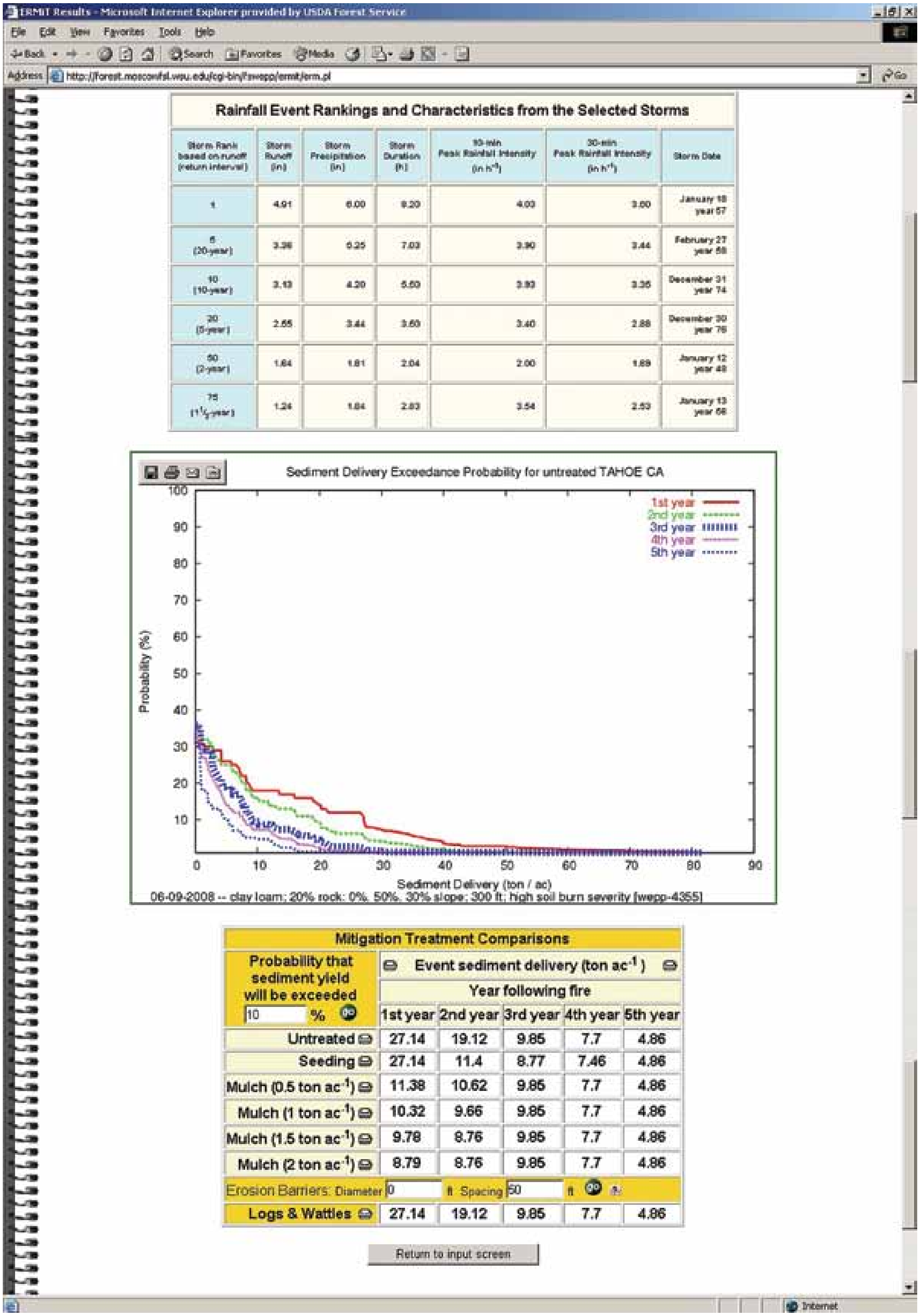
The following were disadvantages to applying the ERMiT for post-fire runoff and erosion estimation. ERMIT does not:

- estimate post-fire peak flow, so it is not adequate for prescribing post-fire road treatments;
- provide pre-fire runoff and erosion information, so it cannot compare pre- and post-fire changes;
- consider post-fire debris flow/torrent; and
- consider watershed shapes and assumes a rectangular hillslope, so ERMiT is difficult to apply for post-fire conditions at a watershed scale (>2 mi^2).

Recent developments now allow WEPP simulations using digital sources of information with Geographic Information Systems (GIS). This GIS wizard is called GeoWEPP (http://www.geog.buffalo.edu/~rensch/geowepp/), and it has been under development for forest conditions since about 2002 with funding from the Joint Fire Science Program (Renschler 2003; Renschler 2008). GeoWEPP will allow BEAR team members to model pre- and post-fire conditions at a watershed scale. See the GeoWEPP web site for current status of the program.

Example

The WEPP model was run to estimate 20 years of the pre- and post-fire runoff and erosion potential for the Red Eagle Fire in 2006. The results show more runoff events with greater risks of flood and erosion (table 21). The WEPP model predicted a dramatic increase in the number of rainfall and snowmelt runoff events from 2 and 0 for pre-fire conditions to 79 and 14 for post-fire conditions.



Rainfall Event Rankings and Characteristics from the Selected Storms

Storm Rank based on runoff (return interval)	Storm Runoff (in)	Storm Precipitation (in)	Storm Duration (h)	10-min Peak Rainfall Intensity (in h^{-1})	30-min Peak Rainfall Intensity (in h^{-1})	Storm Date
1	4.91	6.00	9.20	4.03	3.60	January 18 year 57
5 (20-year)	3.36	5.25	7.03	3.90	3.44	February 27 year 58
10 (10-year)	3.13	4.20	5.60	3.93	3.36	December 31 year 74
20 (5-year)	2.65	3.44	3.60	3.40	2.88	December 30 year 76
50 (2-year)	1.64	1.81	2.04	2.00	1.69	January 12 year 48
75 (1½-year)	1.24	1.84	2.83	3.54	2.53	January 13 year 68

Mitigation Treatment Comparisons

Probability that sediment yield will be exceeded 10 %	Event sediment delivery (ton ac^{-1})				
	Year following fire				
	1st year	2nd year	3rd year	4th year	5th year
Untreated	27.14	19.12	9.85	7.7	4.86
Seeding	27.14	11.4	8.77	7.46	4.86
Mulch (0.5 ton ac^{-1})	11.38	10.62	9.85	7.7	4.86
Mulch (1 ton ac^{-1})	10.32	9.66	9.85	7.7	4.86
Mulch (1.5 ton ac^{-1})	9.78	8.76	9.85	7.7	4.86
Mulch (2 ton ac^{-1})	8.79	8.76	9.85	7.7	4.86
Erosion Barriers: Diameter 0 ft Spacing 50 ft					
Logs & Wattles	27.14	19.12	9.85	7.7	4.86

Figure 15—ERMiT output screen. It reports rainfall event rankings and characteristics (including runoff), the exceedance probability associated with sediment delivery, and mitigation treatment comparisons.

Table 21—Runoff and erosion estimation using the WEPP model for the 2006 Red Eagle Fire, Montana (Sirucek and others 2006).

	Runoff	Soil erosion	Number of rainfall events	Number of snowmelt events
	(inch)	(tons ac^{-1})		
Pre-fire conditions	0.18	0.04	2	0
Post-fire conditions	3.08	127	79	14

Fire-Enhanced Runoff and Gully Initiation (FERGI) model

The FERGI model is used by 2% of the BAER team members in Region 4 (table 8).

The FERGI model was developed by the U.S. Forest Service, Rocky Mountain Research Station, Boise Aquatic Science Lab and is based on several scientific research papers (Istanbulluoglu and others 2002; Istanbulluoglu and others 2003; Istanbulluoglu and others 2004; Luce 2005; Luce and others 2005; Rajagopalan and Lall 1999; Rhodes 2005; Shakesby and others 2000). The FERGI model is a physically based mathematical description of hillslope hydrologic and geomorphic response to a set of weather events, and the model is applicable to any part of the western United States. FERGI estimates the probability of post-fire rainfall excess (mm), runoff generation amount (m^3 s^{-1} m^{-1}), and gully initiation positions (m) on hillslopes with and without mitigations using contour felled logs/log barriers.

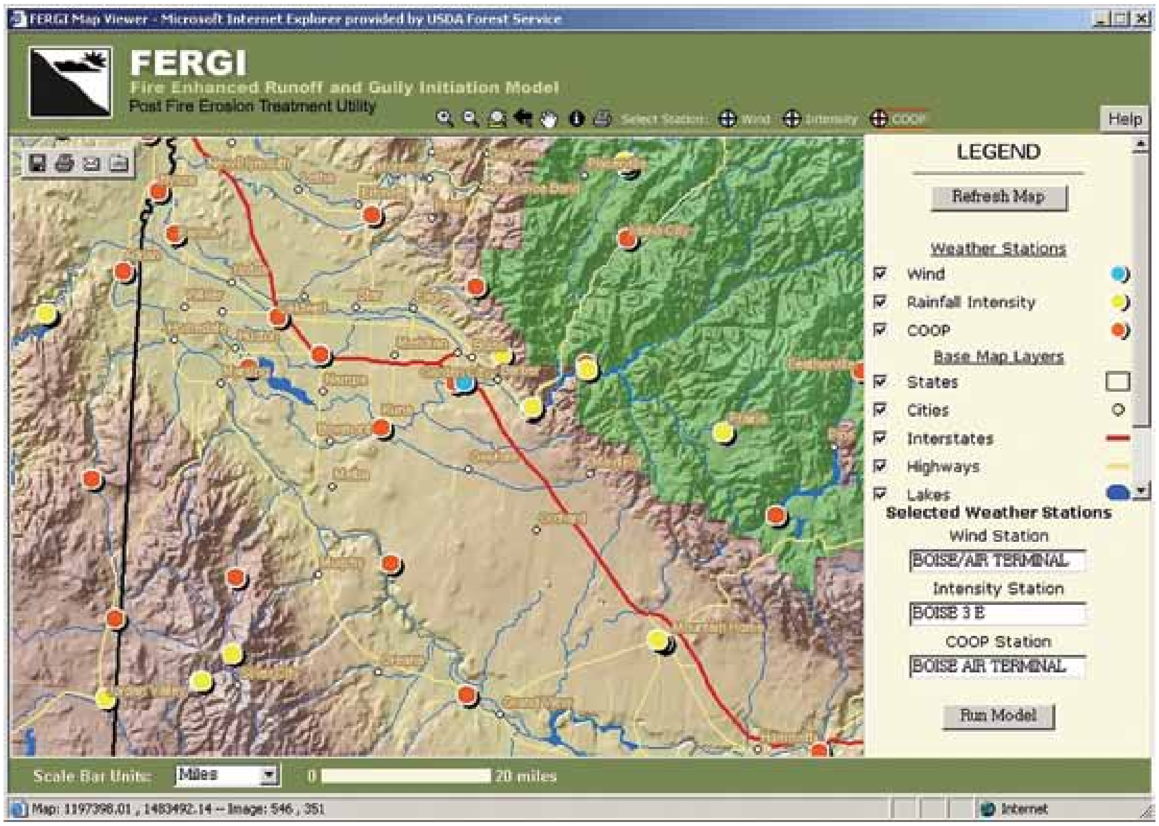
Input Requirements

To use the FERGI model, the following information is required:

- location of three nearest weather stations selected from the FERGI input screen
- depth to water repellent layer, the proportion of the area that is underlain by water repellent soils after a fire
- fractional water repellency
- saturated hydraulic conductivity
- slope
- hillslope length, average length of hillslope before flow begins to accumulate into channels
- D_{50} of soil surface
- storage capacity of barriers, the amount of precipitation that can be stored by the barriers (i.e., the volume of water storage behind barriers divided by the total area over which the measured barriers are applied)
- fraction of area trenched, the total length of scalping times the width of scalped area divided by the total area of the site

Program Availability

The FERGI model is accessible from the Forest Service intranet (http://frames.nbii.gov/fergi/) and run online. Users follow three steps to run the FERGI model: (1) zoom to the area of interest, (2) select each of the three weather stations (fig. 16), and (3) enter soil and hillslope parameters (fig. 17).



Selected Weather Stations

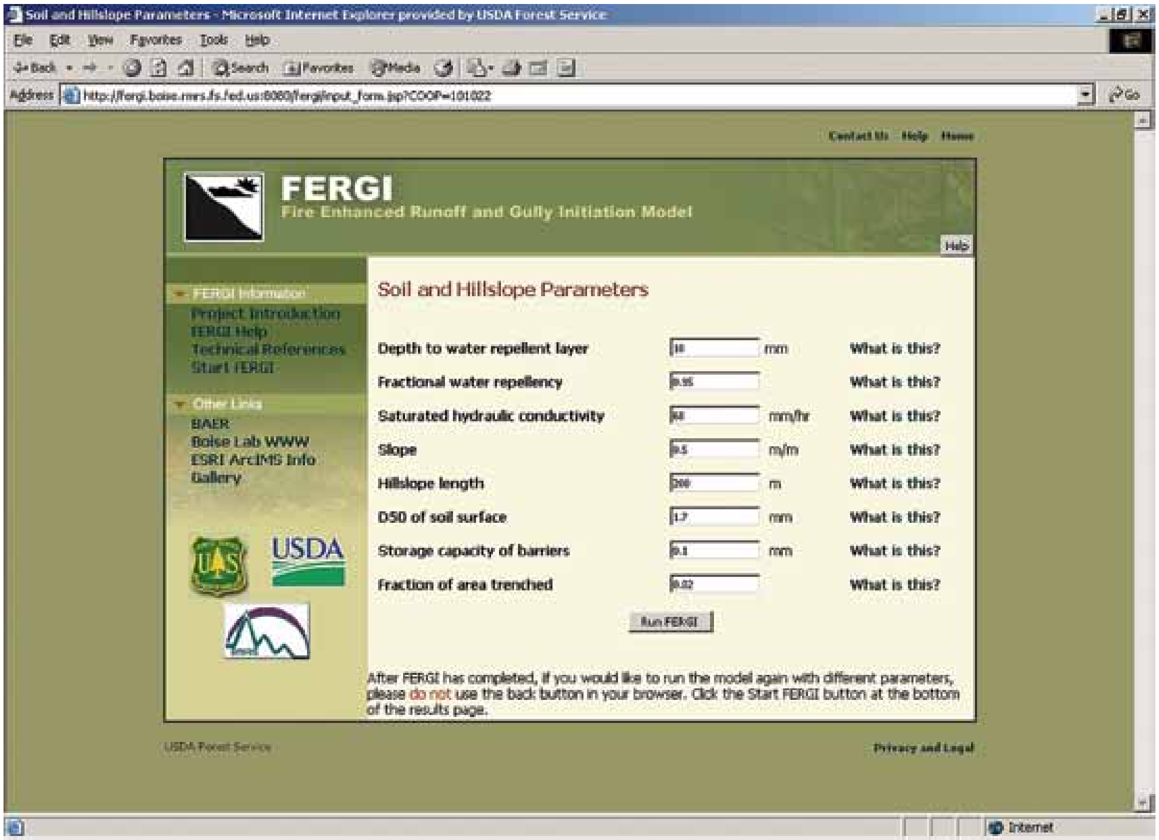
Wind Station: BOISE/AIR TERMINAL

Intensity Station: BOISE 3 E

COOP Station: BOISE AIR TERMINAL

Map: 1197398.01 , 1483492.14 -- Image: 546 , 351

Figure 16—FERGI weather input screen.



http://fergi.boise.rmrs.fs.fed.us:8080/fergi/input_form.jsp?COOP=101022

Soil and Hillslope Parameters

Depth to water repellent layer	10	mm	What is this?
Fractional water repellency	0.95		What is this?
Saturated hydraulic conductivity	60	mm/hr	What is this?
Slope	0.5	m/m	What is this?
Hillslope length	200	m	What is this?
D50 of soil surface	1.7	mm	What is this?
Storage capacity of barriers	0.1	mm	What is this?
Fraction of area trenched	0.02		What is this?

After FERGI has completed, if you would like to run the model again with different parameters, please do not use the back button in your browser. Click the Start FERGI button at the bottom of the results page.

Figure 17—FERGI soil and hillslope input screen.

The FERGI model reports the following (fig. 18):

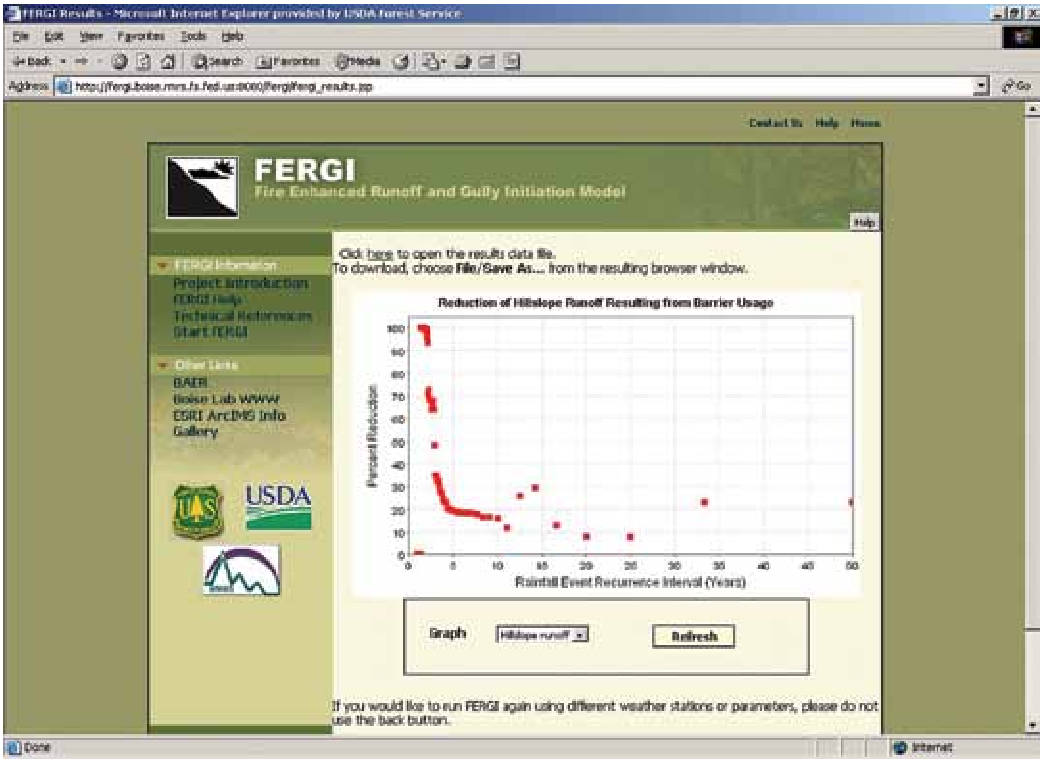
- return interval (yrs; from 1 to 100 years)
- rainfall excess no treatment (mm)
- rainfall excess treatment (mm)
- rainfall excess reduction (%)
- hillslope runoff no treatment ($m^3\ s^{-1}\ m^{-1}$)
- hillslope runoff treatment ($m^3\ s^{-1}\ m^{-1}$)
- hillslope runoff reduction (%)
- gully head no treatment (m)
- gully head treatment (m)
- gully head reduction (%)

This output is provided as graphs (% reduction of rainfall excess, hillslope runoff, and gully length) (fig. 18) and tables of text file.

Advantages

The following were advantages to applying the FERGI for post-fire runoff and erosion estimation. FERGI:

- estimates rainfall excess, post-fire runoff, and gully length of a rectangular strip;
- provides an estimate of the effectiveness of contour felled logs/log barriers as a function of storm return periods;
- is on-line accessible; and
- is process-based, and applicable to the western United States.



Click here to open the results data file.
To download, choose **File/Save As...** from the resulting browser window.

If you would like to run FERGI again using different weather stations or parameters, please do not use the back button.

Figure 18—FERGI output as hillslope runoff graph. Usage of contour felled logs/log barriers is mostly effective for small rainfall recurrence interval (less than 5 years).

Disadvantages

The following were disadvantages to applying the FERGI for post-fire runoff and erosion estimation. FERGI:

- does not provide pre-fire rainfall excess, runoff amount, and gully initiation positions so users cannot compare pre- and post-fire changes;
- does not estimate erosion;
- does not consider post-fire debris flow/torrent;
- is available only for Forest Service intranet;
- requires detailed soil parameter information;
- does not consider watershed shapes and assumes a rectangular hillslope;
- considers only 24-hour storm duration, so it is not applicable to the regions where the damaging storm duration is much shorter, such as 15 or 30 minutes; and
- uses metric units only.

Watershed Response Model for Forest Management (WATBAL)

The WATBAL program has been used by 2% of the BAER team members in Region 1 (table 8).

WATBAL originated from the Northern Region's Water Yield Guidelines, also known as R1/R4 Guidelines (Haupt and others 1976), to establish water yields in response to cumulative watershed development and vegetation manipulation and recovery over time. WATBAL was written in FORTRAN and has evolved using up-to-date methodologies, research findings, and locally derived water/sediment data. WATBAL is currently designed to simulate the potential and most likely effects of primary forest management practices (e.g., timber harvest, road development, and fire) on the responses of watershed and water resources systems with regard to stream flow and sediment regimes (Jones 2005). There are three functional elements in the program:

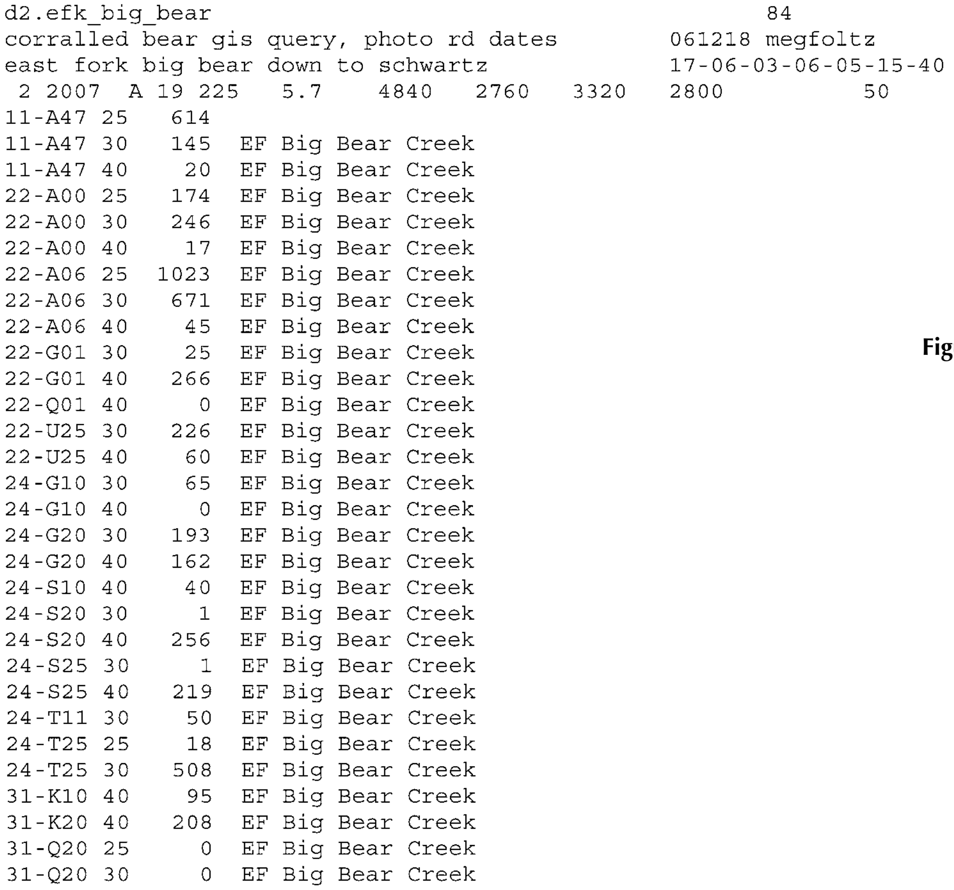
- a water yield model that uses response functions correlated to land characteristics and forest practices that were taken from the Hydrologic Simulation Model of the Colorado Subalpine Forest (Leaf and Brink 1973) and calibrated for the Northern Rocky Mountains;
- a sediment yield procedure based on surface erosion that incorporates the concepts and methodologies for the Idaho Batholith physiographic regions and associated lands (Cline and others 1981); and
- a sediment yield procedure based on mass erosional processes that was developed on the Clearwater National Forest (Jones 2005).

A typical WATBAL watershed input data file and watershed output response summary report is shown in figures 19 and 20.

Advantages

The following were advantages to applying the WATBAL for post-fire runoff and erosion estimation.

- WATBAL is applicable for estimating stream flow (e.g., annual and peak runoff and time to peak) and sediment regime effects of forest management practices, including timber harvest, road development, and fire on watersheds.



```
d2.efk_big_bear                                        84
corralled bear gis query, photo rd dates        061218 megfoltz
east fork big bear down to schwartz             17-06-03-06-05-15-40
 2 2007  A 19 225   5.7    4840   2760   3320   2800          50
11-A47 25   614
11-A47 30   145  EF Big Bear Creek
11-A47 40    20  EF Big Bear Creek
22-A00 25   174  EF Big Bear Creek
22-A00 30   246  EF Big Bear Creek
22-A00 40    17  EF Big Bear Creek
22-A06 25  1023  EF Big Bear Creek
22-A06 30   671  EF Big Bear Creek
22-A06 40    45  EF Big Bear Creek
22-G01 30    25  EF Big Bear Creek
22-G01 40   266  EF Big Bear Creek
22-Q01 40     0  EF Big Bear Creek
22-U25 30   226  EF Big Bear Creek
22-U25 40    60  EF Big Bear Creek
24-G10 30    65  EF Big Bear Creek
24-G10 40     0  EF Big Bear Creek
24-G20 30   193  EF Big Bear Creek
24-G20 40   162  EF Big Bear Creek
24-S10 40    40  EF Big Bear Creek
24-S20 30     1  EF Big Bear Creek
24-S20 40   256  EF Big Bear Creek
24-S25 30     1  EF Big Bear Creek
24-S25 40   219  EF Big Bear Creek
24-T11 30    50  EF Big Bear Creek
24-T25 25    18  EF Big Bear Creek
24-T25 30   508  EF Big Bear Creek
31-K10 40    95  EF Big Bear Creek
31-K20 40   208  EF Big Bear Creek
31-Q20 25     0  EF Big Bear Creek
31-Q20 30     0  EF Big Bear Creek
```

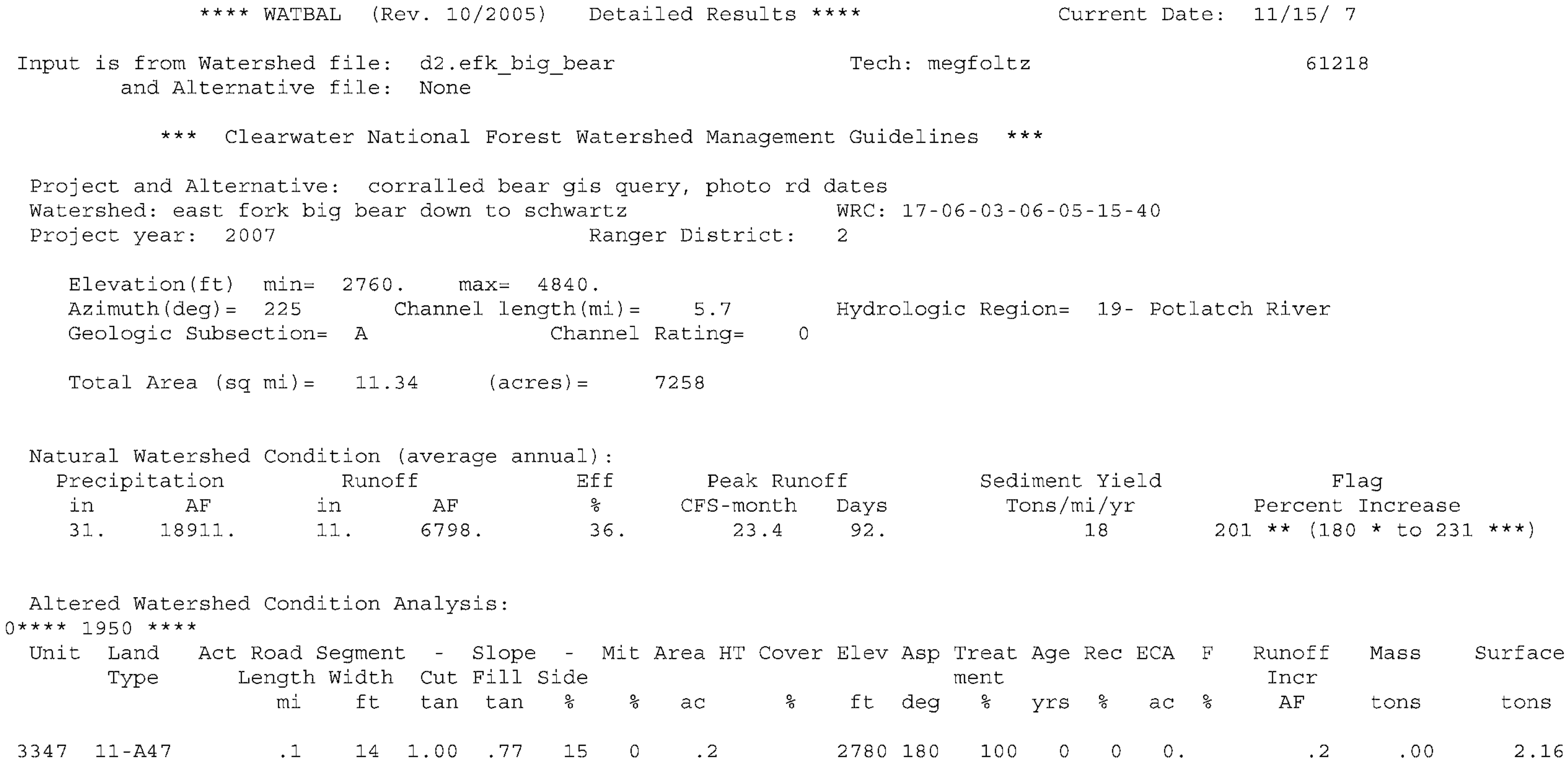
Figure 19—Typical WATBAL watershed input data file format (Foltz, 2008 USDA Forest Service). Adding input data requires understanding of the program and the natural hydrologic and erosional processes.

- The Clearwater National Forest continues to monitor watersheds. Based on the monitoring data, the model is continuously calibrated, validated, and calibrated again and is believed to be relatively accurate.

Disadvantages

The following were disadvantages to applying WATBAL for post-fire runoff and erosion estimation. WATBAL:

- is only applicable to Central and Northern Rocky Mountains for water yield (annual and peak runoff), the Idaho Batholith physiographic region for sediment yield from surface erosion, and Clearwater National Forest in the southern Idaho Batholith for sediment yield from landslides;
- does not consider post-fire debris flow/torrent;
- works best in watersheds of 4 to 40 mi^2, tends to over predict sediment in watersheds smaller than 4 mi^2 and under-predicts sediment in watersheds greater than 40 mi^2 (Jones 2005).
- is not user-friendly; and
- uses English units only.



```
               **** WATBAL  (Rev. 10/2005)   Detailed Results ****               Current Date:  11/15/ 7

 Input is from Watershed file:  d2.efk_big_bear                  Tech: megfoltz                     61218
         and Alternative file:  None

            ***  Clearwater National Forest Watershed Management Guidelines  ***

  Project and Alternative:  corralled bear gis query, photo rd dates
  Watershed: east fork big bear down to schwartz                WRC: 17-06-03-06-05-15-40
  Project year:  2007                        Ranger District:   2

     Elevation(ft)  min=  2760.    max=  4840.
     Azimuth(deg)=  225       Channel length(mi)=    5.7        Hydrologic Region=  19- Potlatch River
     Geologic Subsection=  A              Channel Rating=    0

     Total Area (sq mi)=   11.34     (acres)=     7258


  Natural Watershed Condition (average annual):
    Precipitation         Runoff            Eff       Peak Runoff          Sediment Yield             Flag
     in       AF        in       AF          %      CFS-month   Days         Tons/mi/yr         Percent Increase
     31.    18911.      11.     6798.        36.        23.4     92.               18        201 ** (180 * to 231 ***)


  Altered Watershed Condition Analysis:
0**** 1950 ****
  Unit  Land   Act Road Segment  -  Slope  -  Mit Area HT Cover Elev Asp Treat Age Rec ECA  F   Runoff   Mass    Surface
        Type      Length Width  Cut Fill Side                            ment                    Incr
                     mi    ft   tan  tan   %    %   ac      %    ft  deg   %   yrs  %   ac  %     AF     tons      tons

 3347  11-A47        .1    14  1.00  .77   15   0    .2         2780 180   100   0   0   0.         .2     .00      2.16
```

Figure 20—Typical WATBAL watershed response summary report (Foltz, 2008 USDA Forest Service). Interpretation of output data requires understanding of the program and the natural hydrologic and erosional processes.

Table 22—Pre- and post-fire WATBAL comparison for the 2000 Crooked Fire in the Clearwater National Forest, Idaho, based on fire perimeter as of August 28, 2000. All values are percent increase over baseline condition (Jones 2000).

	Pre-fire				Post-fire			
Watershed	**Sed**[a]	Q_{aa}[b]	Q_{pk}[c]	T_{pk}[d]	**Seda**	Q_{aa}[b]	Q_{pk}[c]	T_{pk}[d]
	- - - - - - - - - - - -%- - - - - - - - - - -				- - - - - - - - - - - -%- - - - - - - - - - -			
Haskell	48[e]	8	8	9	104	15	16	17
Rock	31	5	5	5	295	18	20	19
Pack	9	9	9	10	9	9	9	10
Lower Crooked	14	5	5	6	109	15	16	17
Crooked @ mouth	7	2	2	3	22	3	3	4

[a] Sediment
[b] Annual average flow
[c] Peak flow
[d] Time to peak
[e] Haskell watershed in pre-fire condition produces 48% more sediment than baseline condition.

Example

The Crooked Fire occurred on the Clearwater National Forest in July 28, 2000. WATBAL was used to estimate post-fire sediment and peak flow increases. The pre- and post-fire WATBAL comparison is shown in table 22.

Baer Road Treatments

BAER specialists have been using various road treatments to increase flow and debris flow capacity of road drainage structures due to wildland fires. Depending on regional climate and fire regimes, different road treatments were preferred. Napper (2006) describes implementation details of most of these treatments, including primary use, description, purpose, suitable sites, cost, and construction specifications. The most commonly used road treatments and their popularity by BAER specialists are shown in table 9. A description and discussion of these treatments follow.

Armored ford crossing

An armored ford crossing prevents stream diversion and keeps water in its natural channel; prevents erosion of the road fill and reduces adverse effects to water quality; and maintains access to areas once storm runoff rates diminish. Only a small fraction of BAER specialists recommended armored ford crossing.

Channel debris cleaning

Channel debris cleaning involves removing organic debris and sediment deposits from above the culvert to prevent them from becoming mobilized in debris flows or flood events. Channel debris cleaning is not frequently recommended by BAER specialists.

Culvert inlet/outlet armoring/modification

The culvert inlet/outlet is often armored to protect the culvert inlet and fillslope. Culverts are modified to increase the flow and debris passage capacity to prevent road damage. Flared/winged metal end sections are often attached for these purposes, especially in California. Only a very small fraction of BAER specialists recommended these treatments. Culvert modification is not commonly recommended by the BAER specialists in the other areas.

Culvert removal

Culvert removal uses each Forest's guidelines for culvert hydraulic capacity to determine if a replacement is necessary in the post-fire environment. If vehicle access is not needed, temporary culvert removal is often an option until the area stabilizes. Culvert removal is frequently recommended by Regions 3 and 6 BAER specialists.

Culvert risers

Culvert risers help prevent the culvert from plugging with sediment and floating debris. The risers allow sediment to accumulate while allowing the water to flow through the culvert. This storage of water and sediment also reduces the peak flows. Only Region 5 BAER specialists recommended culvert risers on a small number of occasions.

Culvert upgrading

Culvert upgrading relies on each Forest's guidelines for both hydraulic capacity and aquatic species passage to determine if a culvert should be replaced with one of a larger size. Given the values at risk, the culvert upgrading must be designed and implemented to maintain vehicle access and protect aquatic resources. Culvert upgrading is the second most frequently recommended BAER road treatment. Flow capacity of typical culverts in forestlands is shown in table 23.

Table 23—Flow capacity for circular and pipe-arch culverts (Robison and others 1999).

Circular culverts[a]			Pipe-arch culverts[a]		
Diameter	**Cross-section area culvert**	**Maximum flow in culvert**	**Span × Rise**	**Cross-section area culvert**	**Maximum flow in culvert**
(inches)	(ft^2)	(cfs)	(ft and/or inches)	(ft^2)	(cfs)
15	1.2	3.5	22″ × 13″	1.6	4.5
18	1.8	5	25″ × 16″	2.2	7
21	2.4	8	29″ × 18″	2.9	10
24	3.1	11	36″ × 22″	4.3	16
27	4	15	43″ × 27″	6.4	26
30	4.9	20	50″ × 31″	8.5	37
33	5.9	25	58″ × 36″	11.4	55
36	7.1	31	65″ × 40″	14.2	70
42	9.6	46	72″ × 44″	17.3	90
48	12.6	64	6′-1″ × 4′-7″	22	130
54	15.9	87	7′-0″ × 5′-1″	28	170
60	19.6	113	8′-2″ × 5′-9″	38	240
66	23.8	145	9′-6″ × 6′-5″	48	340
72	28.3	178	11′-5″ × 7′-3″	63	470
78	33.2	219	12′-10″ × 8′-4″	85	650
84	38.5	262	15′-4″ × 9′-3″	107	930
90	44.2	313			
96	50.3	367			
102	56.7	427			
108	63.6	491			
114	70.9	556			
120	78.5	645			
132	95	840			
144	113.1	1,000			

[a] Typical case of ditch relief culvert on forest lands was assumed, which is that the culvert is inlet-controlled, and projecting inlet and headwater depth is equal to diameter or height of culvert.

Debris/trash rack

A debris/trash rack is a barrier across the stream channel that is used to stop debris too large to pass through a culvert. Debris/trash racks are designed for small and medium floating debris. The storage area upstream from the debris/trash rack should be large enough to accumulate the anticipated size and quantity of debris, and be accessible for clean-out equipment. Only Regions 3 and 5 BAER specialists recommended debris/trash racks frequently, whereas other Regions only occasionally recommended them.

Ditch cleaning/armoring

Ditches are cleaned to prevent culvert plugging and armored to prevent erosion from the ditch bed. Many BAER specialists considered ditch cleaning/armoring as an efficient road treatment and, consequently, frequently recommended it.

Hazard/warning sign

Hazard/warning signs inform the public of potential hazards created by the fire, including flooding, falling rock, and debris. Stocking hazard/warning signs for immediate use in advance of the fire season is useful.

Outsloping road

An outsloped road design disperses water along the fillslope and can reduce erosion. Outsloping is often combined with other road treatments such as rolling dip and armored ford crossing. Outsloping is not frequently recommended by BAER specialists.

Relief culvert

An additional relief culvert is sometimes used to increase the flow capacity of water and debris for an existing culvert. A relief culvert is not frequently recommended by BAER specialists.

Road closure

A road closure is intended to prevent unacceptable degradation of critical natural or cultural resources or downstream values. Region 3 BEAR specialists considered a road closure as an alternative to other road treatments to protect road users in the event of flash flooding. However, road closure is generally not liked by the public. A road closure is seldom recommended.

Road decommissioning

Road decommissioning is intended to restore natural hillslope and reduce degradation of natural resources and downstream values. It is seldom recommended; however, it is a viable treatment in cases where roads are either not part of the classified road system or have gone through a process (usually including public involvement) that clears restrictions for decommissioning. Classified roads are not eligible for road decommissioning using BAER funds. There are five levels of treatments for road decommissioning: (1) block entrance, (2) revegetation and waterbarring, (3) remove fill and culverts, (4) establish drainage ways and remove unstable road shoulders, and (5) full obliteration, recontouring, and restoring natural slopes (USDA Forest Service 2003). If road decommissioning is prescribed in BAER, it is usually at the level of full recontouring.

Rolling dip/water bar

A rolling dip/water bar is used to drain water effectively from the road surface and reduce the concentration of flow. A rolling dip/water bar also provides a relief valve when a culvert is plugged. Often, a rolling dip/water bar is armored and it is used instead of a culvert upgrade because of its relatively low cost. Rolling dip/water bar is the most frequently recommended road treatment by BAER specialists.

However, a rolling dip/water bar may erode away with strong currents in high discharge. Tables 24 and 25 show the permissible velocity (1) in a bare channel and (2) in a vegetated channel to withstand erosion. The dipped road surface must be able to withstand these flow velocities.

The overflow discharge over an embankment, such as a drain dip located in the fill over a culvert, can be estimated using the weir formula in equation 5.

$$Q = C\,b\,H^{3/2} \qquad \text{(Eq. 5)}$$

Where:

$Q =$ discharge over an embankment, in $\mathrm{m^3\,s^{-1}}$

$C =$ sill coefficient, in $\mathrm{m^{1/2}\,s^{-1}}$

$b =$ length of the flow section in m

$H =$ total head upstream of the sill in m

The coefficient of C is a function of h/L (h is the head over a sill of width L) for free flow conditions, whereas a correction factor, f, as a function of $h_{d/s}/H$ ($h_{d/s}$ is the head drop of a sill to downstream), may be incorporated in equation 5 for submerged flow conditions (Novak and others 2001).

Table 24—Permissible velocity to withstand erosion (Watkins and Fiddes 1984; Novak and others 2001).

Surface type	50 percentile size	Permissible velocity
	(mm)	($\mathrm{m\,s^{-1}}$)
Fine silt	—	0.25 to 0.8
Sandy clay of low density	—	0.4
Coarse silt, fine sand	0.05	
Fine sand (non-colloidal)	0.25	0.6
Sandy loam (non-colloidal)	—	0.7
Sandy clay of medium density	—	0.8
Silt loam	—	
Medium sand	1.0	
Dense clay	—	1.0
Volcanic ash	—	
Coarse sand	2.5	
Stiff clay	—	1.5
Graded loam to cobbles	—	
Alluvial silt (colloidal)	—	
Graded silt to cobbles (colloidal)	—	1.6
Gravel (medium to fine)	5.0	1.1
Gravel (coarse to medium)	10	1.4
Coarse gravel and cobbles	25	1.9
Cobbles	40	2.4
Cobbles	100	3.6
Bitumen-bound macadam[a]	—	6.0
Asphalt	—	7.0

[a] Type of road construction. It consists of three layers of stones that interlock each other.

Table 25—Permissible velocities in vegetated channels (Watkins and Fiddes 1984).

Vegetation	% slope of drain	Permissible velocities In stable soils	 In erodible soils
		$(m\ s^{-1})$	
Bermuda grass	0 to 5	2.4	1.8
(*Cynodon dactylon*)	5 to 10	2.1	1.5
Buffalo grass	0 to 5	2.1	1.5
(*Buchloe dactyloides*)	5 to 10	1.8	1.2

Table 26—Range of values of C for free flow or modular flow over the embankment (Novak and others 2001).

Surface type	Range of h/L	Range of C
Paved surface	0.15	1.68
	0.20	1.69
	>0.25	1.70
Gravel surface	0.15	1.63
	0.20	1.66
	0.25	1.69
	0.30	1.70

Table 27—Correction factor, *f*, for submerged flow or non-modular flow (Novak and others 2001).

Surface type	Range of $h_{d/s}/H$	*f*
Paved surface	≤0.80	1.00
	0.90	0.93
	0.95	0.80
	0.99	0.50
Gravel surface	≤0.75	1.00
	0.80	0.98
	0.90	0.88
	0.95	0.68
	0.98	0.50

Free flow occurs where a man-made structure creates a drop in water level over the structure resulting in the major part of the total upstream energy head being converted into kinetic energy to obtain critical flow at the control section. Under this condition, the upstream head is independent of downstream conditions.

The opposite of free flow is submerged flow. With submerged flow, the drop in water level over the structure is small and the flow above it remains subcritical. Therefore, the upstream head is affected by downstream conditions (Boiten 2002). Either of these flow conditions is possible in forest conditions. The range of values for C and f are shown in tables 26 and 27.

Storm patrol

A storm patrol keeps culvert and drainage structures functional by cleaning sediment and debris from the inlet between or during storm events. It is an efficient measure to protect the transport infrastructure after a wildfire and provides needed road access throughout the designated storm season by ensuring road drainage function.

Gray Literature From BAER Interviews

From BAER interviews, we obtained various gray literature (i.e., unpublished reports, file reports, or hard to find proceeding papers). Table 28 lists and categorizes the gray literature. This section contains a summary of beneficial information related to post-fire runoff and erosion estimation methods, road treatments, and post-fire monitoring reports. The opinions and values in the following summaries are those of the gray literature authors and not necessarily those of this report's authors. In a few instances, italicized comments reflect what we believed necessary to clarify or correct comments in the gray literature.

Table 28—List of gray literature obtained from BAER interviews.

Literature	USGS regression	NRCS CN	TR-55	WEPP	R1/R4 sediment	Culvert sizing	Rolling dip/water bar	Culvert survey	Evaluation[a]
Cahoon (2005)						×			
Coronado National Forest (2003)		×							
Dixon (2008)	×								
Frazier and others (2005)									×
Furniss (2002)							×		
Gerhardt (2005)	×								
Gerhardt (2006a)		×							
Gerhardt (2006b)		×							
Higginson and Jarnecke (2007)		×							
Johnson (2003)									×
Johnson and Gould (2003)	×								
Jones and others (2006)	×								
Kuyumajian		×							
Lefevre and others (2002)			×						
Parret and others (2004)	×								
Sirucek and others (2006)	×			×				×	
Solt and Muir (2006)		×							
Story (2003)	×	×							
Story and others (2006)	×			×	×				
Stuart (2000)		×						×	

[a] Evaluation of road treatment implementation.

USGS regression methods

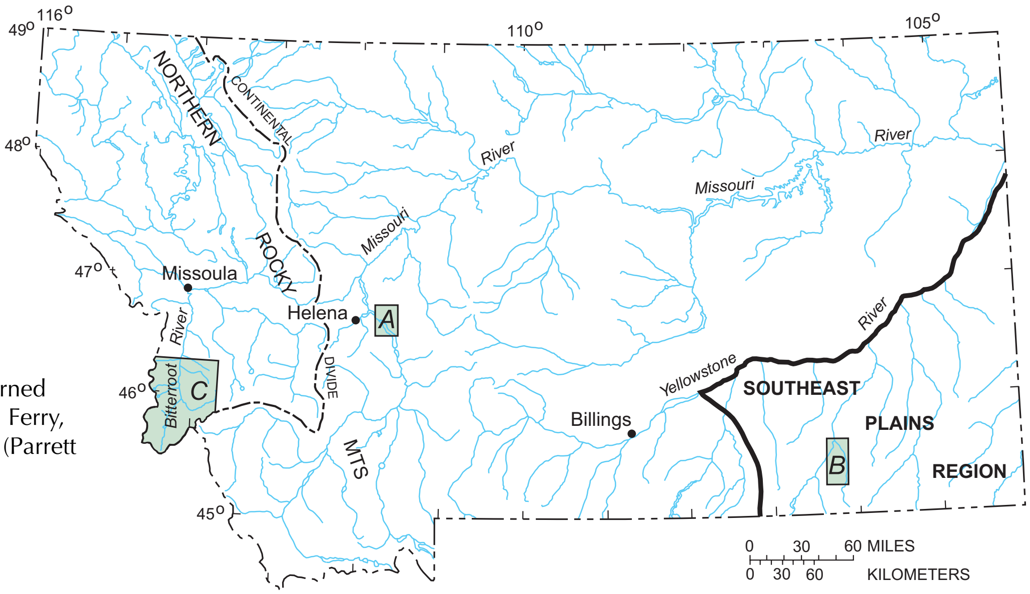
Parrett, Charles; Cannon, Susan H.; Pierce, Kenneth L. 2004. Wildfire-related floods and debris flows in Montana in 2000 and 2001. Water-Resources Investigations Report 03-4319. Denver, CO: U.S. Geological Survey. 22 p.

Following extensive wildfires in summer 2000, flooding and debris flow occurred in three different burned areas in Montana on the Canyon Ferry, Ashland, and Bitterroot Fires (fig. 21).

Approximately 40,000 acres were burned through September in the Canyon Ferry area. Fires included Canyon Ferry Complex and Boulder Complex (Montana Department of Commerce 2003). A U.S. Geological Survey rain gage recorded a 5- to 10-year return period, 15-minute duration event on July 17 on Crittenden Gulch. The resulting measured flow had a pre-fire 200-year return interval. Details of precipitation and peak streamflow discharges are shown in tables 29 and 30.

Approximately 60,000 acres were burned in the Ashland area. Fires included Pease Fire (Montana Department of Commerce 2003). The U.S. Geological Survey rain gage recorded a 100- to 500-year return period, 5-minute duration event on June 30 at a site (site 33) near the center of the Ashland area (table 31). Recurrence intervals for calculated peak stream discharges, based on unburned conditions, were 50 to 100 years at three sites and greater than 500 at five sites (table 32).

The Bitterroot area was the most active of the 2000 fire season and included six different fire complexes, including Valley Complex, Mussigbrod Complex, Skalkaho Complex, Wilderness Complex, Middle Fork Complex, and Blodgett Trailhead. More than 400,000 acres were burned in the Bitterroot area (Montana Department of Commerce 2003). A series of thunderstorms in July 2000 caused flooding and debris flows on small streams. The U.S. Geological Survey rain gage recorded multiple 10- to 25- year return period, 5- to 30-minute duration events on June 15, 20, and 21. The resulting flows had an estimated pre-fire recurrence interval of 200 to 500 years. Details of precipitation and peak streamflow discharges are shown in tables 33 to 35.



Base modified from U.S. Geological Survey 1:500,000, 1965. North American Datum of 1927 (NAD 27)

Figure 21—Location of three burned areas in Montana: A. Canyon Ferry, B. Ashland, and C. Bitterroot (Parrett and others 2004).

Table 29—Data from significant precipitation storm events during 2001 at U.S. Geological Survey precipitation stations in Canyon Ferry area, Montana (Parrett and others 2004).

Crittenden Gulch (site 27)					
7/17			**7/30**		
Storm duration	**Maximum rain depth**	**Recur. interval**	**Storm duration**	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)	(minute)	(inch)	(year)
5	0.17	5	5	0.02	<2
10	0.27	5	10	0.04	<2
15	0.36	5 to 10	15	0.06	<2
30	0.41	2 to 5	30	0.12	<2
60	0.43	2 to 5	60	0.15	<2
Daily total	0.70	<2	Daily total	0.28	<2

Upper Magpie Creek (site 29) 7/17			Lower Magpie Creek (site 30) 7/17		
Storm duration	**Maximum rain depth**	**Recur. interval**	**Storm duration**	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)	(minute)	(inch)	(year)
5	0.13	2	5	0.07	<2
10	0.18	<2	10	0.10	<2
15	0.21	<2	15	0.12	<2
30	0.30	<2	30	0.19	<2
60	0.35	<2	60	0.23	<2
Daily total	0.58	<2	Daily total	0.39	<2

Table 30—Peak streamflow discharges and estimated recurrence interval during 2001 at U.S. Geological Survey streamflow-gaging stations in Canyon Ferry area, Montana (Parrett and others 2004).

Station or stream name	**Drainage area**	**Precip. station site number**	**Date of peak discharge**	**Peak discharge**	**Estimated recur. interval**[a]
	(mi^2)			(cfs)	(year)
Crittenden Gulch at mouth,	2.3	27	7/17	1,020[b]	200
near Helena	2.3	27	7/31	60[b,c]	5 to 10
Magpie Creek above Bar Gulch, near Helena	17.4	29/30[d]	7/17	405	50 to 100
Hellgate Gulch at Forest Service boundary, near Helena	9.2	30	7/17	310[c]	100 to 200

[a] Based on equations developed for ungaged sites in unburned areas by Parrett and Johnson (2004).
[b] Multiple peak flows from thunderstorms
[c] Estimated discharge
[d] Site 29 is located in upper basin, and site 30 nearby the streamflow-gaging station.

Table 31—Data from significant precipitation storm events during 2001 at U.S. Geological Survey precipitation stations in Ashland area, Montana (Parrett and others 2004).

Upper Paget Creek (site 33) 6/30			Coal Bank Creek (site 34) 6/30		
Storm duration	**Maximum rain depth**	**Recur. interval**	**Storm duration**	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)	(minute)	(inch)	(year)
5	0.56	100 to 500	5	0.14	<2
10	0.75	25 to 50	10	0.28	<2
15	086	25	15	0.29	<2
30	0.95	10	30	0.29	<2
60	0.96	5	60	0.29	<2
Daily total	0.96	<2	Daily total	0.29	<2

Table 32—Peak streamflow discharges and estimated recurrence interval during 2001 at U.S. Geological Survey streamflow-gaging stations in Ashland area, Montana (Parrett and others 2004).

Station or stream name	Drainage area	Precip. station site number	Date of peak discharge	Peak discharge	Estimated recur. interval[a]
	(mi^2)			(cfs)	(year)
Home Creek near Ashland	35.4	33	6/30	1,000[b]	50 to 100
Newell Creek near Ashland	4.3	33	6/30	400	50 to 100
Chromo Creek near Ashland	5.2	33	6/30	1,220	>500
Brain Creek near Ashland	8.0	33	6/30	3,200	>500
Paget Creek near Fort Howes Ranger Station, near Otter	14.0	33	6/30	3,500	>500
Hole-in-the-Wall Creek near Ashland	1.5	34	6/30	310	50 to 100
Dry Creek near Ashland	4.5	33	6/30	2,460	>500
King Creek near Ashland	12.4	33	6/30	1,920	>500

[a] Based on equations developed for ungaged sites in unburned areas by Parrett and Johnson (2004).

[b] Estimated discharge

Gerhardt, Nick. 2005. [Personal notes]. September 2. China 10-Flow calculations using USGS regression method.

- assume that peak flow occurs in spring runoff, not fall storm flow
- 10-year, 24-hour storm = 2.8 inches (Miller and others 1973b)
- use 10-year peak flow for Peasley Creek from Kjelstorm and Moffat (1981) = 11.9 cfsm for pre-fire condition
- assume a two-fold 1st year post-fire runoff increase for moderate/high burn severity from Robichaud (2000)
- calculate the area of different burn severities as follows:

Area of burn = 122 acres for high burn
} 714 acres = 1.12 mi^2 = 41%
= 592 acres moderate burn
= 254 acres for low burn
} 1050 acres = 1.64 mi^2 = 59%
= 796 acres unburned
2.76 mi^2

- Calculate post-fire peak flow based on a 10-year, 24-hour storm as follows:

Peak flow from high/moderate burn severity = 23.8 cfsm × 41% = 9.76 cfsm
Peak flow from low burn severity/unburned = 11.9 cfsm × 59% = 7.02 cfsm
16.78 cfsm

Jones, Richard; Mital, Jim. 2003. Burned area report, Beaver Lakes Complex. 11 p.

Jones, Richards [and others]. 2006. Burned area report, Gash Creek Incident. 13 p.

For design storm analysis, a 15-minute, 25-year storm was used that occurred in Sleeping Child Creek on July 15, 2001 (Parrett and others 2004; table 33). The storm produced 200 cfs over a 1.8 mi^2 burned watershed, resulting in 110 cfsm, which was greater than a 500-year runoff event (Parrett and others 2004; table 34). This watershed was selected for the design storm since the runoff

Table 33—Data from significant precipitation storm events during 2001 at U.S. Geological Survey precipitation stations in Bitterroot area, Montana (Parrett and others 2004).

Laird Creek at mouth (site 3)

7/20			7/21		
Storm duration	**Maximum rain depth**	**Recur. interval**	**Storm duration**	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)	(minute)	(inch)	(year)
5	0.12	2	5	0.16	5
10	0.24	5	10	0.31	10
15	0.31	5	15	0.47	10 to 25
30	0.42	2 to 5	30	0.54	10
60	0.43	2 to 5	60	0.58	5 to 10
Daily total	0.44	<2	Daily total	0.58	<2

Laird Creek above Gilbert Creek (site 5)

7/20			7/21		
Storm duration	**Maximum rain depth**	**Recur. interval**	**Storm duration**	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)	(minute)	(inch)	(year)
5	0.21	10 to 25	5	0.15	5
10	0.35	10 to 25	10	0.22	2 to 5
15	0.38	10	15	0.30	5
30	0.42	2 to 5	30	0.35	2 to 5
60	0.43	<2	60	0.47	2 to 5
Daily total	0.43	<2	Daily total	0.61	<2

North Rye Creek (site 7) 7/15			Burke Gulch (site 12) 7/30		
Storm duration	**Maximum rain depth**	**Recur. interval**	**Storm duration**	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)	(minute)	(inch)	(year)
5	0.22	10	5	0.04	<2
10	0.35	10 to 25	10	0.06	<2
15	0.44	10 to 25	15	0.07	<2
30	0.54	10	30	0.09	<2
60	0.62	5 to 10	60	0.12	<2
Daily total	0.64	<2	Daily total	0.78	<2

Sleeping Child Creek (site 14)

7/15		
Storm duration	**Maximum rain depth**	**Recur. interval**
(minute)	(inch)	(year)
5	0.21	5
10	0.38	10 to 25
15	0.53	25
30	0.66	10 to 25
60	0.76	10
Daily total	0.83	<2

Table 34—Peak streamflow discharges and estimated recurrence interval during 2001 at U.S. Geological Survey streamflow-gaging stations in Bitterroot area, Montana (Parrett and others 2004).

Station or stream name	Drainage area	Precip. station site number	Date of peak discharge	Peak discharge	Estimated recur. interval [a]
	(mi^2)			(cfs)	(year)
Little Sleeping Child Creek above Spring Gulch, near Hamilton	9.3	12	7/30	35[b]	2
Laird Creek near Sula	9.3	3	7/20	210[c]	200 to 500
			7/21	220[c]	200 to 500
Laird Creek above Gilbert Creek, near Sula	5.1	5	7/20	160[c]	200 to 500
			7/21	160[c]	200 to 500
North Rye Creek near Conner	17.5	7	7/15	260	100
Burke Gulch near Darby	6.5	12	7/30	3.3	<2
Sleeping Child Creek near Hamilton	37.0	14	7/15	150	<2
Unnamed tributary to Sleeping Child Creek at Hot Springs, near Hamilton	3.6	14	7/15	10	2
Unnamed tributary No. 7 to Sleeping Child Creek near Hamilton	1.8	14	7/15	200[d]	>500

[a] Based on equations developed for ungaged sites in unburned areas by Parrett and Johnson (2004).

[b] Peak discharge from storm of September 30 to October 1, 2000, was 190 cfs with recurrence interval of 100 years.

[c] Multiple peak flows from thunderstorms

[d] Estimated discharge

Table 35—Peak debris-flow discharges on July 15, 2001, at selected tributary sites in the Sleeping Child Creek drainage in Bitterroot area, Montana (Parrett and others 2004).

Unnamed tributary to Sleeping Child Creek	Drainage area	Average channel slope	Estimated peak flow
	(mi^2)	($ft\ ft^{-1}$)	(cfs)
No. 2	0.07	0.43	1,740
No. 3	0.09	0.47	1,860
No. 4	0.10	0.46	1,930
No. 5	0.28	0.31	7,860
No. 6	0.08	0.43	3,500
No. 8	0.41	0.16	2,730

did not include debris and the watershed size was small (<2 mi^2). The burned watershed by the 2003 Beaver Lakes Fire, Idaho, could receive a similar storm and respond similar to Sleeping Child Creek, where burn intensities were high. Storm runoff should be adjusted where burn intensities are less than high. Road drainage structures for a drainage area less than 2 mi^2 should be designed to handle these flows (110 cfsm or less). For watersheds of 5 to 20 mi^2, the design storm should be approximately 23 cfsm (Arkell and Richards 1986).

Johnson, Steve; Gould, Jessica. 2003. Burned area emergency stabilization and rehab plan, Blackfoot Complex Fires, Flathead NF, watershed resource assessment. Libby, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Kootenai National Forest. 10 p.

Table 36 shows the burned area acreages by fire severity for selected watersheds associated with Blackfoot Complex as of September 20, 2003. A USGS method based on Omang (1992) was used to estimate 100-year discharges for selected drainages (table 37). To estimate the potential watershed response from these areas, a *modifier* (flow increase factor) was applied to the USGS predicted pre-fire flow values. The percent of the basin that had either high or moderate

Table 36—The burned acreages by fire severity associated with the 2003 Blackfoot Complex, Montana as of September 20, 2003 (Johnson and Gould 2003).

	Burn severity area			
Site name	**High**	**Moderate**	**Low and unburned**	**Total watershed size**
	- - - - - - - - - - - -	- - - - - - - - - -acres-	- - - - - - - - - - - -	- - - - - - - - - - - -
Sullivan	28,936	1,721	274	30,931
Sullivan below Conner[a]	10,131	1,695	274	12,100
Goldie at HH Reservoir[b]	1,519	835	56	2,410
Goldie Creek at FR 9838[c]	935	479	0	1,114
Clayton	3,840	447	0	4,287

[a] This basin is not enclosed, but analyzed as a unit since this is only part of the Sullivan Creek watershed that was burned.
[b] Goldie at Hungry Horse reservoir
[c] Goldie Creek at Forest Road 9383

Table 37—Predicted pre- and post-fire, 100 year flows based on Omang (1992) for the 2003 Blackfoot Complex, Montana (Johnson and Gould 2003).

Site name	**Watershed area**	**Pre-fire predicted flow**	**Flow increase factor[a]**	**Post-fire predicted flow**
	(acre)	(cfs)		(cfs)
Sullivan	30,931	1,758	1.06	1,871
Sullivan below Conner[b]	12,100	716	1.16	832
Goldie at HH Reservoir[c]	2,410	187	1.37	256
Goldie Creek at FR 9838[d]	1,114	104	1.43	149
Clayton	4,287	340	1.10	375

[a] Assuming 1% increase in flow for every 1% of the contributing watershed area with high and moderate burn severity
[b] This basin is not enclosed, but analyzed as a unit since this is only part of the Sullivan Creek watershed that was burned.
[c] Goldie at Hungry Horse reservoir
[d] Goldie Creek at Forest Road 9383

burn severity was used as the modifier (e.g., 37% of high and moderate burn severity = 1.37 for modifier).

Sirucek, Dean; Olson, Dennis; Butterfly, Henry; Johnson, Steve. 2006. Interagency burned area emergency stabilization & rehabilitation plan, Red Eagle Fire, watershed resource assessment, hydrology and soils. 24 p.

A USGS method based on Parrett and Johnson (2004) was used to estimate design discharges for selected drainages (table 38). To estimate the potential watershed response from these areas, a *modifier* (flow increase factor) was applied to the USGS predicted pre-fire flow values. The percent of the basin that had either high or moderate burn severity was used as the modifier (e.g., 48.6% of high and moderate burn severity = 1.486 for modifier). The modifier was applied to events with return intervals of 25 years or less.

Story, Mark. 2003. [E-mail circulation]. September. Stormflow methods.

For larger watersheds (greater than 5 to 10 mi^2), CN methods are not appropriate since uniform rainfall distribution within the entire watershed usually results in overestimation of the peak flow. For larger watersheds, the USGS regression equations by Omang (1992) can be used to estimate the pre-fire peak flow. The post-fire peak flow is then approximated by assumptions about post-fire water yield increase. On the Skalkaho/Valley Complex Fires in the Bitterroot

Table 38—Predicted pre- and post-fire flows based on Parrett and Johnson (2004) for the 2006 Red Eagle Fire, Montana (Sirucek and others 2006).

Watershed name	Return interval	Pre-fire predicted flow	Flow increase factor[a]	Post-fire predicted flow[b]
	(year)	(cfs)		(cfs)
Divide Creek	2	284	1.486	422
	5	495		736
	10	615		914
	25	919		1,366
	50	1,308	—	Same
	100	1,885	—	Same
Red Eagle Creek	2	832	1.253	1,042
	5	1,292		1,619
	10	1,502		1,882
	25	2,088		2,616
	50	2,870	—	Same
	100	4,022	—	Same

[a] Assuming 1% increase in flow for every 1% of the contributing watershed area with high and moderate burn severity

[b] Post-fire flow = Pre-fire flow × Flow increase factor

National Forest in 2000, it was assumed that high burn severity areas had 1/3 and 1/6 soil water repellencies with a 10-fold increase in surface runoff at the same year and 1 year after the fire. This procedure can be much more accurate if burned sites are located near gaged sites on the same stream and gaged data is used to estimate pre-fire peak flow. This procedure is also most applicable to longer duration precipitation events and snowmelt runoff events.

Story, Mark; Johnson, Steve; Stuart, Bo; Hickenbottom, Jennifer; Thatcher, Ron; Swartz, Scott. 2006. BAER specialist report, hydrology and roads, Derby Fire. Bozeman, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Gallatin National Forest. 17 p.

The Derby Fire burned 223,570 acres on both the Gallatin and the Custer National Forests in Montana in 2006. Stormflow response recovery is related to the reestablishment of grass/shrubs and, on the Gallatin NF, typically takes 1 to 5 years depending on the burn severity. On the Gallatin NF, most of post-fire peak flow increase was observed up to 2 years after the wildfires (Thompson Creek Fire, 2000; Fridley Fire, 2002). The USGS regression equations from Parrett and Johnson (2004) were adjusted to analyze the potential post-fire flooding caused by the Derby Fires for watersheds greater than 5,000 acres. Pre-fire runoff was modified to estimate post-fire runoff using *modifier* that was defined as a ratio of post-fire to pre-fire runoff. Since a 100% peak flow increase was assumed for high and moderate burn severity area, the modifier was 100% plus the percent of the watershed that was categorized into high and moderate burn severity area. For example, if high and moderate burn severity was 45%, then the modifier was 1.45. Table 39 shows how to calculate post-fire peak flow using modifier.

Dixon, Mike. 2008. [Personal note on file with author]. March 17. 100 year flood flow culvert analysis.

Table 39—USGS regression method to calculate post-fire peak flow for large watersheds (>5,000 ac) burned by the 2006 Derby Fire, Montana (Story and others 2006).

Watershed	Total area	High + moderate burn severity		Modifier	Pre Q10	Pre Q25	Post Q10	Post Q25
	(ac)		(%)		(cfs)			
Bad Canyon	12,239	2,685	21.9	1.219	411	677	501	826
Trout Creek	16,866	5,801	34.4	1.344	516	877	693	1179

Table 40—Culvert analysis for 100-year flood flow for Payette National Forest, Idaho using USGS regression method (Dixon 2008).

Road number	Drainage area	Forest cover[a]	Thomas and others[b]			Q and H[c]
			Q_{10}	Q_{50}	Q_{100}	Q_{100}
	(mi^2)	(%)	(cfs)			
50004	0.46	20	24.4	36.7	43.7	42.2
50004	0.56	65	22.5	33.8	40.2	49.1
51823	0.45	65	18.6	27.9	33.2	41.5
51822	0.29	65	12.7	19.0	22.6	29.5

[a] Estimated from aerial photo
[b] Thomas and others (1997)
[c] Quillian and Harenberg (1982)

Curve Number methods

Gerhardt, Nick. 2006a. [Unpublished report]. June 26. NRCS post-fire stormflow model, step-by-step.

FIRE HYDRO (figs. 9 to 11), an Excel spreadsheet, was developed in 2001 by NRCS in Montana for use in post-fire stormflow runoff precipitation (Cerrelli 2005) using CN methods (USDA SCS 1972; USDA SCS 1991). The following steps were suggested when using FIRE HYDRO.

1. Determine if this is an appropriate model to use.
2. Calculate watershed area (acres).
3. Calculate mean watershed slope.
4. Calculate pre-fire composite runoff Curve Number.
5. Calculate post-fire composite runoff Curve Numbers (year 1, 2, and 3).
6. Look up precipitation input values from NOAA Atlas 2 (Miller and others 1973a).
7. Determine storm type and unit peak flow (from nomographs).
8. Compare results to unit area measured values (Parrett and others 2004).
9. Rerun if necessary.
10. Interpret results.

Gerhardt, Nick. 2006b. [Unpublished report]. December 18. Characterization of a post-fire debris flow and flood, Blackerby Fire, Idaho.

The Blackerby Fire on the Nez Perce National Forest near Grangeville, Idaho, occurred in August, 2005. On 19 May 2006, a 0.79-inch precipitation event with a 30-minute duration occurred over a portion of the burned area. The precipitation event was equivalent to a 25-year, 30-minute storm event as determined from NOAA Atlas 2 (table 41).

The NRCS CN flood flow model results used in the BAER analysis (using FIRE HYDRO) were for a 25-year return event and based on the assumption of limited soil and vegetation regeneration during the first year after the fire (table 42). The observed flood discharge value was 71 cfs or 56 cfsm (cfs mi^{-2}). This observed flood discharge was half that of predicted flow. Additionally, the observed debris flow discharge was 620 cfs or 492 cfsm, indicating that debris flow discharge was nearly an order of magnitude greater than the flood discharge (table 43).

Table 41—Local precipitation-frequency values from NOAA Atlas 2 for the 2005 Blackerby Fire, Idaho (Miller and others 1973b; Gerhardt 2006).

	Rainfall duration		
Return interval	30-minute	6-hour	24-hour
	- - - - - - - - - -	-inches-	- - - - - - - - - -
2-year	0.32	0.9	1.6
5-year	0.47	1.1	2.0
10-year	0.63	1.3	2.4
25-year	0.79	1.5	2.9

Table 42—NRCS peak flow discharge model output in the second post-fire period, 1 year after the 2005 Blackerby Fire, Idaho (Gerhardt 2006).

Return interval	Peak flow rate	
	ft^3 sec^{-1}	cfs mi^{-2}
2-year	23	18
5-year	50	40
10-year	85	67
25-year	138	109

Table 43—Observed flood and debris flow on May 19, 2006, 1 year after the 2005 Blackerby Fire, Idaho (Gerhardt 2006).

Observed discharge	Peak flow rate	
	ft^3 sec^{-1}	cfs mi^{-2}
Flood flow	71	56
Debris flow	620	492

Story, Mark. 2003. [E-mail circulation]. September. Stormflow methods.

For small watersheds (less than 5 mi^2), a simple DOS model developed by Hawkins and Greenberg (1990), WILDCAT4, is useful to estimate post-fire peak flow. The WILDCAT4 is a NRCS CN method program that allows the user to chose from a 15-minute to a 24-hour storm. A CN of 90 to 95 is appropriate for a high severity burn without water repellent soils and a CN of 93 to 98 is appropriate for a high severity burn and with water repellent soils.

The WILDCAT4 uses a weighted average CN for a watershed (e-mail circulation, Story 2003) [Author's note: Hawkins (pers. comm. 2008 Univ. of AZ) commented that the WILDCAT4 uses weighted runoffs.]. The WILDCAT4 tends to have a long time of concentrations (T_c). If a shorter T_c is preferred, the user can substitute T_c from equation 5 (Dunne and Leopold 1978; US SCS 1972), which will generate a higher peak flow due to a quicker watershed response to the storm events.

$$T_c = \frac{L^{1.15}}{7700 \cdot H^{0.38}} \qquad \text{(Eq. 6)}$$

Where:

T_c = time of concentration (hr)

L = length of the catchment along the mainstream from the basin outlet to the most distant ridge (ft)

H = difference in elevation between the basin outlet and the most distant ridge (ft)

Storm distributions can be customized into WILDCAT4 program using Arkell and Richards (1986).

For watersheds up to 5 mi^2 (often 10 mi^2), an NRCS CN method using an Excel spreadsheet, FIRE HYDRO (Cerrelli 2005), is useful for estimating post-fire peak flow in Montana. The FIRE HYDRO is applicable for 24-hour rainfall events only and not applicable for short duration rainfall events such as a 1-hour storm or less. Use of FIRE HYDRO for short duration events may result in underestimation of the peak flow.

Stuart, Bo. 2000. Maudlow Fire, Burned Area Emergency Rehabilitation (BAER) plan. Townsend, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Helena National Forest.

Snowmelt runoff does not provide peak flow events in the fire area. During June to early September, convective rainstorms have moderate intensity over the fire area. Monsoon type rainfall events in spring and summer pose greatest risk to the watersheds of concern. The NOAA Atlas 2 (Miller and others 1973a) indicated 1.6, 2.0, and 2.4 inches of rainfall for 2-, 5-, and 10-year, 24-hour storms for the Maudlow Fire area. In order to estimate storm event peak flow, an NRCS CN method, FIRE HYDRO (Cerrelli 2005), was used. The SCS Type I rainfall distribution curve (fig. 4) was assumed for unit peak flows. GIS was used to generate watershed acreage, burn severity acres by watershed, and watershed slopes for FIRE HYDRO. Based on observations of unburned conditions, land type/cover type, burn intensity, and water repellency conditions, the CN ranged from 60 to 64 for unburned areas, 70 to 72 for low burn severity, and 80 for moderate burn severity. There was no high burn severity area in the Maudlow Fire area. Potential peak flow reduction with BAER treatments was modeled by assuming the combination of seeding, contour-felling, fencing, and road drainage would reduce the CN of a moderate burn severity area to CN 75 and reduce the CN of a low burn severity area to CN 66. Table 44 shows the results from NRCS, FIRE HYDRO, ranging from 66 cfs in Timber Gulch to 532 cfs in Dry Creek.

Higginson, Brad; Jarnecke, Jeremy. 2007. Salt Creek BAER-2007 Burned Area Emergency Response. Provo, UT: Unita National Forest; hydrology specialist report. 11 p.

The WILDCAT4 (Hawkins and Greenberg 1990) was used to estimate pre- and post-fire runoff on the 2007 Salt Creek Fire, Utah. Approximately 21,996 acres (34.4 mi^2) were burned within the fire parameters, whereas 2,663 acres (4.2 mi^2) were unburned. Approximately 22% and 64% of the burned area had

Table 44—Estimated post-fire time of concentration (T_c) and peak flows for 10-year, 24-hour storm (Q_{10}) using FIRE HYDRO (Cerrelli 2005) for the 2000 Maudlow Fire, Montana (Stuart 2000).

Watershed	T_c	Q_{10}
	(hour)	(cfs)
Sulphur Bar	1.8	172
Tributary to Sulphur Bar	0.8	70
Dry Creek	2.6	532
Timber Gulch	1.0	66

high and moderate severity burn. The selected watersheds (0.7 to 4.0 mi^2) were modeled for pre- and post-fire peak flow.

Annual precipitation consists mainly of winter snowfall and spring rainfall; however, short-duration, high-intensity summer/fall thunderstorms often produce flash flooding in the area. Thunderstorms during the fire caused flooding within the area on 25 July 2007 and 27 July 2007. To estimate pre- and post-fire peak flow, the 10-year and 25-year, 30-minute storms were used: 0.77 inch and 1.0 inch from NOAA Atlas 14 (Bonnin and others 2006). To estimate pre- and post-fire peak flow, the following assumptions were made:

- The storm was distributed over the entire watershed.
- There is a SCS Type II rainfall distribution (fig. 4).
- The pre-fire CNs were obtained from soil surveys. Otherwise, CNs were based on a vegetation type with (1) hydrologic soil group D (table 13), (2) hydrologic condition between good and fair, and (3) tables in US SCS (1991).

Post-fire CNs were based on pre-fire CNs and burn severities:

- High burn severity CN = pre-fire CN + 15
- Moderate burn severity CN = pre-fire CN + 10
- Low burn severity CN = pre-fire CN + 5
- Maximum CN value is 100

The time of concentration was based on equation 5 (US SCS 1972; Dunne and Leopold 1978).

Tables 45 and 46 show a dramatic increase in the calculated peak flows in drainages with moderate and high burn severities for the five selected watersheds. Use of the 25-year storm produced a very high peak flow that was beyond the treatable range; therefore, a 10-year storm was chosen for design storm.

Approximately 0.5 inches of rainfall was received during the fire on 25 July 2007. The storm caused flooding in the Serviceberry Hollow and Water Hollow drainages. Observed flows were estimated as follow:

- *Serviceberry Hollow*—flow was approximately 25 ft wide by average depth of 2.5 ft. Assuming a conservative velocity of 5 ft s^{-1}, the estimated discharged was 313 cfs.
- *Water Hollow*—flow was approximately 11 ft wide by average depth of 3 ft. Assuming a conservative velocity of 5 ft s^{-1}, the estimated discharged was 165 cfs.

These estimated values correlated well with the modeling results.

Table 45—Pre- and post-fire modeling results for the selected watersheds for 10-year, 30-minute storm (0.77 inch) on the 2007 Salt Creek Fire, Utah, using the WILDCAT4 (Hawkins and Greenberg 1990) (Higginson and Jarnecke 2007).

		Pre-fire modeling			Post-fire modeling		
Watershed	**Area**	**Total runoff**	**T_c[a]**	**Peak flow**	**Total runoff**	**T_c[a]**	**Peak flow**
	(mi^2)	(ac-ft)	(hr)	(cfs)	(ac-ft)	(hr)	(cfs)
Rolley Canyon	1.2	6.0	0.76	107	29.9	0.67	522
Serviceberry Hollow	4.0	10.4	1.01	147	32.9	0.90	458
Water Hollow Tributary #1	0.7	2.9	0.59	82	9.6	0.45	270
Water Hollow Tributary #2	1.8	6.9	0.73	153	20.7	0.67	440
Rocky Ridge Creek	1.2	1.3	0.64	35	5.1	0.54	132

[a] Time of concentration

Table 46—Pre- and post-fire modeling results for the selected watersheds for 25-year, 30-minute storm (1.0 inch) on the 2007 Salt Creek Fire, Utah, using the WILDCAT4 (Hawkins and Greenberg 1990) (Higginson and Jarnecke 2007).

		Pre-fire modeling			Post-fire modeling		
Watershed	**Area**	**Total runoff**	**T_c[a]**	**Peak flow**	**Total runoff**	**T_c[a]**	**Peak flow**
	(mi^2)	(ac-ft)	(hr)	(cfs)	(ac-ft)	(hr)	(cfs)
Rolley Canyon	1.2	11.2	0.76	201	39.7	0.67	716
Serviceberry Hollow	4.0	20.8	1.01	290	49.2	0.90	687
Water Hollow Tributary #1	0.7	5.0	0.54	143	12.6	0.45	354
Water Hollow Tributary #2	1.8	14.3	0.73	312	31.8	0.67	680
Rocky Ridge Creek	1.2	3.0	0.64	81	8.1	0.54	209

[a] Time of concentration

Kuyumajian, Greg. [Personal note]. Greg's Curve Number thoughts.

- High burn severity w/water repellent soils CN = 95
- High burn severity w/o water repellent soils CN = 90 to 91
- Moderate burn severity w/water repellent soils CN = 90
- Moderate burn severity w/o water repellent soils CN = 85
- Low burn severity CN = pre-fire CN + 5
- Straw mulch with good coverage CN = 60
- Seeding w/log erosion barriers 1 year after fire CN = 75
- Log erosion barriers w/o water repellent soils CN = 85

U.S. Forest Service Coronado National Forest. 2003. Aspen Fire, Coronado National Forest, BAER hydrology report. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Region, Coronado National Forest: 24–30.

The WILDCAT4 (Hawkins and Greenberg 1990) was used to estimate peak flow runoff in key watersheds under pre- and post-fire conditions on the 2003 Aspen Fire, Arizona. Limited sampling of water repellency conditions indicated moderate water repellency occurred on severely burned soils. Therefore, all severely burned soils had moderate water repellency (table 47).

Table 47—Pre- and post-fire Curve Number for the 2003 Aspen Fire, Arizona (U.S. Forest Service Coronado National Forest 2003).

Hydrologic Soil Group	Pre-fire CN	Post-fire CN High burn severity	Moderate burn severity	Low burn severity
B	56	65	—	—
C	67	70 to 75	80	90
D	77	80 to 85	90	95

Solt, Adam; Muir, Mark. 2006. Warm Fire-hydrology and watershed report. Richfield, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Fishlake National Forest. 9 p.

The WILDCAT4 (Hawkins and Greenberg 1990) was used to estimate pre- and post-fire runoff on the 2006 Warm Fire, Utah. The short duration, high intensity monsoonal storms can cause flash flooding and erosional events that were of greatest concern within and downstream of the burned area. The vegetation recovery for the Warm Fire was estimated at 3 years. The 10-year recurrence interval was selected for a design storm, which has a 10% chance of occurring in any given year and 27% chance of occurring in the next 3 years and was calculated using equation 7 (Gilman 1964). Also, 30-minute duration was selected to reflect the short duration, high intensity precipitation events that were common in the area.

$$P = 1 - \left[1 - \left(\frac{1}{T}\right)\right]^{N} \qquad \text{(Eq. 7)}$$

Where:

P = the probability of a rainfall having a given return period (T) occurring at least once in N years

Pre- and post-fire CNs were determined from a combination of sources, including Cerrelli (2005) and Dunne and Leopold (1978). The limestone derived soils of the burned area were determined to be in hydrologic soil group D (low infiltration) and in the ponderosa pine/juniper vegetation type (table D3). The following CNs were selected for the 2006 Warm Fire, Utah:

- Pre-fire CN = 80
- High burn severity CN = 90
- Moderate burn severity CN = 85
- Low burn severity and unburned CN = 80

TR-55

Lefevre, Robert [and others]. 2002. BAER report, Bullock Fire, Coronado National Forest, Arizona. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Region, Coronado National Forest. 14 p.

The TR-55 model was used to estimate post-fire peak flows. Table 20 shows the analysis that was conducted. The “2-year post-fire equivalent” displays the corresponding flood level expected from a typical 2-year storm event. In other words, there is a 50% chance of a storm event that might happen in any given year.

WEPP model

Sirucek, Dean; Olson, Dennis; Butterfly, Henry; Johnson, Steve. 2006. Interagency burned area emergency stabilization & rehabilitation plan, Red Eagle Fire, watershed resource assessment, hydrology and soils. 24 p.

The WEPP model was used to estimate 20 years of pre- and post-fire runoff and erosion potential. The results showed more runoff events with greater risks of flood and erosion (table 21). The WEPP model predicted dramatic increases of rainfall and snowmelt runoff events from 2 and 0 for pre-fire conditions to 79 and 14 for post-fire conditions.

R1/R4 sediment model

Story, Mark; Johnson, Steve; Stuart, Bo; Hickenbottom, Jennifer; Thatcher, Ron; Swartz, Scott. 2006. BAER specialist report, hydrology and roads, Derby Fire. 17 p.

Potential sediment increase from the 2006 Derby Fire, Montana, was modeled using the R1/R4 sediment model (Cline and others 1981). The sediment coefficient was adjusted based on existing road, timber harvest, and burn unit conditions. The R1/R4 model estimated the sediment increase much less than the WEPP model, because the R1/R4 model used sediment delivery and routing coefficients to estimate sediment levels at accounting points at or near the Gallatin NF.

Culvert sizing

Cahoon, Joel. (2005, August 11—last update). Circular culvert design spreadsheet [Online]. Available: http://www.wti.montana.edu/Documents/Reports/PDF/CMP_Hydraulics.xls [2008, July 8].

A quick and useful Excel template was developed for culvert sizing. The spreadsheet can be downloaded from the website. The spreadsheet displays a culvert rating curve based on inlet, outlet, and head variable, and automatically adjusts flow type to entrance and exit conditions. The spreadsheet can generate rating tables and display them by adjusting the variables, including culvert diameter, length, and slope. The following comments should be noted:

1. The spreadsheet was developed for corrugated metal pipe culverts.
2. Prior to opening the file in Excel, go to the Tools/Add-Ins menu and select (1) Analysis ToolPak, (2) Analysis ToolPak—VBA, and (3) Solver Add-in then update Add-Ins link. Quit Excel, re-load Excel, enable macros, and open the file.
3. The spreadsheet numbers that the user adjusts are displayed in blue.
4. Simply change the blue numbers, and select “Run” to generate a new rating curve.

Rolling dip/water bar

Furniss, Michael J. (2002—last update). The six-D system for effective waterbars [Online]. Available: http://www.fs.fed.us/r5/baer/six-d.html [2008, July 13].

Waterbars control erosion on roads, skid trails, trails, and firelines. Waterbars should break up larger drainage areas into smaller drainages that can handle runoff during heavy rainfall resulting in little or no erosion. Waterbars should also break up runoff so it reduces the energy available to erode the road surface. There are six D's to make effective waterbars.

1. *Drainage area*. When deciding where to put waterbars, estimate the drainage area. If the road or trail width is 12 feet or less, table 48 can be used. If the road or trail is wider than 12 feet, or runoff is contributed from cutslope (e.g., seepage or leaking), then adjustments should be made as discussed in 2.
2. *Distance*. Distance is the spacing between waterbars on a road or trail. If there is runoff contribution from a cutslope or small stream crossing, place a waterbar at that location so that water can keep flowing downhill without disturbing that road or trail surface much. If the road or trail is wider than 12 feet, modify the distance in table 48 by the proportion of that wider road width to 12 feet. For example, if a road is 15 feet wide, the drainage area is one quarter greater. Therefore, the distance should be one quarter less than indicated in table 48.
3. *Diagonal*. Do not oppose the flow energy. Waterbars built diagonal to the road lead the water away and are more efficient. Also, a diagonal waterbar has a gentle slope along its base; therefore, it is smoother and easier to drive over. A simple rule is to add "5" to the road gradient and build the waterbar that number of degrees off the road centerline.
4. *Divert*. A good waterbar should convey the water off the road or trail. It should be deep enough to handle the flow, and at the same time, durable to last as long as needed. Excavation is much more effective than fill-in for creating durable and effective waterbars.
5. *Discharge*. A good waterbar should discharge the flow. If it blocks the flow, or is a dam, the waterbar will likely fail. It should have an open outlet.
6. *Dissipate*. A good waterbar should dissipate the flow below the outlet to exhaust its erosive energy and let the water infiltrate into the soil. Slash, rock, or debris are often placed below the outlet. Enough buffer distance is also considered.

Table 48—Recommended maximum spacing for waterbars on temporary roads, trails, skid trails, and fire lines (Furniss 2002).

	Erosion hazard rating for area			
Gradient	**4 to 5 Low**	**6 to 8 Medium**	**9 to 10 High**	**11 to 13 Very high**
(%)	- - - - - - - - - - - - - - - (ft)	- - - - - - - - - - - - - - - - -		
1 to 6	400	350	300	250
7 to 9	300	250	200	150
10 to 14	200	175	150	125
15 to 20	150	120	90	60

Culvert survey for treatment assessment

Sirucek, Dean; Olson, Dennis; Butterfly, Henry; Johnson, Steve. 2006. Interagency burned area emergency stabilization & rehabilitation plan, Red Eagle Fire, watershed resource assessment, hydrology and soils. 24 p.

A field review of stream crossing/culverts was conducted on the roads within the 2006 Red Eagle Fire, Montana. The existing conditions were described for each culvert installation to assess the potential impact of post-fire peak flow to each site. Table 49 shows culvert survey information and road treatment recommendations.

Table 49—Summary information for culverts affected by the 2006 Red Eagle Fire, Montana (Sirucek and others 2006).

Stream	Road name	Culvert size	Height of culvert rust-line	Stream bank-full width	Basin burned above culvert[a]	Recommendation
		- - - - - - - - - - - - - - - -inches or ft- - - - - - - - - - - - - - - -				
Fox Creek	Truck trail road	18”	9” depth	18” to 24”	H	Clean out
Livermore	A road	18”	10” to 11”	36” to 38”	H	Replace w/24” squash[b] CMP[c]
Livermore	A road	Native wood (collapsed)	NA	24” to 28”	H	Replace w/36” squash CMP[c]
Livermore	A road	24”	13”	24” to 28”	H	Replace w/36” squash CMP[c]
Livermore	A road	30”	5”	40” to 48”	H	Clean out
Livermore	A road	36”	20”	44” to 48”	L	Clean out
Livermore	A road	24”	7”	44” to 48”	L	Clean out
South Fork Milk	Milk road spur	26” by 40” (squashed)	New, no rustline, 12” flow depth at examination	55” to 65”	H	Clean out
South Fork Milk	Milk road spur	24”	14”	36” to 40”	H	Replace w/36” squash CMP[c]
Fox Creek	A road	36”	24” newly constructed beaver exposure	10 ft	H	Replace w/48” squash CMP[c]
Fox Creek	A road	18”	6”	24”	H	Clean out
Fox Creek	A road	18”	Nearly filled w/sediment	48”	H	Clean out
Fox Creek	D road	36”	18” nearly blocked by old beaver fill, and compressed	6 ft	H	Replace w/48” squash CMP[c]
Fox Creek	B road	18”	2”	Draw	H	Upsize
Fox Creek	B road	18”	2”	Draw	H	Clean out
Fox Creek	B road	36”	10”	10 ft w/beaver complex	H	Upsize culvert (72” squash)
Fox Creek	B road	18”	Unknown	Draw	L	Clean out

[a] H = 75% or more of the basin burned with high and moderate burn severity; L = 50% or less.
[b] Pipe-arch culvert made by squashing 24” culvert
[c] Corrugated Metal Pipe

Stuart, Bo. 2000. Maudlow Fire, Burned Area Emergency Rehabilitation (BAER) plan. Townsend, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Helena National Forest.

A culvert survey was completed for the burned areas of Dry Creek and three affected tributaries to Deep Creek, Sulphur Bar Creek, Blacktail Creek, and Cedar Bar Creek. The purpose of this survey was to qualitatively assess erosion hazard and culvert plugging that might compound the degradation of the aquatic resources from damaging heavy storm/runoff events. Table 50 shows the culvert survey to assess road and drainage hazard for the Maudlow Fire, Montana, in 2000.

Evaluation of road treatment implementation

Johnson, Ada Suzanne. 2003. Aspen Fire 2003 treatment success monitoring report. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwest Region, Coronado National Forest. 21 p.

The Aspen Fire burned 84,750 acres in the Coronado National Forest, Arizona, in June and July, 2003. Emergency road treatments were applied to 6 miles of road, and road treatments were evaluated during and upon completion by visual observation (table 51). The road treatments were successful in protecting roads and maintaining access to residences and critical communication sites, and continue to perform as expected, with the single exception of Turkey Run Road where a culvert was removed and a rolling dip was constructed.

The rolling dip failed under base-flow conditions. The natural gradient of stream bed drops 2.5 to 3 ft (0.8 to 0.9 m) over the width of the road crossing. The downstream side of the dip eroded and the road was very close to impassible for long wheel-base vehicles. The drainage showed little or no evidence of increased flows since the fire. Also, a culvert at the mouth of the canyon was damaged. Runoff from heavy rains pushed boulders and debris across the roadway and significantly damaged the shoulder and integrity of the roadway downstream. Boulders and debris should be considered when assessing road treatments.

Frazier, Jim; [and others]. 2005. BAER report, Cedar Fire, Cleveland National Forest, California. San Diego, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Cleveland National Forest. 12 p.

Road treatments were implemented after the 2003 Cedar Fire, California, including restoring drainage function, installing drainage features and gates, conducting storm patrols, and posting warning signs. Significant rainfall events occurred the week of October 18, 2004, and the following January and February, resulting in the 3rd wettest seasons on record. A road survey was conducted in February and March of 2005 to assess road conditions and review the effectiveness of treatments installed in spring 2004. Loss of upslope vegetation and large precipitation events produced larger than expected runoff, resulting in culvert capacities being exceeded, erosion occurring at structures, and headcuts and culverts being severely undercut. Table 52 shows a summary of road treatments initially implemented and those implemented after the 2005 wet winter season.

Table 50—Culvert survey results to assess road and drainage hazard for the 2000 Maudlow Fire, Montana (Stuart 2000).

Drainage	Culvert at risk	Locations	Diameter	Comments
			(inch)	
Cedar Bar Creek	None			Rehab cat lines and hand lines.
Blacktail Creek	4190a	7N, 4E, S36b	18	Do not replace due to lack of burn area. above culvert
Sulphur Bar Creek	147a	7N, 4E, S34a	36	Remove.
	147b	6N, 4E, S1d	36	Clean debris from inlet.
	147c	6N, 4E, S12a	24	Clean debris from inlet.
	4187a	6N, 4E, S2a	36	Replace w/48″ countersunk pipe.
	4187b	6N, 4E, S2b	24	Consider temporary removal.
	4187c	6N, 4E, S35c	18	Cross drain replace w/fish passage.
Dry Creek	259a	6N, 4E, S24c	72 equiv.	Pvt[a]; remove debris.
	259b	6N, 4E, S25a	72 equiv.	Pvt[a]; replace sagging culvert.
	259c	6N, 4E, S30b	18	Upgrade cross drain pipe.
	259d	6N, 4E, S30a	18	Upgrade cross drain pipe.

[a] Pavement

Table 51—Evaluation of road treatment implementation for the 2003 Aspen Fire, Arizona (Johnson 2003).

Road name	Treatment	Evaluation relative to goals	Evaluation method
Fern Ridge Road	Remove culverts	Culverts removed, road passable	Visual observation by forest engineer
Sykes Knob Road	Remove culverts	Culverts removed, road passable	Visual observation by forest engineer
Turkey Run Road	Remove culvert	Culvert removed, road passable	Visual observation by forest engineer
Marshall Gulch Road	Place trash rack at inlet to deflect material over road	Goal accomplished, trash rack placed	Trash rack observed in place
Summerhaven main road	Place trash racks at two culvert inlets to deflect material over road	Trash rack placed	Visual observation by hydrologists
Mt Lemmon Lookout	Remove culverts	Culverts removed, road passable	Visual observation by forest engineer
Road into Willow Creek	Armor and buttress three crossings	Culvert removed, road passable	Visual observation by forest engineer
Sabino Canyon Rec. Road	Install concrete aprons on bridge approaches	Apron installed	Visual observation by forest engineer

Table 52—Summary of road treatments initially implemented and after the 2005 wet winter season for the 2003 Cedar Fire, California (Frazier and others 2005).

Road number	Road name	Recommended treatments	
		Initially implemented	**After the 2005 wet season**
13S09	Dye Canyon	Further assessment needed	
13S10	Westside	Restore drainage function, construct/ reconstruct dips and overside drains, riprap fill slopes, storm patrol, and BAER warning signs.	Restore drainage function, reconstruct dips, repair/replace damaged overside drains, re-install riprap (9.5 mi).
13S11	Cedar Creek	Restore drainage function, construct/ reconstruct dips and overside drains, riprap fill slopes, storm patrol, and BAER warning signs.	Restore drainage function, reconstruct dips, repair/replace damaged overside drains, re-install riprap (3.8 mi).
14S03	Garnet Peak	No treatments recommended	
14S04	Deer Park	Restore drainage function and storm patrol.	Restore drainage function, reconstruct dips, repair/replace damaged overside drains, re-install riprap (3.3 mi).
14S05	Pine Creek	Restore drainage function and place riprap for fillslope protection.	Restore drainage function, repair/replace damaged overside drains, re-install riprap (7.0 mi).
14S07	Tule Springs	Restore drainage function, construct overside drains, riprap, storm patrol, and BAER warning signs.	Restore drainage function, reconstruct dips, repair/replace damaged overside drains, re-install riprap (4.0 mi).
14S08	Conejos Valley	Restore drainage function, storm patrol, and BAER warning signs.	
14S08	Dubois	Restore drainage function, rock dips, upsize culvert, storm patrol, BAER warning signs, and a metal end-section on an existing 60″ CMP[a].	
15S21	Miners	Replace and upsize an existing overside drain.	Restore drainage function, reconstruct dips, repair/replace overside drains, re-install riprap (1.2 mi w/approx 50% on Capitan Grande Indian Reservation).
15S24	Goude	Restore drainage function and storm patrol.	
15S30	Anderson Truck Trail	Restore drainage function, construct dips and overside drains, place riprap at the end of existing overside drain flumes, storm patrol, and BAER warning signs.	Restore drainage function, reconstruct dips, repair/replace damaged overside drains, re-install riprap, replace two 30″×60″ CMP[a] culverts, replace lost aggregate surfacing (1.6 mi plus 0.9 mi on private lands).

[a] Corrugated Metal Pipe

Summary of Gray Literature on BAER Road Treatments

From the various gray literature discussed, we summarized the following information for BAER road treatments:

- USGS regression and NRCS Curve Number methods were mostly used to estimate post-fire peak flow. However, these methods are not well established for post-fire conditions. Many BAER team members used their own rules to use USGS regression and NRCS CN methods; therefore, there is no consistent way to estimate post-fire peak flow.
- Design tools, as well as information on culverts and rolling dips/water bars, were available. Little information was found for the other road treatments.
- Many BAER road treatments for individual stream crossings were prescribed based on road/culvert survey, without considering capacities of existing road structure and increased post-fire peak flow. A road/culvert survey can give the current road/culvert conditions after the fire to help managers prescribe road treatments. However, a road/culvert survey alone might not provide enough information to prescribe road treatments for individual stream crossings.
- Most monitoring efforts were made on hillslope treatments, and little information was available to evaluate road treatment effectiveness. The most commonly used monitoring method was visual observation.

Conclusions

Our analysis of Burned Area Reports, the literature, interview comments, and gray literature lead us to the following conclusions:

- Post-fire road conditions should be evaluated and road treatments implemented only if the values at risk warrant the treatment.
- Road treatment implementation should be based on regional characteristics, including the timing of the first damaging storm and window of implementation.
- Post-fire peak flow estimation is important for selecting appropriate road treatments. USGS regression and NRCS Curve Number methods are mostly used.
- USGS regression and NRCS Curve Number methods are not well established for post-fire conditions. Several BAER team members use simple rules of their own.
- Rolling dip/water bar, culvert upgrading, and ditch cleaning/armoring are the most frequently used road treatments.
- Rolling dip/water bar and ditch cleaning/armoring are preferred by all Regions. For Regions 1 and 4, culvert upgrading is preferred, especially for fish-bearing streams. For Region 3, culvert removal with road closure and warning signs are preferred.
- Little information is available on estimating flood and debris flow capacities of road treatments other than culverts and rolling dip/water bar.
- No data is available on estimating and evaluating other road treatment capacities (e.g., rolling dips and water bars).
- Many BAER road treatments were recommended for individual stream crossings based on road/culvert surveys, without considering the capacities of existing road structures and increased post-fire peak flows.
- Relatively little monitoring of BAER road treatments has been conducted. Treatment effectiveness has focused mainly on hillslope treatments such as seeding, contour-felled logs, and mulch, with little information available on road treatments.

Recommendations

Based on the findings of this study, we recommend the following to further expand our knowledge and understanding of road treatment effects in the post-fire environment:

- Post-fire peak flow estimation methods vary. Further research is needed to ensure that the BAER specialists can easily compare pre- to post-fire peak flow changes.
- There exists insufficient knowledge of the capacity of BAER road treatments to pass estimated flood and debris flows. Design tools should be developed to estimate flood and debris flow capacity of BAER road treatments (e.g., ford crossings, and ditch cleaning) so that the BAER specialists can select road treatments based on post-fire peak flow changes and the road treatment capacities.
- Insufficient data is available to evaluate road treatment effectiveness. More systematic monitoring and further research are recommended to evaluate road treatment effectiveness.

References

Arkell, Richard E.; Richards, Frank. 1986. Short duration rainfall relations for the western United States. Conference on climate and water management—a critical era and conference on the human consequences of 1985's climate; 1986 August 4-7; Asheville, NC. Boston, MA: American Metrological Society: 136-141.

Berenbrock, Charles. 2002. Estimating the magnitude of peak flows at selected recurrence intervals for streams in Idaho. Water-Resources Investigations Report 02-4170. Denver, CO: U.S. Geological Survey. 59 p.

Bigio, Erica R.; Cannon, Susan H. 2001. Compilation of post-wildfire runoff data from the western United States. Open-File Report 2001-474. Denver, CO: U.S. Geological Survey. 24 p.

Boiten, Wubbo. 2002. Flow measurement structures. Flow Measurement and Instrumentation. 13(5-6): 203-207.

Bonnin, Geoffrey M.; Martin, Deborah; Lin, Bingzhang; Parzybok, Tye; Yekta, Michael; Riley, David. 2006. NOAA Atlas 14. Precipitation-frequency atlas of the United States. Volume I version 4.0: semiarid southwest (Arizona, Southeast California, Nevada, New Mexico, Utah). Silver Spring, MD: NOAA.

Calkin, Dave E.; Hyde, Kevin D.; Robichaud, Peter R.; Jones, J. Greg; Ashmun, Louise E.; Loeffler, Dan. 2007. Assessing post-fire values-at-risk with a new calculation tool. Gen. Tech. Rep. RMRS-GTR-205. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 32 p.

Cerrelli, G. A. 2005. FIRE HYDRO, a simplified method for predicting peak discharges to assist in the design of flood protection measures for western wildfires. In: Moglen, Glenn E., eds. Proceedings: 2005 watershed management conference—managing watersheds for human and natural impacts: engineering, ecological, and economic challenges; 2005 July 19-22; Williamsburg, VA. Alexandria, VA: American Society of Civil Engineers: 935-941.

Chin, David A. 2000. Surface-water hydrology. In: Chin, David A. Water-resources engineering. Upper Saddle River, NJ: Prentice Hall: chapter 6.

Cline, R.; Cole, G.; Megahan, W.; Patten, R.; Potyondy, J. 1981. Guide for predicting sediment yields from forested watersheds (the R1/R4 sediment guidelines). Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern and Intermountain Regions.

Cocke, Allison E.; Fulé, Peter Z.; Crouse, Joseph E. 2005. Comparison of burn severity assessments using Differenced Normalized Burn Ratio and ground data. International Journal of Wildland Fire. 14(2): 189-198.

Cooper, Richard M. 2005. Estimation of peak discharges for rural, unregulated streams in western Oregon. Scientific Investigations Report 2005-5116. Reston, VA: U.S. Geological Survey. 134 p.

Daly, Christoper. 2007 (October 24—last update). PRISM Group [Homepage of Prism Group], [Online]. Available: http://www.prism.oregonstate.edu/ [2007, November 6].

DeBano, L. F.; Neary, D. G.; Ffolliott, P. F. 1998. Fire's effects on ecosystems. New York, NY: John Wiley & Sons. 333 p.

Dunne, Thomas; Leopold, Luna B. 1978. Water in environmental planning. New York, NY: W. H. Freeman and Company. 818 p.

Elliot, William J. 2007 (January 22—last update). Forest Service WEPP Interfaces [Homepage of Forest Service WEPP Interfaces], [Online]. Available: http://forest.moscowfsl.wsu.edu/fswepp/ [2008, January 3].

Farmer, E. E.; Fletcher, J. E. 1972. Rainfall intensity-duration-frequency relations for the Wasatch Mountains of northern Utah. Water Resources Research. 8(1): 266-271.

Farnsworth, R. K.; Thompson, E. S.; Peck, E. L. 1982. Evaporation altas for the contiguous 48 United States. NOAA Technical Report NWS 33. Silver Spring, MD: National Oceanic and Atmospheric Administration. 26 p.

Fenneman, N. M. 1946. Physical divisions of the United States: U.S. Geological Survey map prepared in cooperation with the Physiographic Committee of the Geological Survey, scale 1:7,000,000 (reprinted 1964). Reston, VA: U.S. Geological Survey.

Flanagan, D. C.; Livingston, S. J., eds. 1995. WEPP user summary. NSERL Report No.11. West Lafayette, IN: U.S. Department of Agriculture, Agricultural Research Service, National Soil Erosion Research Laboratory. 131 p.

Flint, R. F. 1955. Pleistocene geology of eastern South Dakota. Professional Paper 262. Reston, VA: U.S. Geological Survey. 173 p.

Foltz, Meg. 2008. A WATBAL watershed program input data and summary report for U.S. Department of Agriculture, Forest Service, Clearwater National Forest. Unpublished data supplied to author by M. Foltz, a Clearwater National Forest hydrologist.

Gallaher, B. M.; Koch, R. J. 2004. Cerro Grande Fire impacts to water quality and stream flow near Los Alamos National Laboratory: Results of four years of monitoring. LA-14177. Springfield, VA: U.S. Department of Commerce, National Technical Information Service. 195 p.

Gilman, Charles S. 1964. Rainfall. In: Chow, Ven Te. Handbook of applied hydrology. New York, NY: McGraw-Hill: section 9.

Grove, Matt; Harbor, Jon; Engel, Bernard. 1998. Composite vs. distributed curve numbers: effects on estimates of storm runoff depths. Journal of the American Water Resources Association. 34(5): 1015-1023.

Harris, D. D.; Hubbard, Larry L.; Hubbard, Lawrence E. 1979. Magnitude and frequency of floods in western Oregon. Open-File Report 79-553. Portland, OR: U.S. Geological Survey. 35 p.

Harris, D. D.; Hubbard, Lawrence E. 1983. Magnitude and frequency of floods in eastern Oregon. Water-Resources Investigations Report 82-4078. Denver, CO: U.S. Geological Survey. 39 p.

Haupt, H. F. [and others]. 1976. Forest hydrology, part II, hydrologic effects of vegetation manipulation. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

Hawkins, R. H.; Greenberg, R. J. 1990. WILDCAT4 Flow Model. [This edition further enhances Moore's version] School of Renewable Natural Resources, University of Arizona, Tucson, AZ. BLM contact: Dan Muller, Denver, CO.

Hawkins, R. H. 2008. Personal communication with the model developer of WILDCAT4 at U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow Forest Science Laboratory.

Higginson, Brad; Jarnecke, Jeremy. 2007. Salt Creek BAER-2007 Burned Area Emergency Response. Provo, UT: Unita National Forest; Hydrology Specialist Report. 11 p.

Istanbulluoglu, Erkan; Tarboton, David G.; Pack, Robert T.; Luce, Charles. 2003. A sediment transport model for incision of gullies on steep topography. Water Resources Research. 39(4): 1103.

Istanbulluoglu, Erkan; Tarboton, David G.; Pack, Robert T.; Luce, Charles. 2002. A probablistic approach for channel initiation. Water Resources Research. 38(12): 1325.

Istanbulluoglu, Erkan; Tarboton, David G.; Pack, Robert T.; Luce, Charles. 2004. Modeling of the interactions between forest vegetation, disturbances, and sediment yields. Journal of Geophysical Research. 109: F01009.

Jennings, Marshall E.; Thomas, Wilbert O., Jr.; Riggs, H. C. 1994. Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993. Water-Resources Investigations Report 94-4002. Denver, CO: U.S. Geological Survey. 196 p.

Johnson, Ada Suzanne. 2003. Aspen fire 2003 treatment success monitoring report. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwest Region, Coronado National Forest. 21 p

Johnson, Steve; Gould, Jessica. 2003. Burned area emergency stabilization and rehab plan, Blackfoot Complex Fires, Flathead NF, watershed resource assessment. Libby, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Kootenai National Forest. 10 p.

Jones, Richard. 2000. BAER report, Crooked Fire, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 15 p.

Jones, Richard. 2005. Watershed response model for forest management: WATBAL technical users guide, revised. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 36 p.

Kenney, Terry A.; Wilkowske, Chris D.; Wright, Shane J. 2007. Methods for estimating magnitude and frequency of peak flows for natural streams in Utah. Scientific Investigations Report 2007-5158. Reston, VA: U.S. Geological Survey. 28 p.

Key, Carl H.; Benson, Nathan C. 2006. Landscape assessment: Sampling and analysis methods. In: Lutes, Duncan C., eds. FIREMON: Fire Effects Monitoring and Inventory System. Gen. Tech. Rep. RMRS-GTR-164-CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

Kjelstorm, L. C.; Moffat, R. L. 1981. A method for estimating flood-frequency parameters for streams in Idaho. Open-File Report 81-909. Boise, ID: U.S. Geological Survey. 101 p.

Knowles, Scott M.; Sumioka, Steve S. 2001. The national flood-frequency program-methods for estimating flood magnitude and frequency in Washington, 2001. USGS Fact Sheet 016-01. Reston, VA: U.S. Geological Survey. 4 p.

Kuyumjian, Gregory A. 2007. Personal communication with a Santa Fe National Forest hydrologist at U.S. Department of Agriculture, Forest Service, Santa Fe National Forest.

Leaf, C. F.; Brink, G. E. 1973. Hydrologic simulation model of the Colorado subalpine forest. Research Paper RM-107. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

Lefevre, Robert [and others]. 2002. BAER report, Bullock Fire, Coronado National Forest, Arizona. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Region, Coronado National Forest. 14 p.

Livingston, Russell K.; Earles, T. Andrew; Wright, Kenneth R. 2005. Los Alamos post-fire watershed recovery: a curve-number-based evaluation. In: Moglen, Glenn E., eds. Proceedings: 2005 watershed management conference—managing watersheds for human and natural impacts: engineering, ecological, and economic challenges; 2005 July 19-22; Williamsburg, VA. Alexandria, VA: American Society of Civil Engineers: 471-481.

Luce, Charles H.; Tarboton, David G.; Istanbulluoglu, Erkan; Pack, Robert T. 2005. Reply to comment by Johnathan J. Rhodes on “Modeling of the interactions between forest vegetation, disturbances, and sediment yields.” Journal of Geophysical Research. 110: F01013.

Luce, Charles. 2005. Land use and land cover effects on runoff processes: fire. Encyclopedia of Hydrological Sciences. 13: 1831-1837.

Mann, Michael P.; Rizzardo, Julé; Satkowski, Richard. 2004. Evaluation of methods used for estimating selected streamflow statistics, and flood frequency and magnitude, for small basins in north coastal California. Scientific Investigations Report 2004-5068. Reston, VA: U.S. Geological Survey. 92 p.

Mason, Robert R., Jr.; Fuste, Luis A.; King, Jeffrey N.; Thomas, Wilbert O., Jr. 2000. The national flood-frequency program—methods for estimating flood magnitude and frequency in rural areas in New Mexico. USGS Fact Sheet 050-00. Reston, VA: U.S. Geological Survey. 4 p.

Miller, J. F.; Frederick, R. H.; Tracey, R. J. 1973a. NOAA Atlas 2. Precipitation-frequency atlas of the western United States. Volume I—Montana. Silver Spring, MD: NOAA.

Miller, J. F.; Frederick, R. H.; Tracey, R. J. 1973b. NOAA Atlas 2. Precipitation-frequency atlas of the western United States. Volume V—Idaho. Silver Spring, MD: NOAA.

Miller, Kirk A. 2003. Peak-flow characteristics of Wyoming streams. Water-Resources Investigations Report 03-4107. Denver, CO: U.S. Geological Survey. 79 p.

Montana Department of Commerce. (2003—last update). Montana Fire Facts, Fires of 2000 [Homepage of Montana Fires of 2000], [Online]. Available: http://visitmt.com/fire/2000fires/fires2k.htm [2008, July 11].

Moody, John A.; Martin, Deborah A. 2001. Hydrologic and sedimentologic response of two burned watersheds in Colorado. Water-Resources Investigations Report 01-4122. Denver, CO: U.S. Geological Survey. 142 p.

Moody, John A.; Martin, Deborah A.; Haire, Sandra L.; Kinner, David A. 2007. Linking runoff response to burn severity after a wildfire. Hydrological Processes. 22(13): 2063-2074. DOI: 10.1002/hyp.6806.

Napper, Carolyn. 2006. Burned Area Emergency Response treatment catalog. Watershed, Soil, Air Management 0625 1801—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology & Development Center. 254 p.

National Oceanic and Atmospheric Administration. 2008 (March 19—last update). NOAA's National Weather Service Hydrometeorological Design Studies Center [Hompage of HDSC], [Online]. Available: http://www.nws.noaa.gov/oh/hdsc/index.html [2008, May 6].

Neary, Daniel G.; Ffolliott, Peter F.; Landsberg, Johanna D. 2005. Fire and streamflow regimes. In: Neary, Daniel G.; Ryan, Kevin C.; DeBano, Leonard F., eds. Wildland fire in ecosystems-effects of fire on soil and water. Gen. Tech. Rep. RMRS-GTR-42-volume 4. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: chapter 5.

Novak, P.; Moffat, A. I. B.; Nalluri, C.; Narayanan, R. 2001. Hydraulic structures (3rd ed.). London, UK: Taylor & Francis Group. 666 p.

Office of Federal Procurement Policy. 2008. Federal Acquisition Regulation (FAR). 48 CFR Part 16.5.

Omang, R. J. 1992. Analysis of the magnitude and frequency of floods and the peak-flow gaging network in Montana. Water-Resources Investigations Report 92-4048. Denver, CO: U.S. Geological Survey. 70 p.

Parrett, Charles; Cannon, Susan H.; Pierce, Kenneth L. 2004. Wildfire-related floods and debris flows in Montana in 2000 and 2001. Water-Resources Investigations Report 03-4319. Denver, CO: U.S. Geological Survey. 22 p.

Parrett, Charles; Johnson, D. R. 2004. Methods for estimating flood frequency in Montana based on data through water year 1998. Water-Resources Investigations Report 03-4308. Denver, CO: U.S. Geological Survey. 101 p.

Quillian, E. W.; Harenberg, W. A. 1982. An evaluation of Idaho stream gaging networks. Open-Fire Report 82-865. Boise, ID: U.S. Geological Survey. 61 p.

Rajagopalan, B.; Lall, U. 1999. A k-nearest-neighbor simulator for daily precipitation and other weather variables. Water Resources Research. 35(10): 3089-3101.

Renschler, C. S. 2003. Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. Hydrological Processes. 17(5): 1005-1017.

Renschler, Chris S. 2008 (March 28—last update). GeoWEPP: the Geo-spatial interface for the Water Erosion Prediction Project [Homepage of GeoWEPP], [Online]. Available: http://www.geog.buffalo.edu/~rensch/geowepp/ [2008, May 6].

Rhodes, Jonathan J. 2005. Comment on "Modeling of the interactions between forest vegetation, disturbances, and sediment yields" by Erkan Istanbulluoglu and others Journal of Geophysical Research. 110: F01012.

Robichaud, P. R. 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. Journal of Hydrology: 231-232; 220-229.

Robichaud, P. R. 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. International Journal of Wildland Fire. 14(4): 475-485.

Robichaud, P. R.; Beyers, J. L.; Neary, D. G. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Robichaud, Peter R.; Elliot, William J.; Pierson, Fredrick B.; Hall, David E.; Moffet, Corey A. 2006 (January 18—last update). Erosion Risk Management Tool (ERMiT) Ver. 2006.01.18. [Homepage of ERMiT Erosion Risk Management Tool], [Online]. Available: http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl [2008, March 3].

Robichaud, Peter R.; Elliot, William J.; Pierson, Fredrick B.; Hall, David E.; Moffet, Corey A.; Ashmun, Louise E. 2007. Erosion Risk Management Tool (ERMiT) user manual (version 2006.01.18). Gen. Tech. Rep. RMRS-GTR-188. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Robison, E. George; Mirati, Albert; Allen, Marganne. 1999. Oregon road/stream crossing restoration guide: spring 1999. Salem, OR: Oregon Department of Forestry. 79 p.

Sando, Steven K. 1998. Techniques for estimating peak-flow magnitudue and frequency relations for South Dakota streams. Water-Resources Investigations Report 98-4055. Denver, CO: U.S. Geological Survey. 48 p.

Sauer, V. B. 1974. Flood characteristics of Oklahoma streams. Water-Resources Investigations Report 52-73. Denver, CO: U.S. Geological Survey. 301 p.

Schmidt, Larry J. 1987. Calculated risk: a tool for improving design decisions. In: 18th International Erosion Control Association Conference; 1987 February 26-27; Reno, NV. Proc. Steamboat Springs, CO: International Erosion Control Association: 279-283.

Seaber, P. R.; Kapinos, F. P.; Knapp, G. L. 1987. Hydrologic unit maps. Water-Supply Paper 2294. Denver, CO: U.S. Geological Survey. 63 p.

Shakesby, R. A.; Doerr, S. H.; Walsh, R. P. D. 2000. The erosional impact of soil hydrophobicity: current problems and future research directions. Journal of Hydrology. 231-232: 178-191.

Sirucek, Dean; Olson, Dennis; Butterfly, Henry; Johnson, Steve. 2006. Interagency burned area emergency stabilization & rehabilitation plan, Red Eagle Fire, watershed resource assessment, hydrology and soils. 24 p.

Springer, Everett P.; Hawkins, Richard H. 2005. Curve number and peakflow responses following the Cerro Grande Fire on a small watershed. In: Moglen, Glenn E., eds. Proceedings: 2005 watershed management conference-managing watersheds for human and natural impacts: engineering, ecological, and economic challenges; 2005 July 19-22; Williamsburg, VA. Alexandria, VA: American Society of Civil Engineers: 459-470.

Story, Mark. 2002. A Excel spreadsheet to calculate peakflows from the 2000 Skalkaho/Valley Complex Fires in Montana. Unpublished draft supplied to author by M. Story.

Story, Mark. 2003. Stormflow Methods. E-mail circulation among Forest Service Region 1 hydrologists. Unpublished note supplied by D. Sirucek, a Flathead Nation Forest hydrologist. On file with author.

Story, Mark; Johnson, Steve; Stuart, Bo; Hickenbottom, Jennifer; Thatcher, Ron; Swartz, Scott. 2006. BAER specialist report, hydrology and roads, Derby Fire. Bozeman, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Gallatin National Forest. 17 p.

Stuart, Bo. 2000. Maudlow Fire, Burned Area Emergency Rehabilitation (BAER) plan. Townsend, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Helena National Forest.

Stuebe, M. M.; Johnston, D. M. 1990. Runoff volume estimation using GIS techniques. Water Resources Bulletin. 26(4): 611-620.

Sumioka, S. S.; Kresch, D. L.; Kasnick, K. D. 1998. Magnitude and frequency of floods in Washington. Water-Resources Investigations Report 97-4277. Denver, CO: Geological Survey. 91 p.

Thomas, Blakemore E.; Hjalmarson, H. W.; Waltemeyer, S. D. 1997. Methods for estimating magnitude and frequency of floods in the southwestern United States. Water-Supply Paper 2433. Denver, CO: Geological Survey. 195 p.

U.S. Department of Agriculture, Agricultural Research Service and Forest Service. 2008 (January 23—last update). Cligen Weather Generator, expanded and improved [Homepage of Cligen], [Online]. Available: http://topsoil.nserl.purdue.edu/nserlweb/weppmain/cligen/ [2008, February 7].

U.S. Department of Agriculture, Forest Service. 2003. Forest Service Manual 7712.11, Exhibit 01. Available at: www.fs.fed.us/im/directives/dughtml/fsm.html [2007, May 28].

U.S. Department of Agriculture, Forest Service. 2007 (January 1—last update). Remote Sensing Applications Center: What is a BARC? [Homepage of BARC], [Online]. Available: http://www.fs.fed.us/eng/rsac/baer/barc.html [2008, February 7].

U.S. Department of Agriculture, Geological Survey 2007 (March 14—last update). Welcome to StreamStat [Homepage of StreamStat], [Online]. Available at: http://water.usgs.gov/osw/streamstats/index.html [2008, May 11].

U.S. Department of Agriculture, Natural Resources Conservation Service. 2005a (January 1—last update). Hydraulics and Hydrology: Tools and Models—WinTR-20 [Homepage of WinTR-20], [Online]. Available: http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR20.html [2008, October 24].

U.S. Department of Agriculture, Natural Resources Conservation Service. 2005 (January 1—last update). Hydraulics and Hydrology: Tools and Models—WinTR-55 [Homepage of WinTR-55], [Online]. Available: http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html [2008, February 7].

U.S. Department of Agriculture, Soil Conservation Service. 1972. Hydrology. In: National engineering handbook. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service: section 4.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Urban hydrology for small watersheds. Technical Release 55. Chester, PA: U.S. Department of Agriculture, Soil Conservation Service. 91 p.

U.S. Department of Agriculture, Soil Conservation Service. 1986. Urban hydrology for small watersheds. Technical Release 55. Chester, PA: U.S. Department of Agriculture, Soil Conservation Service. 156 p.

U.S. Department of Agriculture, Soil Conservation Service. 1991. Engineering field handbook: chapter 2—estimating runoff. In: National engineering handbook. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service: part 650.

U.S. Weather Bureau. 1961. Rainfall frequency atlas of the United States. Technical Paper 40. Silver Spring, MD: National Oceanic and Atmospheric Administration. 115 p.

Vaill, J. E. 2000. Analysis of the magnitude and frequency of floods in Colorado. Water-Resources Investigations Report 99-4190. Denver, CO: Geological Survey. 35 p.

Waananen, A. O.; Crippen, J. R. 1977. Magnitude and frequency of floods in California. Water-Resources Investigations Report 77-21. Denver, CO: Geological Survey. 96 p.

Waltemeyer, S. D. 1996. Analysis of the magnitude and frequency of peak discharge and maximum observed peak discharge in New Mexico. Water-Resources Investigations Report 96-4112. Denver, CO: Geological Survey. 79 p.

Watkins, L. H.; Fiddes, D. 1984. Highway and urban hydrology in the tropics. London, UK: Pentech Press Limited. 206 p.

White, D. 1988. Grid-based application of runoff curve numbers. Journal of Water Resources Planning and Management. 114(6): 601-612.

Appendix A—Example Data and Interview Forms

Interview questionnaire for BAER teams

Survey date: *14 Mar 07*

Survey location: *Grangeville, ID*

Interviewee name:

Address: *Nez Perce National Forest, Grangeville, ID*

Telephone number:

E-mail:

Please provide the information of BAER activities that you participated in as much as you can remember, starting from the most recent BAER activity to year 1999.

Year	Fire name	Region	National Forest
2000	Three Bears, Wilderness Cx	1	Bitterroot and Nez Perce
2000	Burnt Flats	1	Nez Perce (Clearwater)
2000	Valley Cx	1	Bitterroot
2001	Taco	1	Nez Perce (Salmon River)
2002	Kelly Creek	1	Nez Perce (Salmon River)
2003	Berg 3	1	Nez Perce (Salmon River)
2003	Fiddle	1	Nez Perce (Salmon River)
2003	Wilderness Cx	1	Nez Perce (Moose Creek)
2003	Slims Cx	1	Nez Perce (Red River, Moose Creek)
2005	Blackerby	1	Nez Perce (Clearwater)
2005	China 10	1	Nez Perce (Clearwater)
2005	Upper Meadow	1	Nez Perce (Moose Creek)
2005	West Fork	1	Nez Perce (Salmon River)
2006	Heavens Gate	1, 6	Nez Perce (Salmon River), Wallowa-Whitman (Hells Canyon NRA)
2006	Meadow	1	Nez Perce (Moose Creek)
2007	Poe Cabin	1, 6	Nez Perce (Salmon River), Wallowa-Whitman (Hells Canyon NRA)
2007	Rattlesnake	1	Nez Perce (Red River, Salmon River)

Please let us know if you have **ANY** BAER reports (FS-2500-8) including initial, interim, and final reports and any BAER related information (gray literature).

BAER Report Questionnaire

What kind of method did you use to calculate/estimate the values in the following section in a BAER report? For example, if you came up with that value from your experience, write “Personal Experience.” If you have the reference publication that you used for that method, please let us know.

Part IV – Hydrologic Design Factors

A. Estimated vegetation Recovery Period, (years): *Personal experience, forest ecologist*

B. Design Chance of Success, (percent): *Professional judgment*

C. Equivalent Design Recurrence Interval, (years): *Usually 10 years*

D. Design Storm Duration, (hours): *For snowmelt, 24 hours; for low elevation storm flow, 6 hours; sometimes 30 min*

E. Design Storm Magnitude, (inches): *NOAA Atlas*

F. Design Flow, (cfs/mi^2): *For low elevation storm flow, NRCS CN method; for mid, high elevation, spring snowmelt RO, USGS StreamStats*

G. Estimated Reduction in Infiltration, (percent): *Actual infiltration tests on burned/unburned area*

H: Adjusted Design Flow, (cfs/mi^2): *For low elevation storm flow, NRCS CN method; for mid, high elevation, spring snowmelt RO, USGS StreamStats; modify moderate and high severity burn area RO × 2 (100% increase) and estimate peak flow for 1st year after fire*

Road Treatment Questionnaire

Please answer following questions based on your general experience.

What are the three most frequently used road treatments?

The most: *Culvert upsize*

Second most: *Rolling/armored dips*

Third most: *Additional relief culvert*

Reason to choose the treatment: *Values at risk*

Was there an alternative road treatment available?

What do you think are the three most effective road treatments?

The most: *Culvert upsize*

Second most: *Culvert removal*

Third most: *Rolling/armored dips*

Reason to choose the treatment:

How do you calculate road treatment cost (be careful to ask this; i.e., was there a standard/guideline to estimate road treatment cost?)?
Engineer's suggestion; regional cost guide

Any comment on BAER road treatments: *NRCS CN method is highly subjective to CN input by user; Nez Perce not using WATBAL; check upstream to include debris to estimate RO; too much debris expected, trash rack and outburst (winged) inlet is recommended; hydromulch culslopes; usually BAER team members have BAER case or bag*

Aftermath Road Treatment Questionnaire

Please answer the following questions using the table below. If you have any written report or documentation related to the following questions, please let us know. (This questions best to ask to local district hydrologists).

Was there a large (or damaging) storm/runoff event in BAER road treatment areas?

If so, please let us know the following information.

(1) **Name** and (2) **Year** of BAER treated fires, and (3) **Location** of BAER road treatment areas.
(4) **When** the large (or damaging) **storm/runoff** events occurred (after the road treatments).
(5) **Magnitude of storm** and (6) **Magnitude of runoff**, such as precipitation and runoff amount.
(7) Did the road treatment **fail or hold**?
(8) If failed, what do you think is the primary **reason** for this road treatment to fail?
(9) If failed, did the treated **road section fail too or** did **only the road treatment fail**?
(10)After this road treatment failed, what did you do (**failure aftermath**)?

(1)	Fire name	*Blackerby Fire*	
(2)	Fire year	*2005*	
(3)	Fire/BAER location	*Grangeville, ID*	
(4)	When storm/runoff?	*19 May 06*	
(5)	Storm magnitude (inch)	*0.78 inch for 30 min*	
(6)	Runoff magnitude (cfs)	*71 cfs (56 cfs mi^{-2}) for flood flow; 620 cfs (492 cfs mi^{-2}) for debris flow*	
(7)	Fail/Hold	*Storm flow failed to pass*	
(8)	Reason for failure	*Exceeding culvert capacity (35 cfs)*	
(9)	Road section failed/only treatment?	*Only treatment*	
(10)	Failure aftermath	*Cleanout*	

Appendix B—List of Gray Literature from BAER Interviews

Region 1

Nick Gerhardt

Gerhardt, Nick. 2005. [Personal notes on file with author.] September 2. China 10—Flow calculations using USGS regression method.

Gerhardt, Nick. 2006. [Personal notes on file with author.] June 26. NRCS post-fire stormflow model, step-by-step.

Gerhardt, Nick. 2006. [Personal notes on file with author.] December 18. Characterization of a post-fire debris flow and flood, Blackerby Fire, Idaho.

Parrett, Charles; Johnson, D. R. 2004. Methods for estimating flood frequency in Montana based on data through water year 1998. Water-Resources Investigations Report 03-4308. Denver, CO: U.S. Geological Survey. 101 p.

Richard Jones

Cahoon, Joel. (2005, August 11—last update). *Circular Culvert Design Spreadsheet* [Online]. Available: http://www.wti.montana.edu/Documents/Reports/PDF/CMP_Hydraulics.xls [2008, July 8].

Cerrelli, G. A. 2005. FIRE HYDRO, a simplified method for predicting peak discharges to assist in the design of flood protection measures for western wildfires. In: Moglen, Glenn E., eds. Proceedings: 2005 watershed management conference—managing watersheds for human and natural impacts: engineering, ecological, and economic challenges; 2005 July 19–22; Williamsburg, VA. Alexandria, VA: American Society of Civil Engineers: 935–941.

Jones, Richard. 1996. [Personal notes on file with author.] January 1. The CLWFLOOD program predicts flood frequencies using eight procedures (revised).

Jones, Richard. 2000. September 11. BAER report, Crooked Fire, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 15 p.

Jones, Richard; Mital, James. 2003. September 26. Burned area report, Beaver Lakes Complex, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 11 p.

Jones, Richard; Mital, James. 2003. September 26. BAER report, Hopeful 2 Fire, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 10 p.

Jones, Richard; Mital, James. 2003. September 26. BAER report, Bear's Oil, Wendover, Pleasant, and Rhodes Fires, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 12 p.

Mital, James. 2000. October 16. BAER report, Snow Creek Fire, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 12 p.

Mital, James. 2000. October 16. BAER report, Elizabeth Fire, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 10 p.

Mital, James. 2001. September 17. BAER report, Walton Fire, Clearwater National Forest, Idaho. Orofino, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Clearwater National Forest. 11 p.

Snook, Ed; Jones, Richards [and others]. 2006. September 13. Burned area report, Gash Creek Incident Fire, Bitterroot National Forest, Montana. Hamilton, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Bitterroot National Forest. 13 p.

Rick Patten

Patten, Rick. 2006. October 31. Burned area report, Ulm Peak Fire, Idaho Panhandle National Forests, Idaho. Coeur d'Alene, ID: U.S. Department of Agriculture, Forest Service, Northern Region, Idaho Panhandle National Forests. 27 p.

Dean Sirucek

Gardner, Beth; Boelman, Shawn. 2004. [Personal notes on file with author.] February 17. Crazy Horse BAER-modifications on item C. of the original BAER specs-install corrugated metal pipe. 29 p.

Interagency Burned Area Emergency Response Team. 2003. August 29. Interagency Burned Area Emergency Stabilization and Rehabilitation Plan, Robert and Trapper Creek Fires, Water Resource Assessment. Hungry Horse and West Glacier, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Flathead National Forest, and National Park Service, Glacier National Park. 20 p.

Sirucek, Dean; Olson, Dennis; Butterfly, Henry; Johnson, Steve. 2006. Interagency burned area emergency stabilization & rehabilitation plan, Red Eagle Fire, watershed resource assessment, hydrology and soils. 24 p.

Mark Story

Cahoon, Joel. (2005, August 11–last update). *Circular Culvert Design Spreadsheet* [Online]. Available: http://www.wti.montana.edu/Documents/Reports/PDF/CMP_Hydraulics.xls [2008, July 8].

Story, Mark; Johnson, Steve; Stuart, Bo; Hickenbottom, Jennifer; Thatcher, Ron; Swartz, Scott. 2006. September. BAER specialist report, hydrology and roads, Derby Fire. Bozeman, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Gallatin National Forest. 17 p.

Story, Mark. 2003. [Personal notes on file with author.] September. Stormflow methods.

Bo Stuart

Story, Mark; Johnson, Steve; Stuart, Bo; Hickenbottom, Jennifer; Thatcher, Ron; Swartz, Scott. 2006. September. BAER specialist report, hydrology and roads, Derby Fire. Bozeman, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Gallatin National Forest. 17 p.

Stuart, Bo. 2000. September 26. Maudlow Fire, Burned Area Emergency Rehabilitation (BAER) plan. Helena, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Helena National Forest.

Stuart, Bo. 2003. September 22. Snow-Talon Fire Burned Area Emergency Rehabilitation (BAER) Plan. Helena, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Helena National Forest. 57 p.

Region2

Greg Bevenger

Johnson, Steve; Gould, Jessica. 2003. Burned area emergency stabilization and rehab plan, Blackfoot Complex Fires, Flathead NF, watershed resource assessment. Libby, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Kootenai National Forest. 10 p.

Solt, Adam; Muir, Mark. 2006. July 8. Warm Fire-hydrology and watershed report. Richfield, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Fishlake National Forest. 9 p.

Souders, Charles. 2006. July 8. Warm Fire burned area, Kaibab NF, Burned Area Emergency Response assessment, soil resource conditions. Silver City, NM: U.S. Department of Agriculture, Forest Service, Southwest Region, Gila National Forest. 9 p.

Region 3

Robert Lefevre

Eychaner, James H. 1984. Estimation of magnitude and frequency of floods in Pima County, Arizona, with comparisons of alternative methods. Water-Resources Investigations Report 84-4142. Denver, CO: U.S. Geological Survey. 69 p.

Furniss, Michael J. (2002-last update). *The six-D system for effective waterbars* [Online]. Available: http://www.fs.fed.us/r5/baer/six-d.html [2008, July 13].

Lefevre, Robert. [Personal notes on file with author.] Greg's Curve Number thoughts.

Lefevre, Robert; [and others]. 2002. June 18. BAER report, Bullock Fire, Coronado National Forest, Arizona. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Region, Coronado National Forest. 14 p.

Pearthree, Philip A.; Youberg, Ann. 2006. Recent debris flows and floods in southern Arizona. Arizona Geology 36(3). 6 p.

Roeske, R. N. 1978. Methods for estimating the magnitude and frequency of floods in Arizona. Arizona Department of Transportation report: ADOT-RS-15(121) final report. Phoenix, AZ: U.S. Department of Transportation, Federal Highway Administration. 82 p.

Solomon, Rhey; Maxwell, Jim; Shaw, Doug; Schmidt, Larry. 1981. June 18. Watershed condition hydrology overview. Hydrology Notes. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Wildland Fire Lessons Learned Center. 2006. Burned Area Emergency Response (BAER) Lessons Learned. Scratchline, Issue 15. 6 p.

U.S. Forest Service Coronado National Forest. 2003. Aspen Fire, Coronado National Forest, BAER hydrology report. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Region, Coronado National Forest: 24-30.

Greg Kuyumajian

Gallaher, Bruce M.; Koch, Richard J. 2004. September. Cerro Grande Fire impacts to water quality and stream flow near Los Alamos National Laboratory: results of four years of monitoring. LA-14177. Springfield, VA: U.S. Department of Commerce, National Technical Information Service. 195 p.

Johnson, Ada Suzanne. 2003. Aspen Fire 2003 treatment success monitoring report. Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwest Region, Coronado National Forest. 21 p.

Kuyumajian, Greg. 2007. [Personal notes on file with author.] April 24. BAER design storms, FY 2000-2003, southwestern region, USDA Forest Service.

Grant Loomis

Baldys, Stanley III; Hjalmarson, H. W. 1994. Effects of controlled burning of chaparral on streamflow and sediment characteristics, East Fork Sycamore Creek, central Arizona. Water-Resources Investigations Report 93-4102. Denver, CO: U.S. Geological Survey. 33 p.

Reed, William B.; Schaffner, Mike. 2007. Effects of wildfire in the mountainous terrain of southeast Arizona: an empirical formula to estimate 5-year peak discharge from small post-burn watersheds. NOAA Technical Memorandum NWS WR-279. Springfield, VA: U.S. Department of Commerce, National Technical Information Service. 22 p.

Reneau, Steven L.; Kuyumajian, Gregory A. 2004. December. Rainfall-runoff relations in Pueblo Canyon, New Mexico, after the Cerro Grande Fire. Los Alamos National Laboratory Report LA-UR-04-8810. Los Alamos, NM: Los Alamos National Laboratory. 32 p.

Schaffner, Mike; Reed, William B. 2005. (2005-last update). *Effects of wildfire in the mountainous terrain of southeast Arizona: post-burn hydrologic response of nine watersheds* [Homepage of 2005 Technical Attachments 05-01], [Online]. Available: http://www.wrh.noaa.gov/wrh/TA05.php [2008, July 25].

White, William D. 1994. Geomorphic response of six headwater basins fifteen years after the La Mesa Fire, Bandelier National Monument. In: Allen, Craig D, ed. Fire effects in southwestern forests: proceedings of the second La Mesa Fire symposium; 1994 March 29-31; Los Alamos, NM. Proc. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 95-113.

Region 4

Mike Dixon

Dixon, Mike. 2008. [Personal notes on file with author.] March 17. 100 year flood flow culvert analysis.

Terry Hardy and John Thorton

Schmidt, Larry J. 1987. Calculated risk: a tool for improving design decisions. In: 18th International Erosion Control Association Conference; 1987 February 26-27; Reno, NV. Proc. Steamboat Springs, CO: International Erosion Control Association: 279-283. Stream Notes; 1998 October. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 5 p.

BAER—Burned Area Emergency Response burn severity field data sheet.

Region 5

Mike Bradshaw

Frazier, Jim; [and others]. 2005. March 31. BAER report, Cedar Fire, Cleveland National Forest, California. San Diego, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Cleveland National Forest. 12 p.

Alex Janicki

Janicki, Alex [and others]. 2003. July 8. BAER report, Woodlot Fire, Stanislaus National Forest, California. Sonora, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Stanislaus National Forest. 12 p.

Carolyn Napper

Napper, Carolyn. 2006. June 15. BAER report, Arrastre Fire, San Bernardino National Forest, California. San Bernardino, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Bernardino National Forest. 8 p.

Stamer, Marc [and others]. 2006. January 31. BAER report, Plunge Fire, San Bernardino National Forest, California. San Bernardino, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Bernardino National Forest. 11 p.

Gregory Napper

Napper, Gregory S. 1999. [Unpublished BAER course material on file with author.] May 3–7. Burned Area Emergency Rehabilitation techniques course.

Mike Parenti

Parenti, M. [and others]. 2002. [Unpublished hydrology report on file with author.] June 11. Hydrologist Report, Arrowhead Fire, San Bernardino National Forest.

Parenti, M. [and others]. 2003. [Unpublished guideline on file with author.] May 1. Modified Rational GIS flow model users guide 1.0.

Parenti, M. [and others]. 2003. [Unpublished guideline on file with author.] May 1. Revised Universal Soil Loss Equation GIS model users guide 1.0.

Appendix C—USGS Regression Methods

The USGS regression methods were developed to estimate peak flow discharge for gaged and ungaged natural flow streams, which were categorized into (1) a gaged site, (2) a site near a gaged site near the same stream, and (3) an ungaged site. StreamStats are available for many states (fig. 1), which is a web-based tool used to obtain streamflow information (http://water.usgs.gov/osw/streamstats/index.html), and estimate peak flow in a given location. For most other western United States, two USGS regression methods for ungaged sites are available. Thomas and others (1997) developed the USGS regression methods in the southwestern United States (fig. C.1). Additionally, each state has one or more publications of USGS regression methods of its own. This report summarizes the USGS regression methods by Thomas and others (1997) and other state-by-state USGS regression methods for ungaged sites in the western United States. Peak flow discharge for gaged sites and sites near gaged site near stream are estimated by the following methods.

Gaged Sites

Weighted estimates were considered to be the best estimates of flood frequency at a gaged site, and the following equation was used for the weighted estimate (Sauer 1974):

$$Q_{T(w)} = \frac{Q_{T(s)}N + Q_{T(r)}E}{N + E} \tag{Eq. C.1}$$

Where:

$Q_{T(w)}$ = weighted discharge, in ft^3/sec, for T-year recurrence interval

$Q_{T(s)}$ = station value of the discharge, in ft^3/sec, for T-year recurrence interval

$Q_{T(r)}$ = regression value of the discharge, in ft^3/sec, for T-year recurrence interval

N = number of years of station data used to compute $Q_{T(s)}$

E = equivalent years of record for $Q_{T(r)}$

Figure C.1—Flood Regions in the Southwestern United States (Thomas and others 1997).

Sites Near Gaged Sites on the Same Stream

Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites. The drainage-area ratio should be approximately between 0.5 and 1.5. If ungaged and gaged basins have similar characteristics in topography, geology, and vegetation, and the drainage-area ratio requirement, the following equations can be used for peak flow:

$$Q_{T(u)} = Q_{T(g)}(A_u / A_g)^x \qquad \text{(Eq. C.2)}$$

Where:

$Q_{T(u)}$ = peak flow, in ft^3/sec, at ungaged site for T-year recurrence interval
$Q_{T(g)}$ = peak flow, in ft^3/sec, at gaged site for T-year recurrence interval
A_u = drainage area, in mi^2, at ungaged site
A_g = drainage area, in mi^2, at gaged site
x = exponent for each flood region as follows:

Flood region		
Name	**Number**	**Exponent, *x***
High-Elevation	1	0.8
Northwest	2	0.7
South-Central Idaho	3	0.7
Northeast	4	0.7
Eastern Sierra	5	0.8
Northern Great Basin	6	0.6
South-Central Utah	7	0.5
Four Corners	8	0.4
Western Colorado	9	0.5
Southern Great Basin	10	0.6
Northeastern Arizona	11	0.6
Central Arizona	12	0.6
Southern Arizona	13	0.5
Upper Gila Basin	14	0.5
Upper Rio Grande Basin	15	0.5
Southeast	16	0.4

Applicable when the drainage area ratio (A_u/A_g) is between 0.5 and 1.5.

Ungaged Sites

Flood-frequency relations at ungaged sites were estimated using the regional models of regression equations and developed using basin and climate characteristics as explanatory variables in the flowing section. There are three models in equations C.3 through C.8 to express the relation between peak flow and basin and climate characteristics. The most common relation is in the following form:

$$Q_T = a\,\mathrm{A}^b\,\mathrm{B}^c \qquad \text{(Eq. C.3)}$$

The following linear relation is obtained by logarithmic transformation:

$$\log Q_T = \log a + b \log A + c \log B + \dots, \qquad \text{(Eq. C.4)}$$

Where:

Q_T = peak flow, in ft^3/sec, for T-year recurrence interval
A and B = explanatory variables
a, b, c = regression coefficients

Drainage area is the most significant explanatory variable, and in some cases, the relation between the logarithm of peak flow (Q_T) and the logarithm of drainage area is not linear. The following form of equations is used in such cases:

$$Q_T = 10^{\left(a + bAREA^x\right)} B^c\ , \qquad \text{(Eq. C.5)}$$

or the logarithmic transformation:

$$\log Q_T = a + b\ \mathrm{AREA}^x + c \log B + \dots, \qquad \text{(Eq. C.6)}$$

Where:

AREA = drainage area
B = other basin or climatic characteristic
x = exponent for AREA for which the relation is made linear

The third form of equations is another method to account for a nonlinear relation between the logarithm of Q_T and the logarithm of drainage area.

$$Q_T = a\ \mathrm{AREA}^b\,(B\text{-}d)^c, \qquad \text{(Eq. C.7)}$$

or the logarithmic transformation:

$$\log Q_T = \log a + b \log \mathrm{AREA} + c \log(B\text{-}d) + \dots, \qquad \text{(Eq. C.8)}$$

Where:

d = a constant, which is less than the minimum value of B, for which the relation is made linear

Explanatory Variables

For the purpose of the report by Thomas and others (1997), six basin and climate characteristics are referred to as explanatory variables and are used as terms in the model equations. The abbreviation for each variable and method of measuring the variable are as follows:

1. AREA is the drainage area, in square miles, and is determined by planimetering the contributing drainage area on the largest scale topographic map available.

2. ELEV is the mean basin elevation, in feet above sea level, and is determined by placing a transparent grid over the drainage-basin area, which is drawn on the largest scale topographic map available. The elevations of a minimum of 20 equally spaced points are determined, and the average of the points is taken. As many as 100 points may be needed for large basins.
3. PREC is the mean annual precipitation, in inches, and is determined by placing a transparent grid over an isohyetal map of mean annual precipitation. The drainage-area boundary is drawn on the map, the mean annual precipitation is determined at each grid intersection, and the values are averaged for the basin.
4. EVAP is the mean annual free water-surface evaporation, in inches, and was determined for gages sites by linear interpolation between the isolines of map 3 from Farnsworth and others (1982). The value used for the regression equations was the value at the gaged-site location; therefore, in the application of the regression equations, the study-site location should be used. To use the methods from the report by Thomas and others (1997), EVAP should be estimated for the study site by linear interpolation between the isolines of EVAP shown in figures C.2, C.7, and C.22.
5. LAT is the latitude of the gaged site, in decimal degree, and is determined using the largest scale topographic map available. The value used for the regression equations was the value at the gaged-site location; therefore, in the application of the regression equations, the study-site location should be used. Decimal degrees are the minutes and seconds of the latitude converted to a decimal.
6. LONG is the longitude of the gaged site, in decimal degrees, and is determined using the largest scale topographic map available. The value used for the regression equations was the value at the gaged-site location; therefore, in the application of the regression equations, the study-site location should be used. Decimal degrees are the minutes and seconds of the longitude converted to a decimal.

The USGS regression methods for regions developed by Thomas and others (1997) are shown in fig. C.1 and tables C.1 to C.16. Additionally, other state-by-state USGS regression methods for ungaged sites in the western United States follow in the form of tables and figures arranged in alphabetical order.

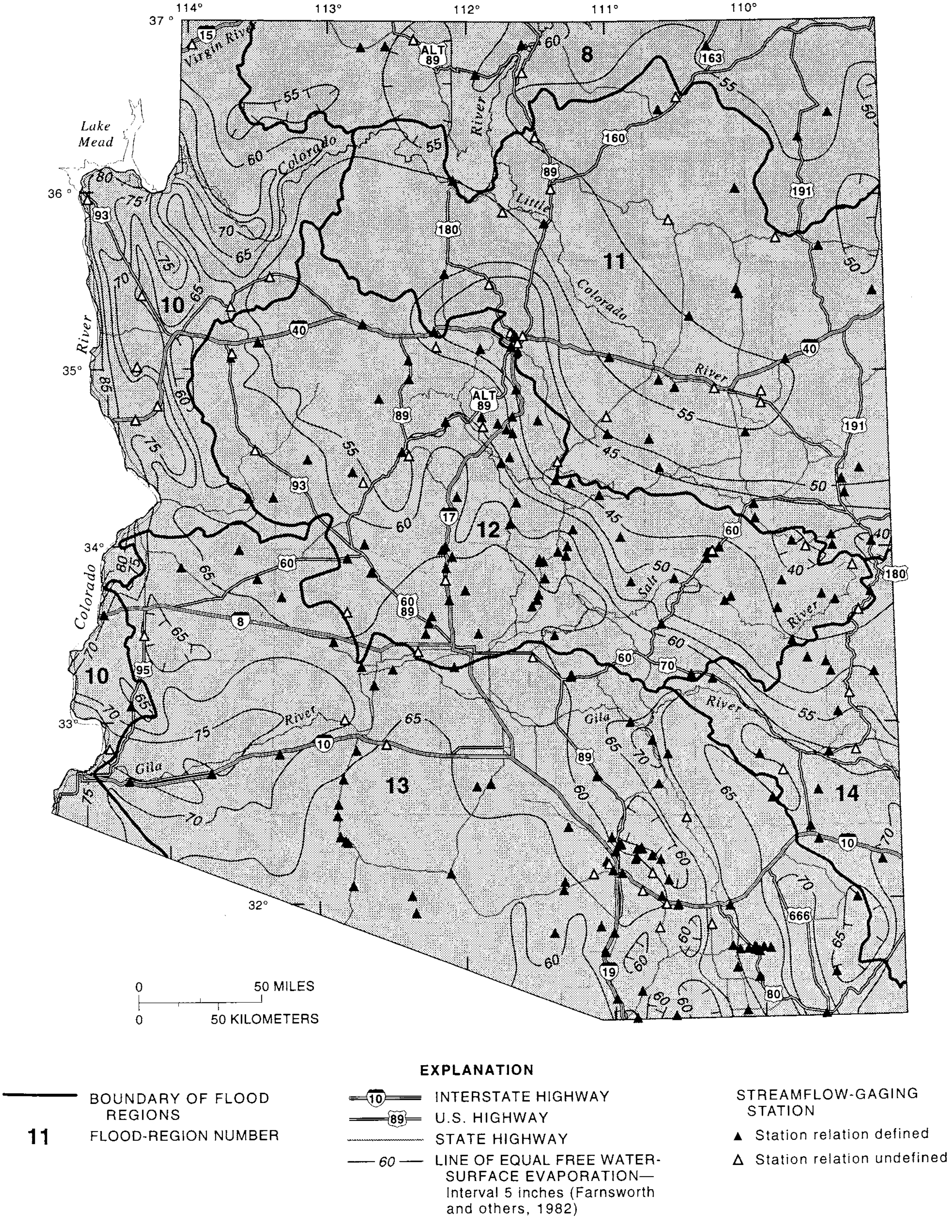


Figure C.2—Free water-surface evaporation for Arizona (Farnsworth and others 1982; Thomas and others 1997).

Digital base from U.S. Geological Survey 1:2,000,000, 1970

Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

Figure C.3—Hydrologic Regions of California (Jennings and others 1994; Waananen and Crippen 1977).

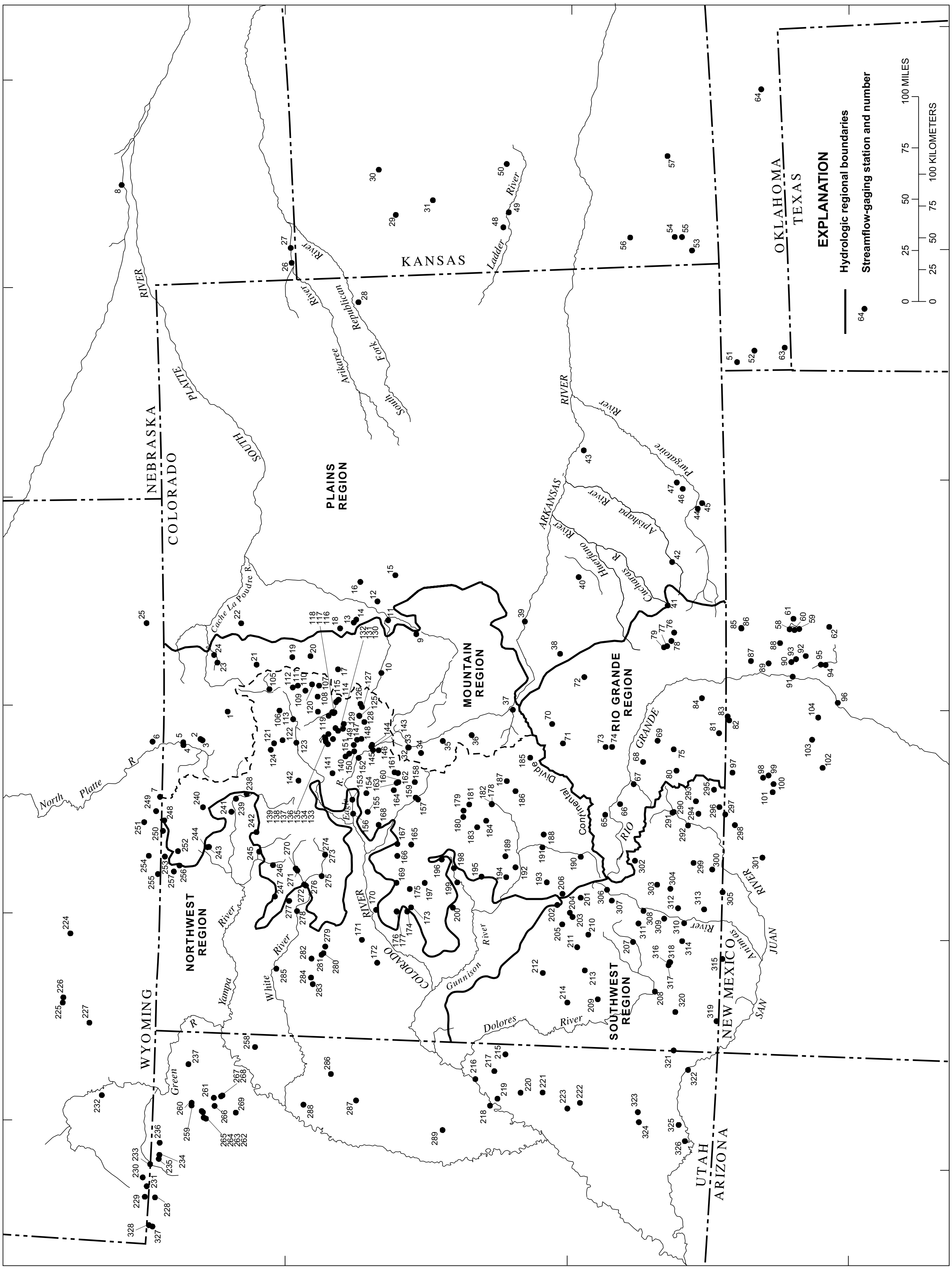
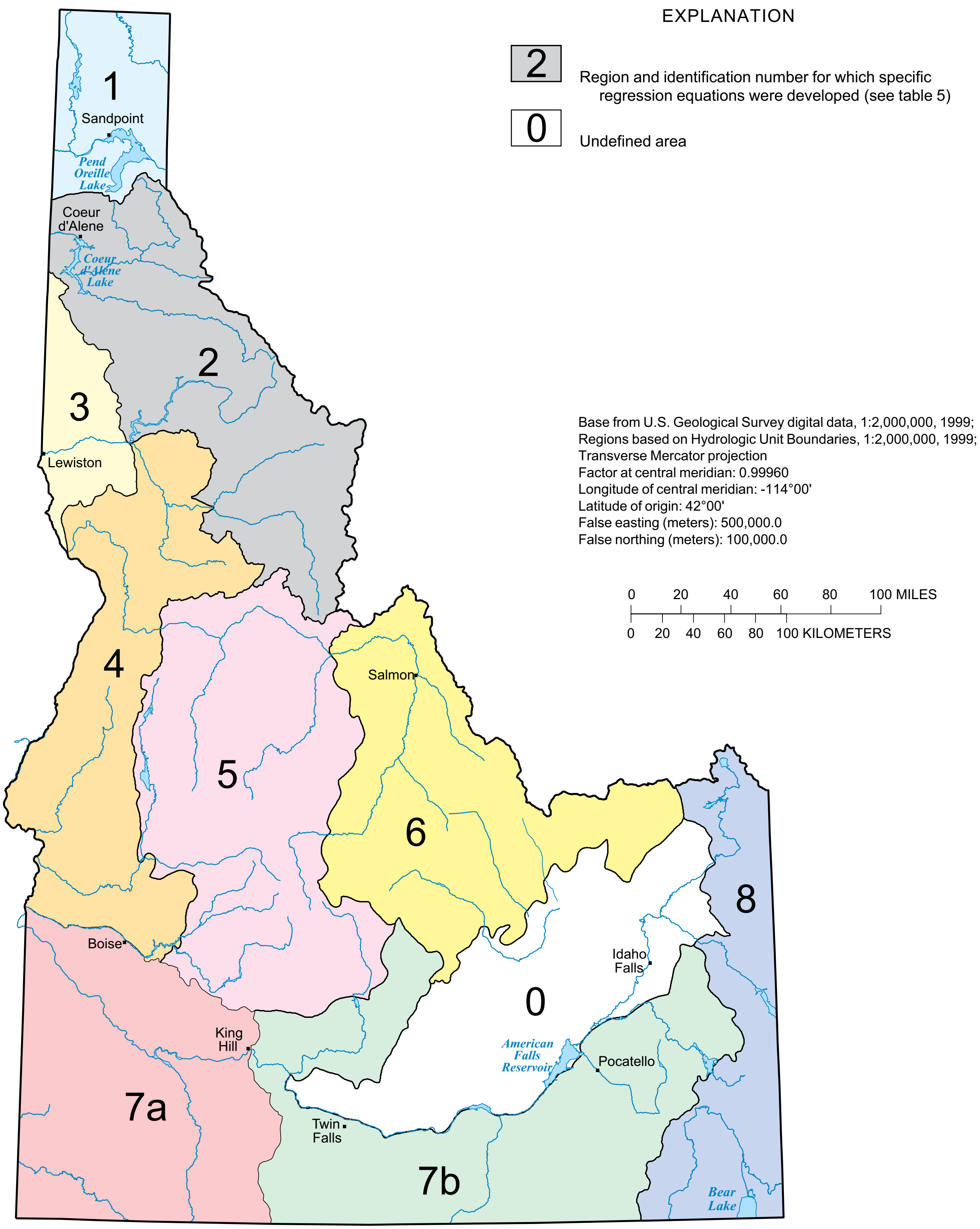


Figure C.4—Hydrologic Regions and location of streamflow-gaging stations in Colorado and adjacent States (Vaill 2000).



Base from U.S. Geological Survey digital data, 1:2,000,000, 1999;
Regions based on Hydrologic Unit Boundaries, 1:2,000,000, 1999;
Transverse Mercator projection
Factor at central meridian: 0.99960
Longitude of central meridian: -114°00'
Latitude of origin: 42°00'
False easting (meters): 500,000.0
False northing (meters): 100,000.0

Figure C.5—Hydrologic Regions of Idaho (Berenbrock 2002).

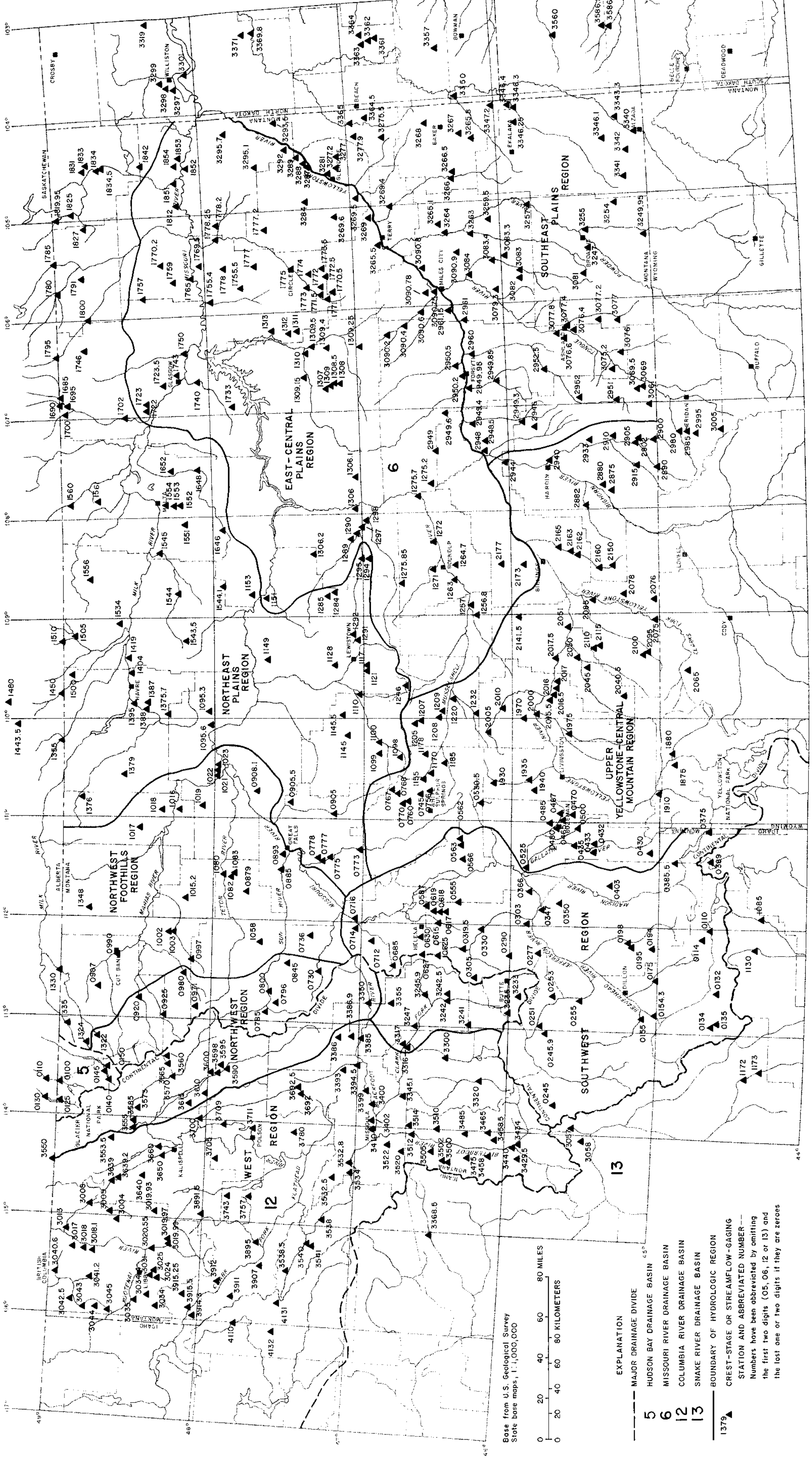


Figure C.6—Map showing boundaries of Hydrologic Regions and location of crest-stage and streamflow-gaging stations in Montana and adjacent areas (Omang 1992).

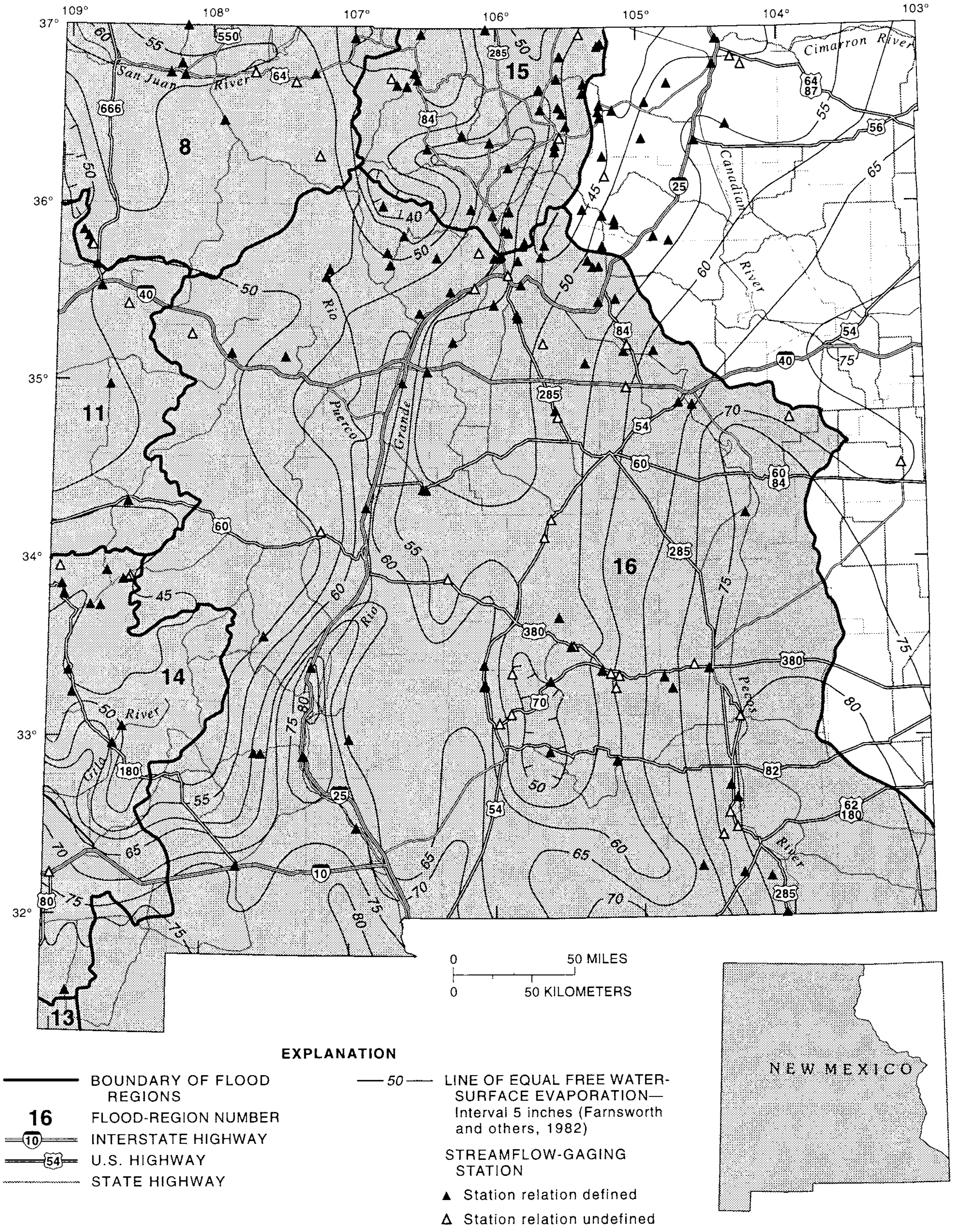


Figure C.7—Free water-surface evaporation for New Mexico (Farnsworth and others 1982; Thomas and others 1997).

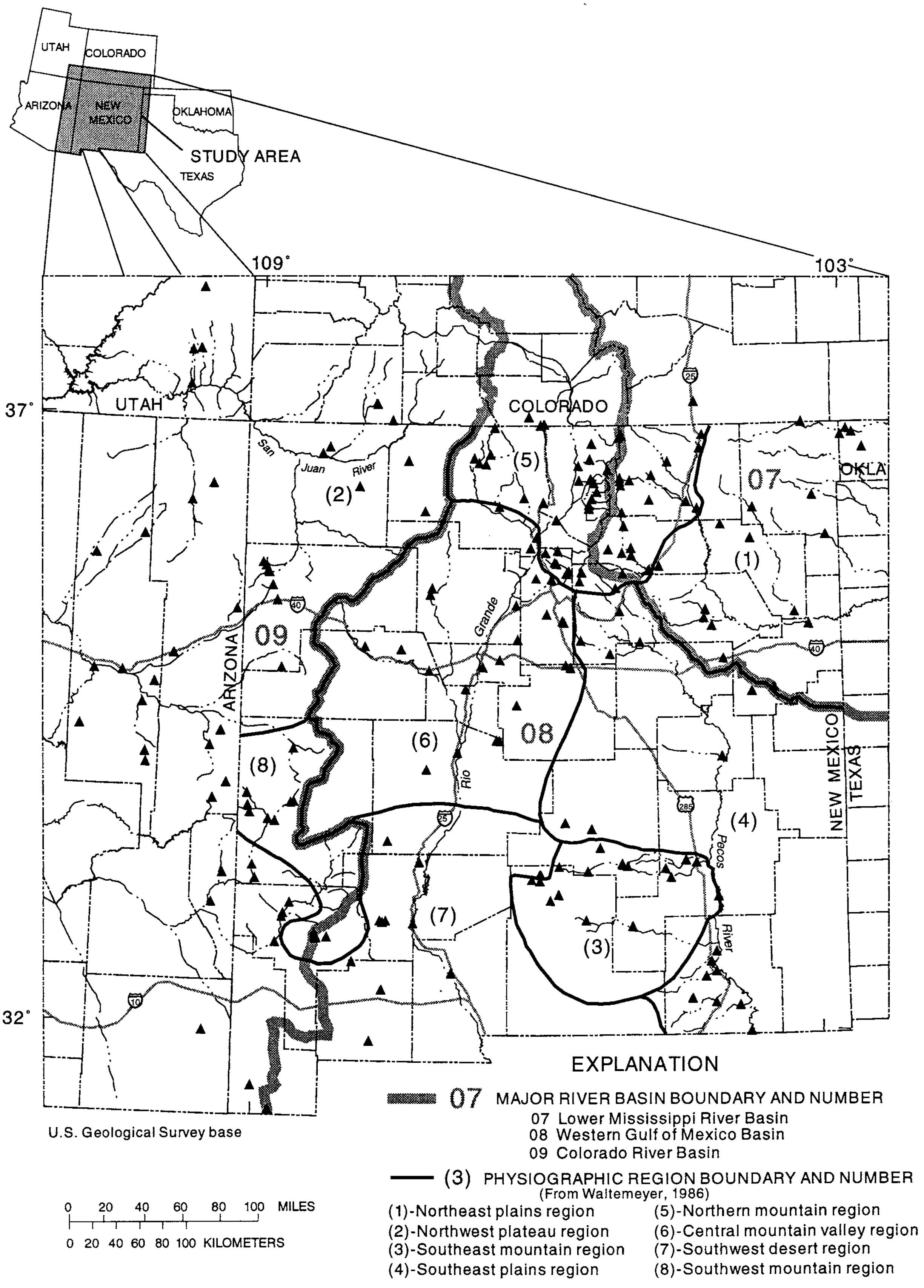
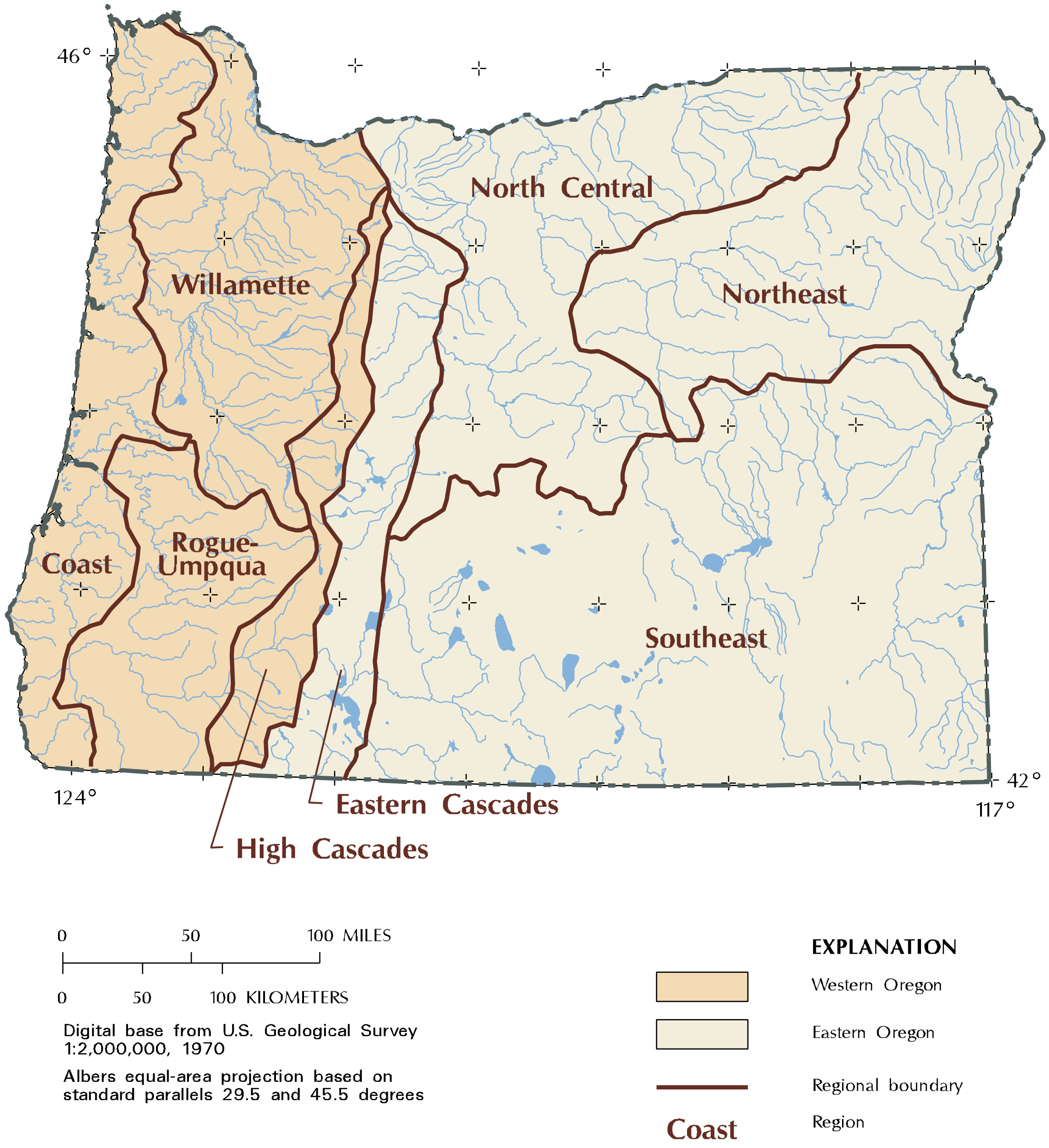


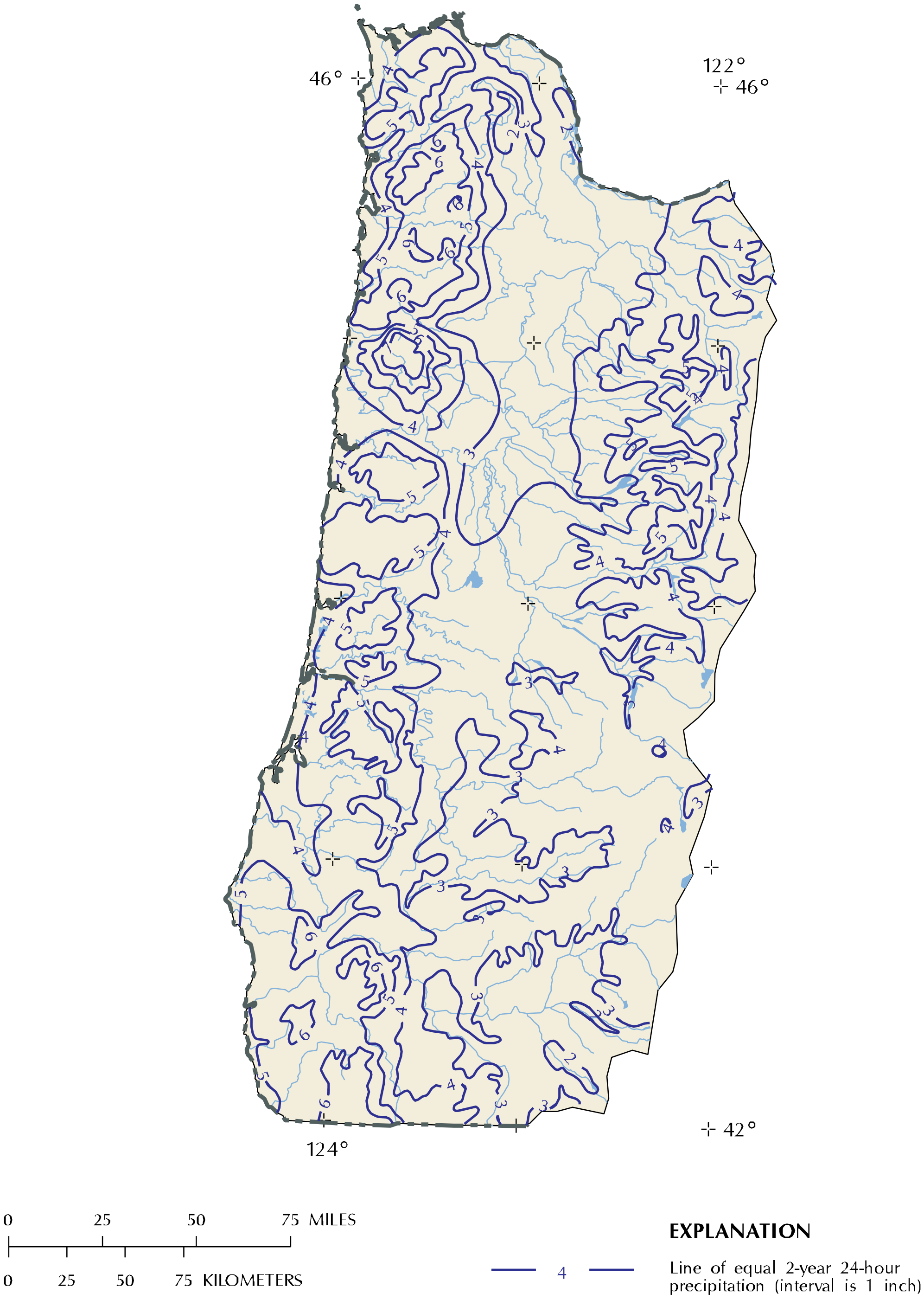
Figure C.8—Hydrologic Regions of New Mexico (Waltemeyer 1996).



Digital base from U.S. Geological Survey
1:2,000,000, 1970

Albers equal-area projection based on
standard parallels 29.5 and 45.5 degrees

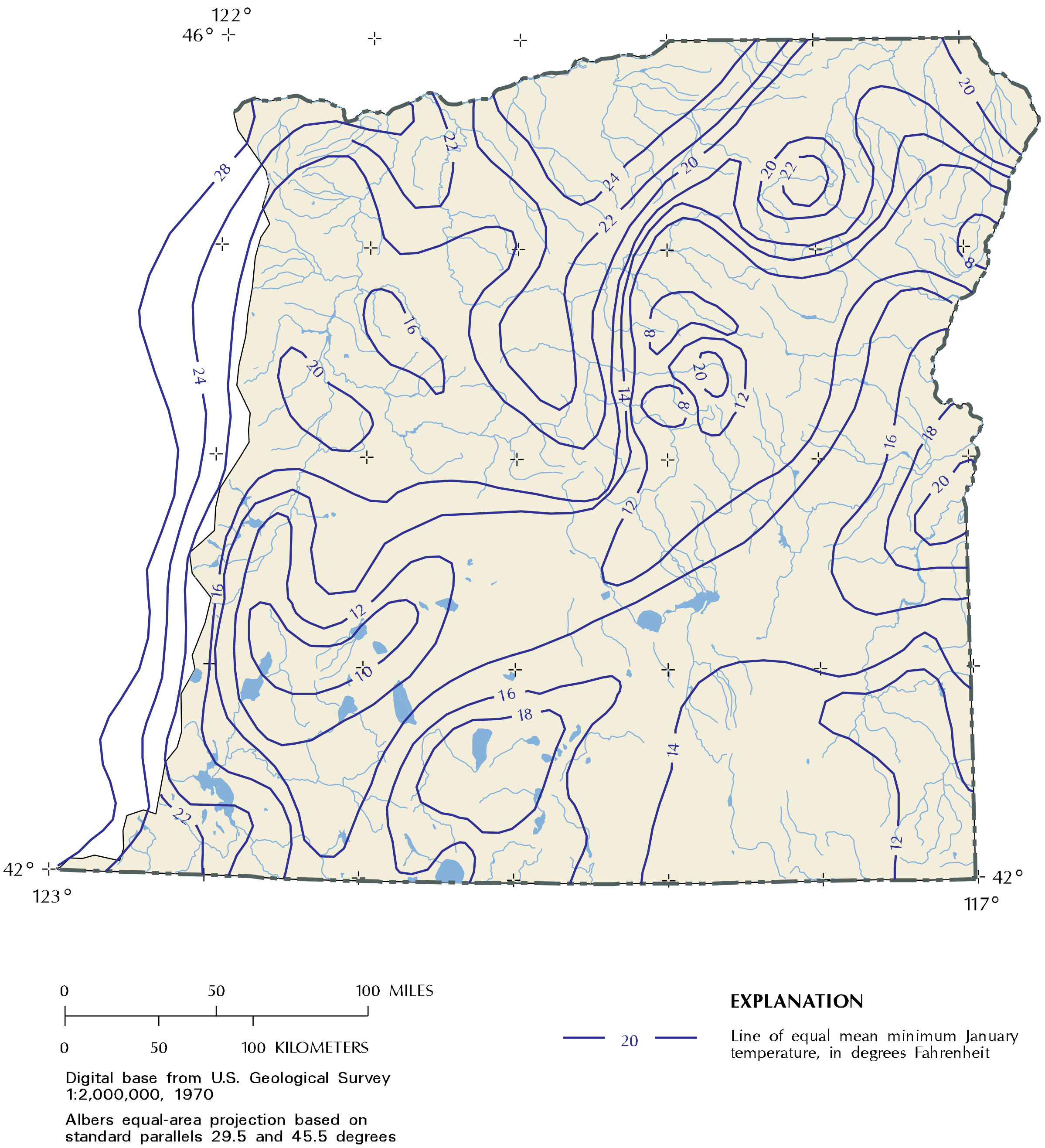
Figure C.9—Hydrologic Regions of Oregon (Jennings and others 1994).



Digital base from U.S. Geological Survey 1:2,000,000, 1970

Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

Figure C.10—The 2-year, 24-hour rainfall intensities in western Oregon (Jennings and others 1994).



Digital base from U.S. Geological Survey 1:2,000,000, 1970

Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

EXPLANATION

Line of equal mean minimum January temperature, in degrees Fahrenheit

Figure C.11—Mean daily minimum January temperature in eastern Oregon (Jennings and others 1994).

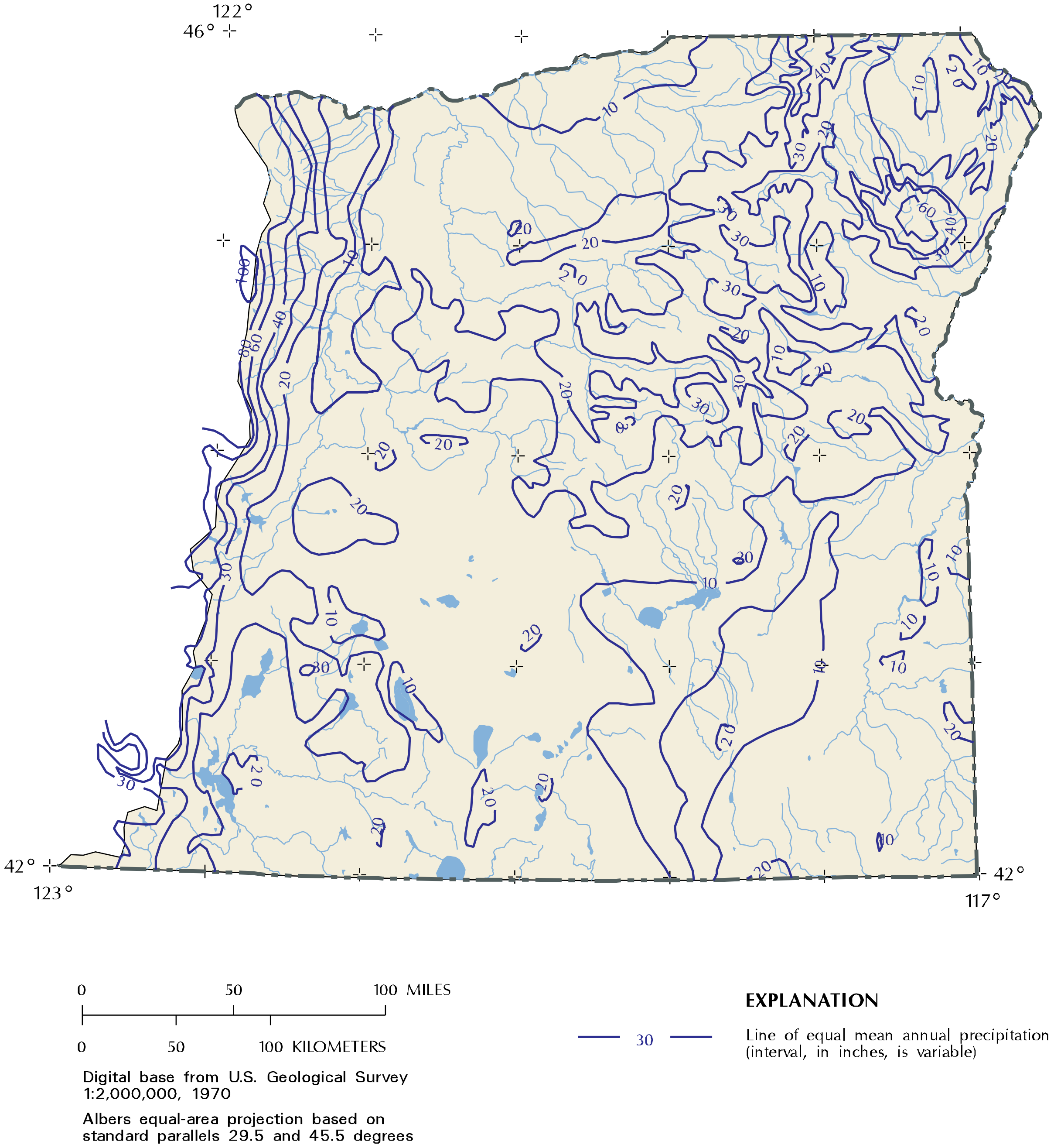


Figure C.12—Mean annual precipitation in eastern Oregon (Jennings and others 1994).

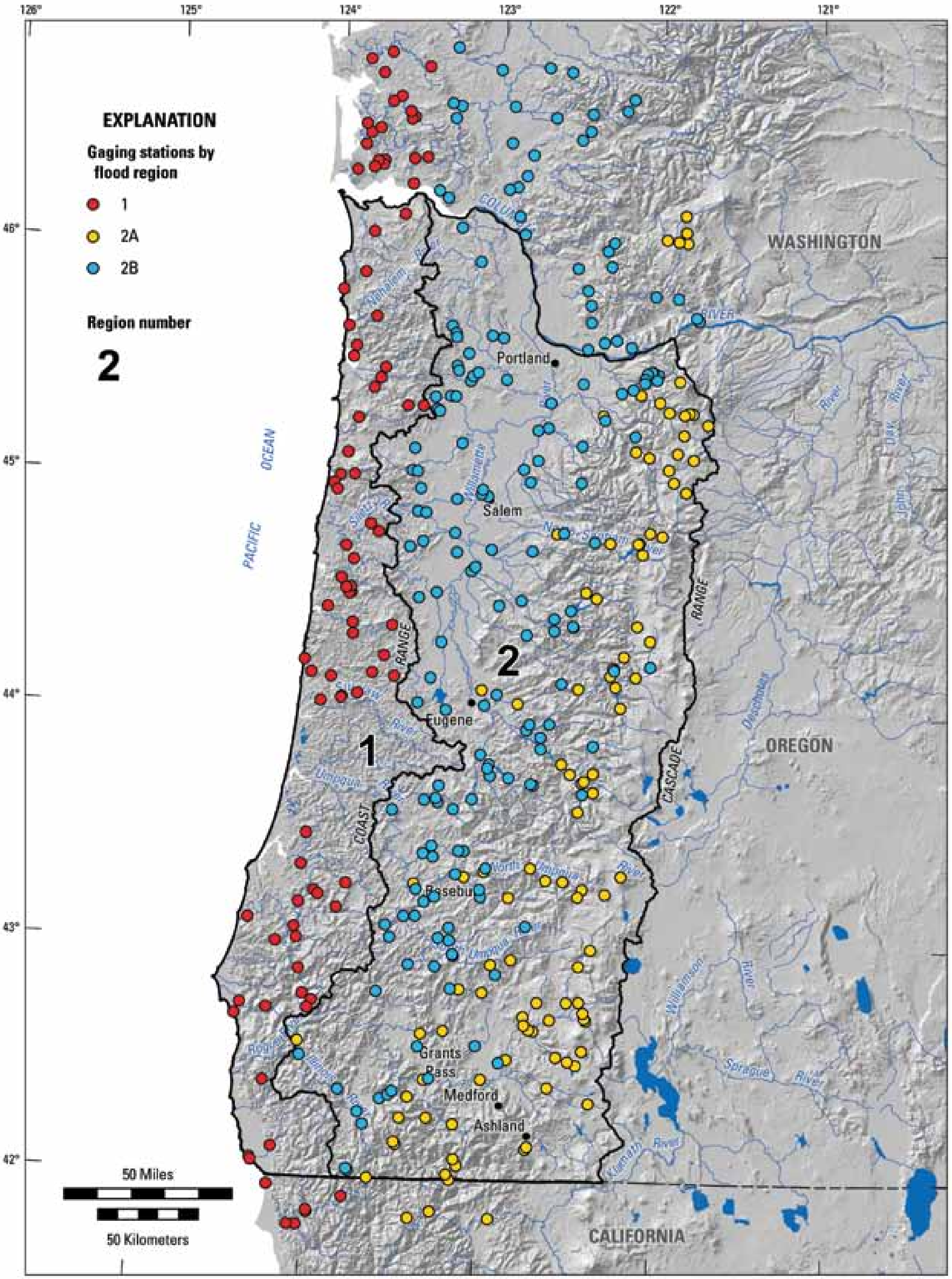


Figure C.13—Hydrologic regions of western Oregon (Cooper 2005). Regions 2A and 2B cannot be separated into discrete areas and shown together as Region 2; however, the gaging stations associated with Regions 2A and 2B give a rough approximation of the areal extent of each Region.

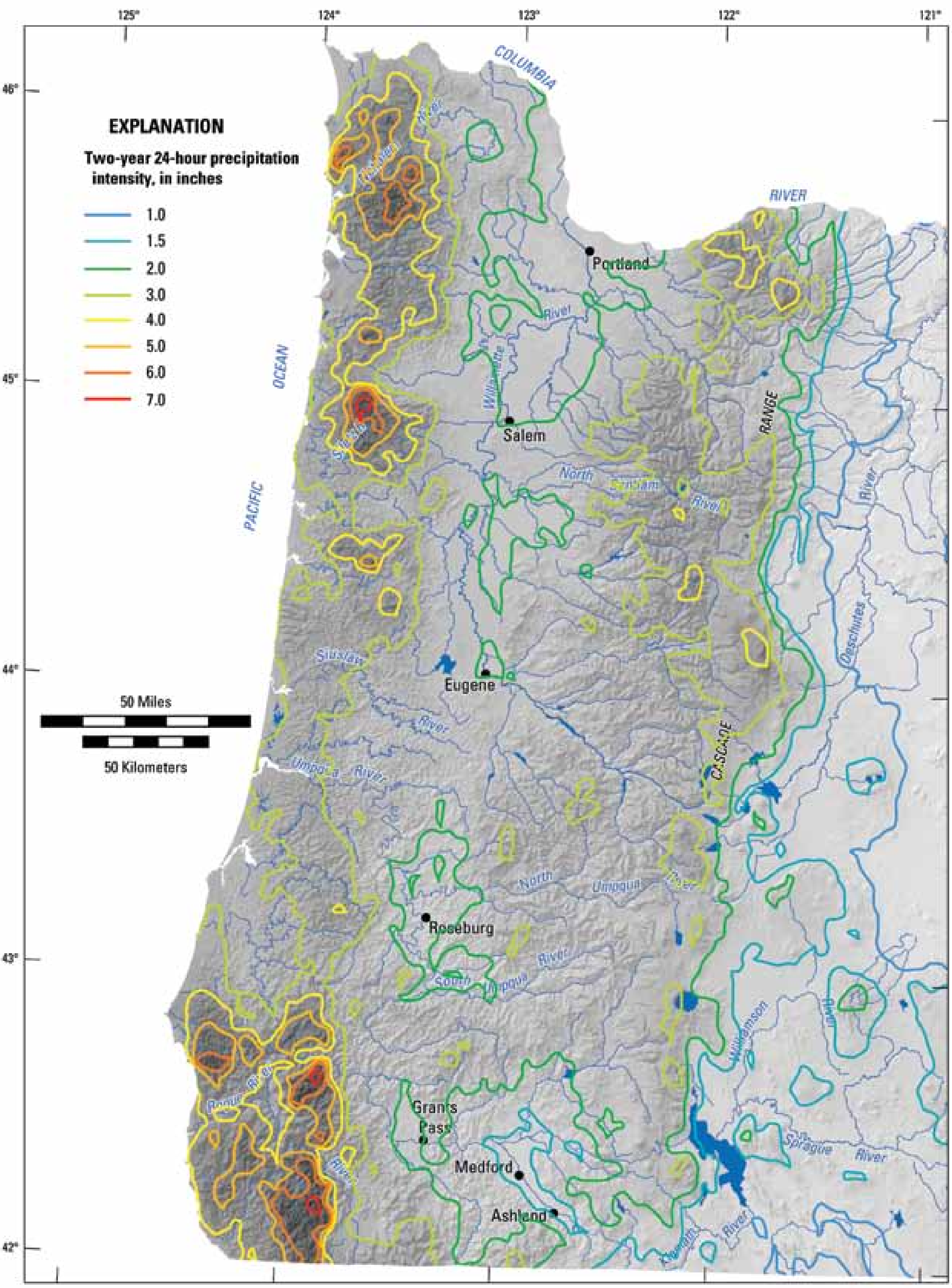


Figure C.14—The 2-year, 24-hour rainfall intensity of western Oregon (1961 to 1990; Cooper 2005). The isolines are superimposed on both a shaded relief map of elevation and the Geographic Information System grid of the 2-year, 24-hour precipitation intensities on which the isolines are based. Darker areas represent higher precipitation intensities.

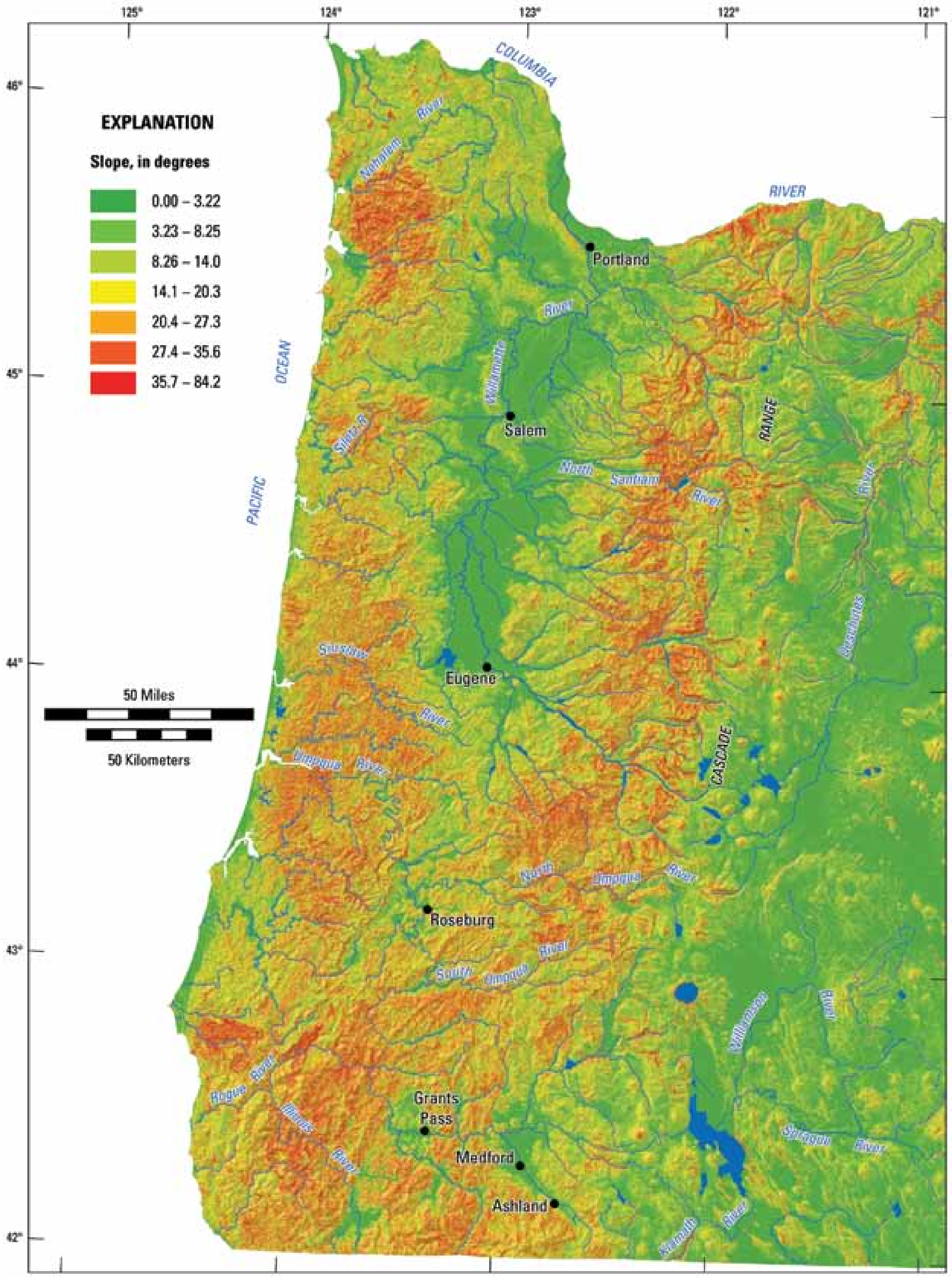


Figure C.15—Areal distribution of basin slope in western Oregon (Cooper 2005).

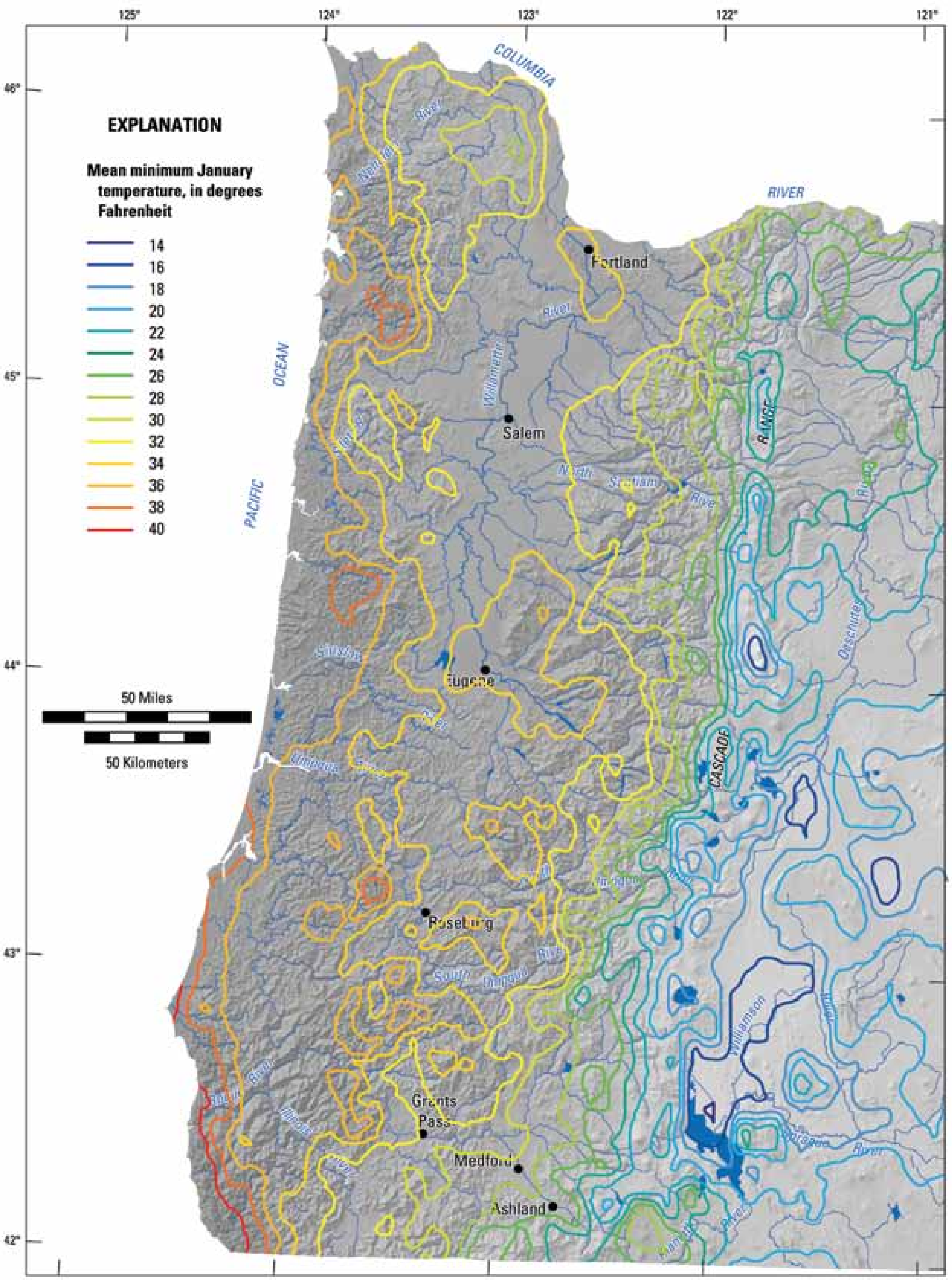


Figure C.16—Mean minimum January temperature of western Oregon (1961 to 1990; Cooper 2005). The isolines are superimposed on both a shaded relief map of elevation and the Geographic Information System grid of the mean minimum January temperatures on which the isolines are based. Darker areas represent higher temperatures.

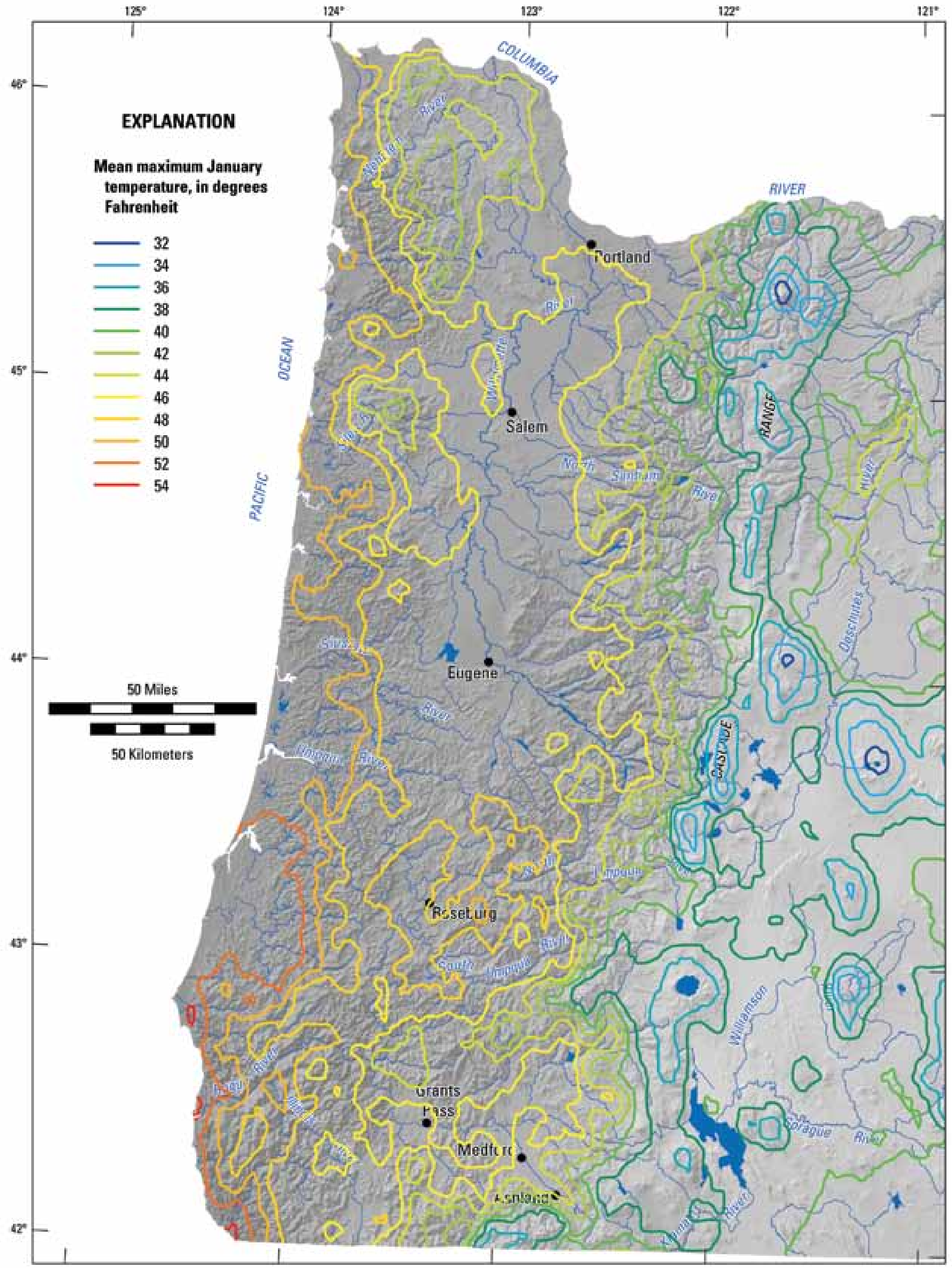


Figure C.17—Mean maximum January temperature of western Oregon (1961 to 1990; Cooper 2005). The isolines are superimposed on both a shaded relief map of elevation and the Geographic Information System grid of the mean maximum January temperatures on which the isolines are based. Darker areas represent higher temperatures.

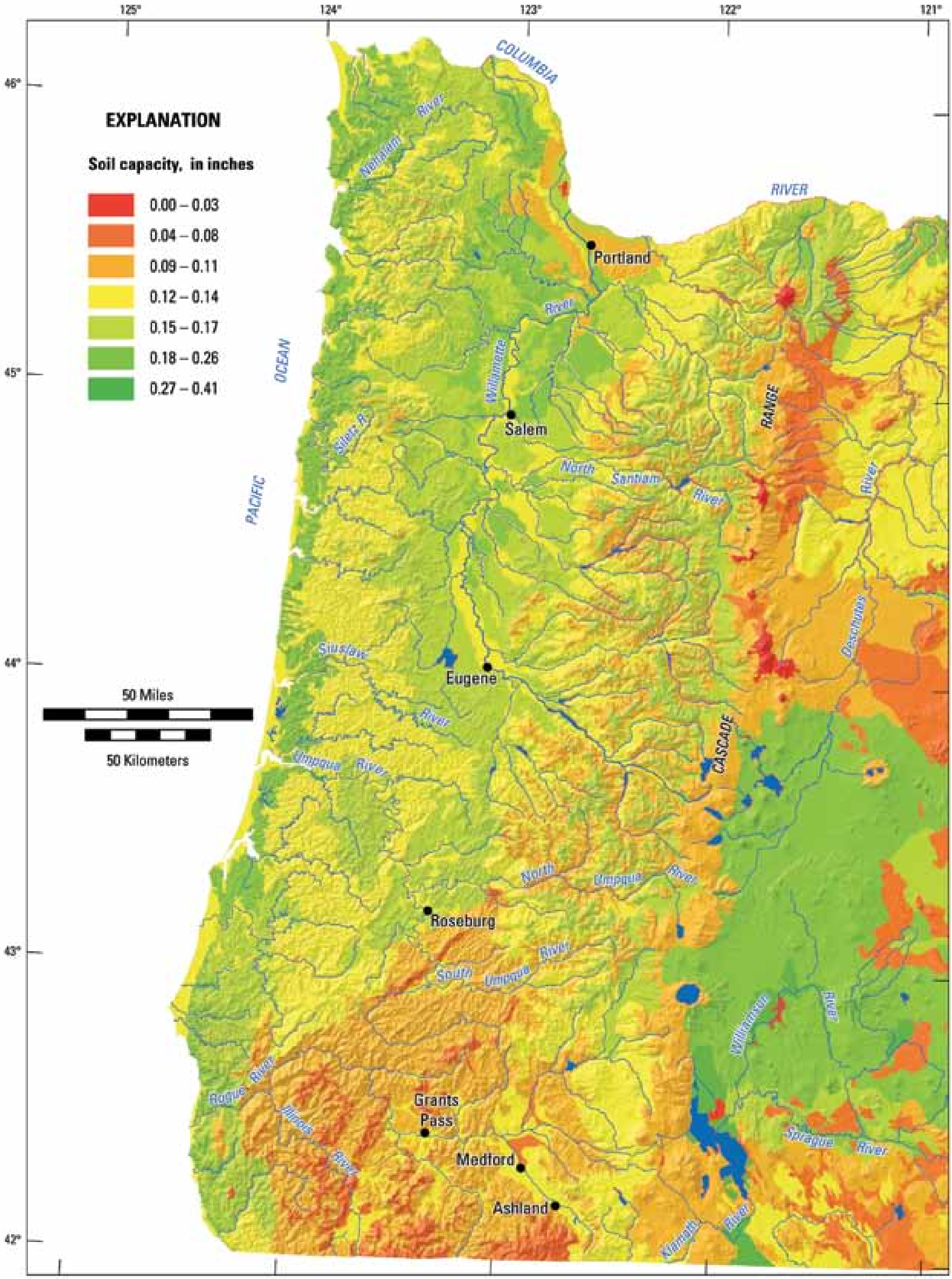


Figure C.18—Areal distribution of soil storage capacity in western Oregon (Cooper 2005).

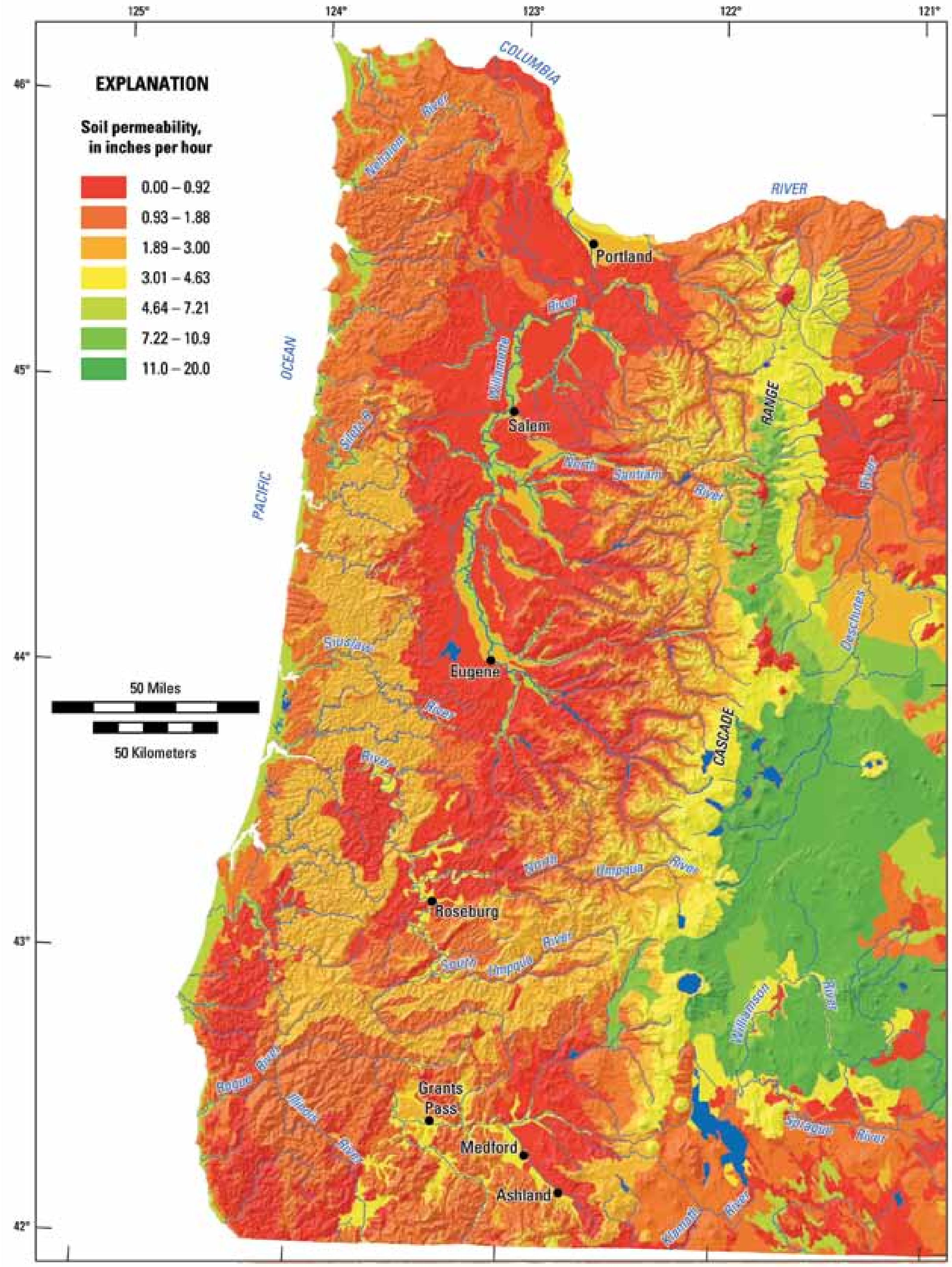


Figure C.19—Areal distribution of soil permeability in western Oregon (Cooper 2005).

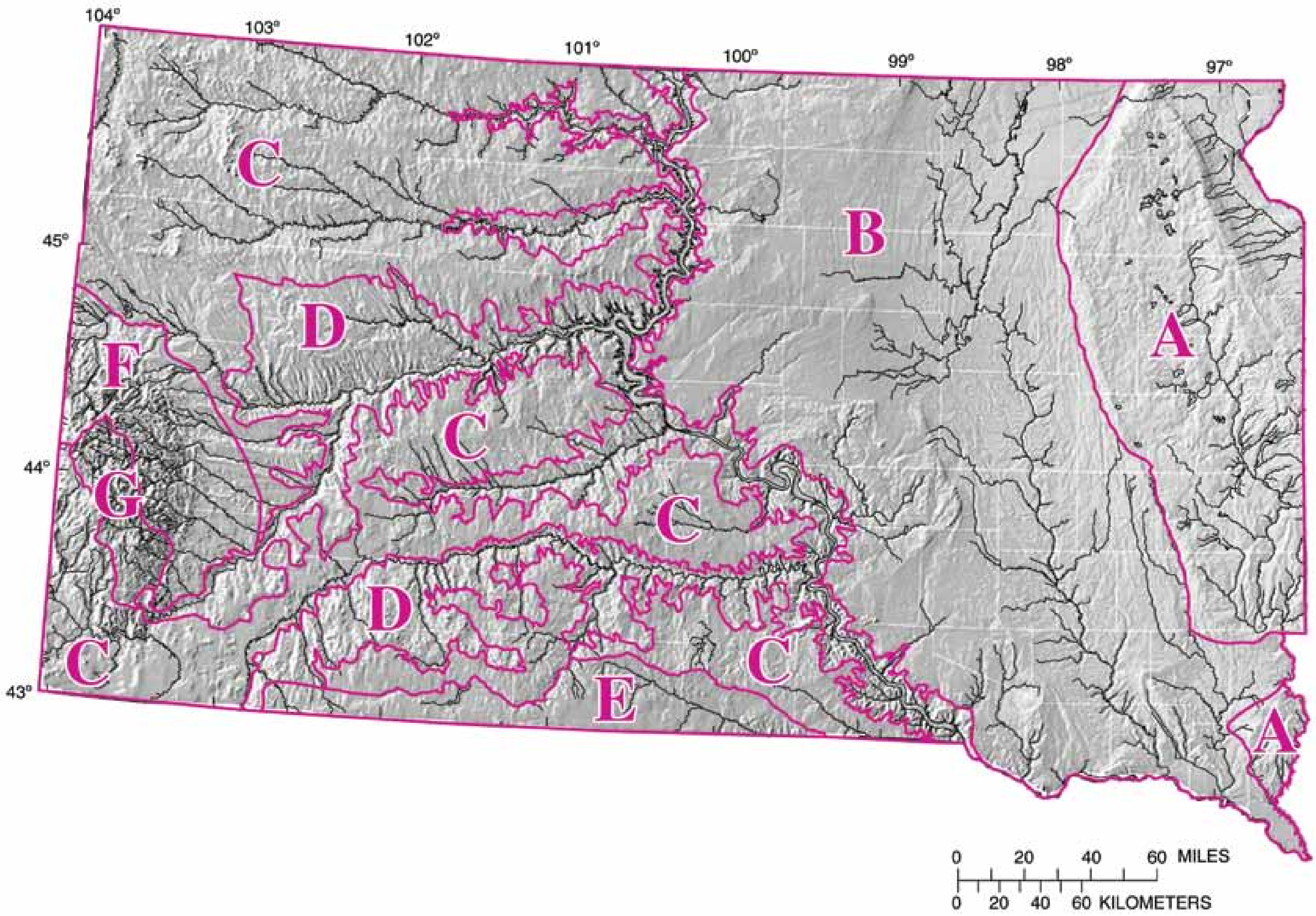


Figure C.20—Hydrologic Sub-Regions determined for the regional peak-flow frequency analysis for South Dakota (Sando 1998).

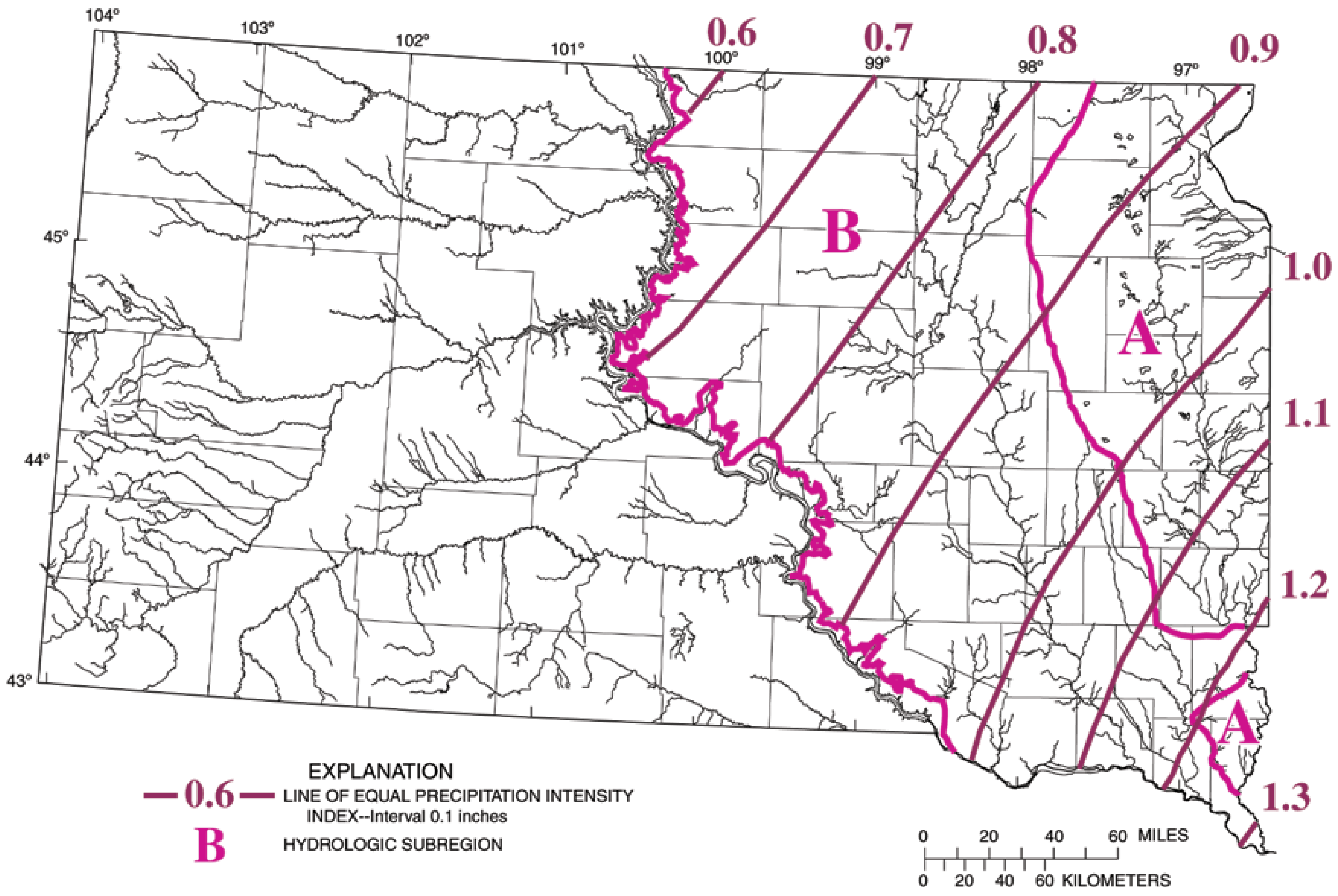


Figure C.21—Isolines of Precipitation Intensity Index (PII) for South Dakota (Sando 1998; determined by subtracting 1.5 inches from 2-year, 24-hour precipitation isoclines, in inches, as given in U.S. Weather Bureau [1961] and interpolating between those isolines).

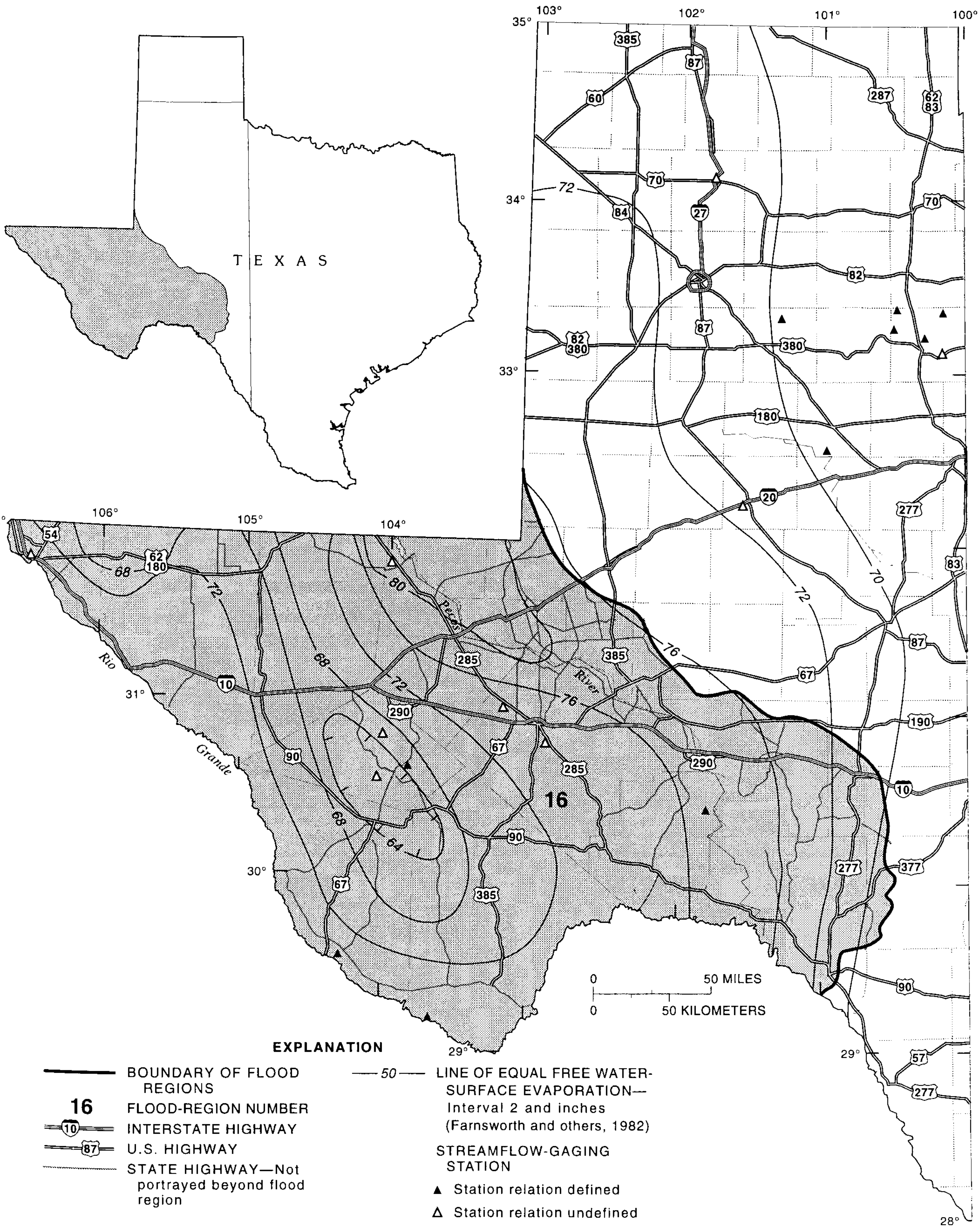


Figure C.22—Free water-surface evaporation for Texas (Farnsworth and others 1982; Thomas and others 1997).

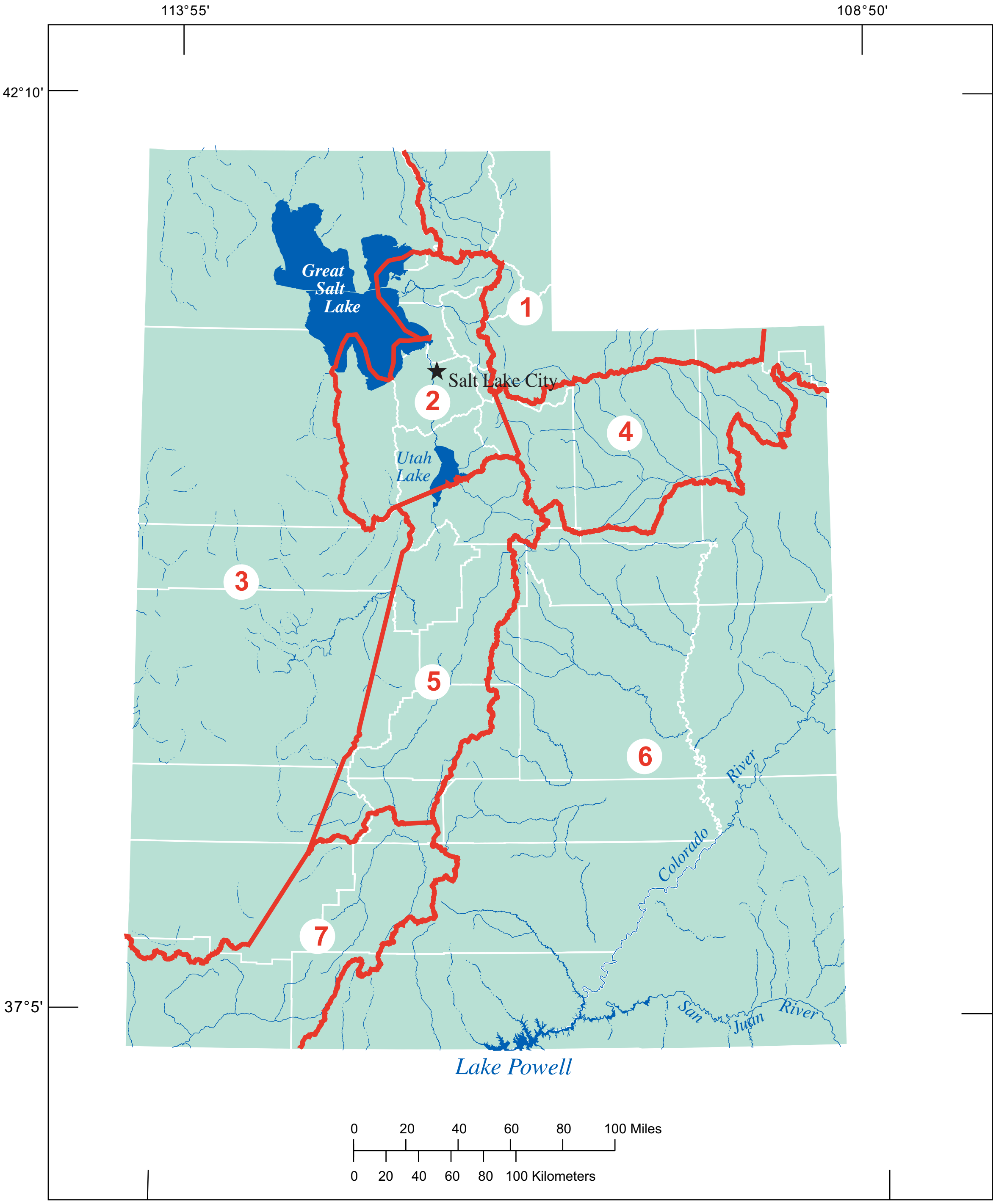


Figure C.23—Geohydrologic Regions of Utah (Kenney and others 2007).

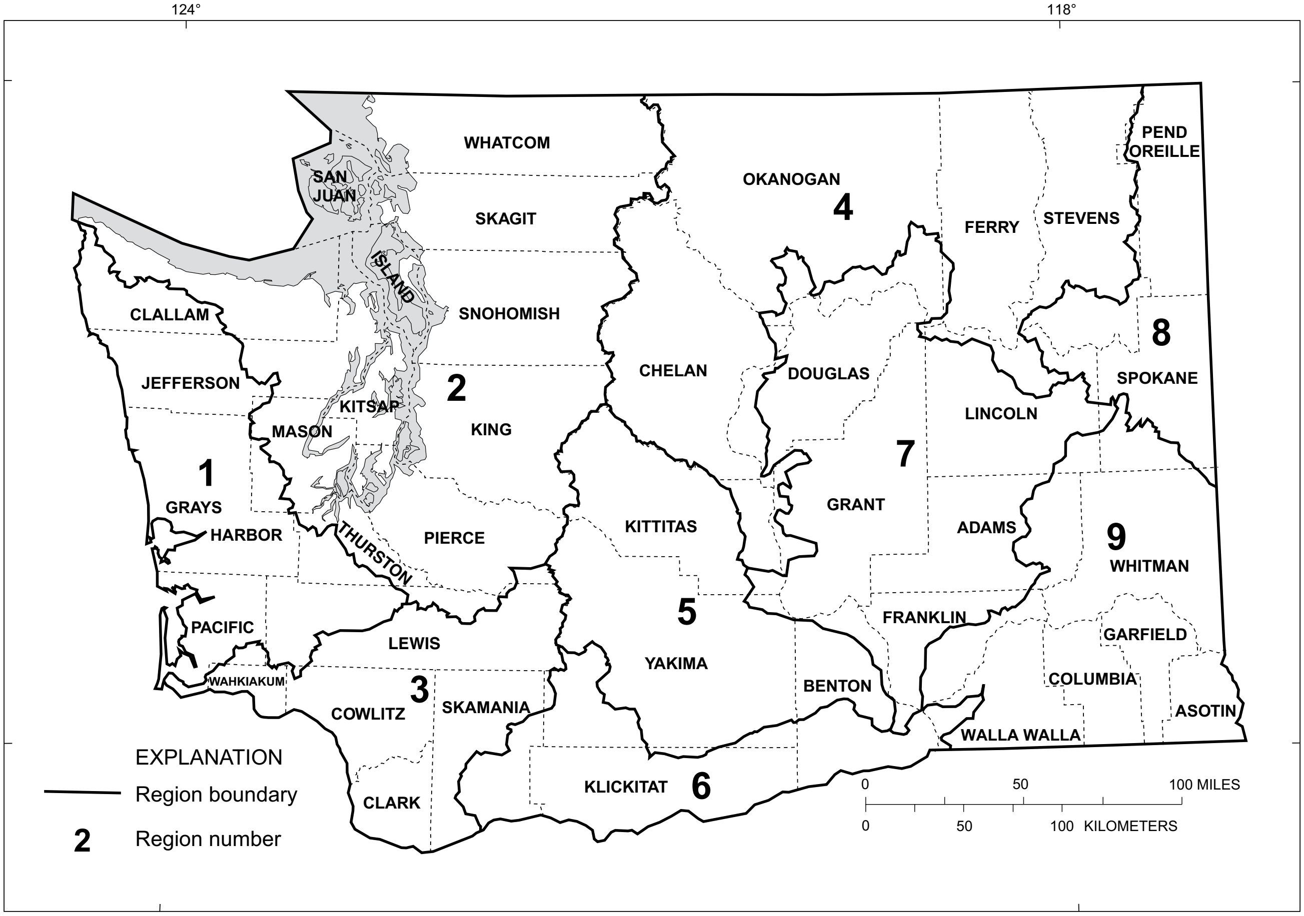
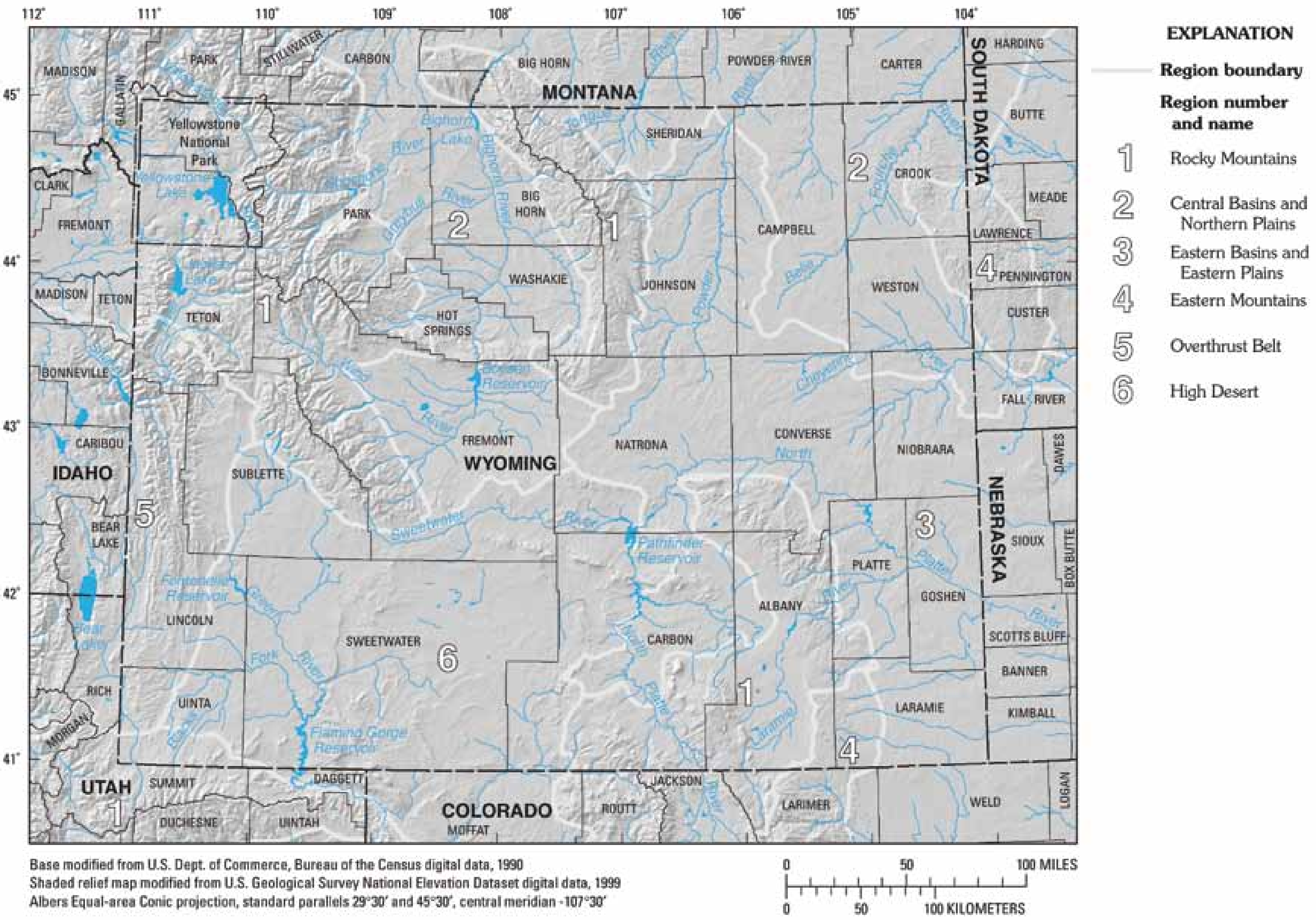


Figure C.24—Hydrologic Regions of Washington (Knowles and Sumioka 2001; Seaber and others 1987; Sumioka and others 1998).



Base modified from U.S. Dept. of Commerce, Bureau of the Census digital data, 1990
Shaded relief map modified from U.S. Geological Survey National Elevation Dataset digital data, 1999
Albers Equal-area Conic projection, standard parallels 29°30′ and 45°30′, central meridian -107°30′

Figure C.25—Hydrologic Regions for determining peak-flow characteristics of Wyoming streams (Miller 2003).

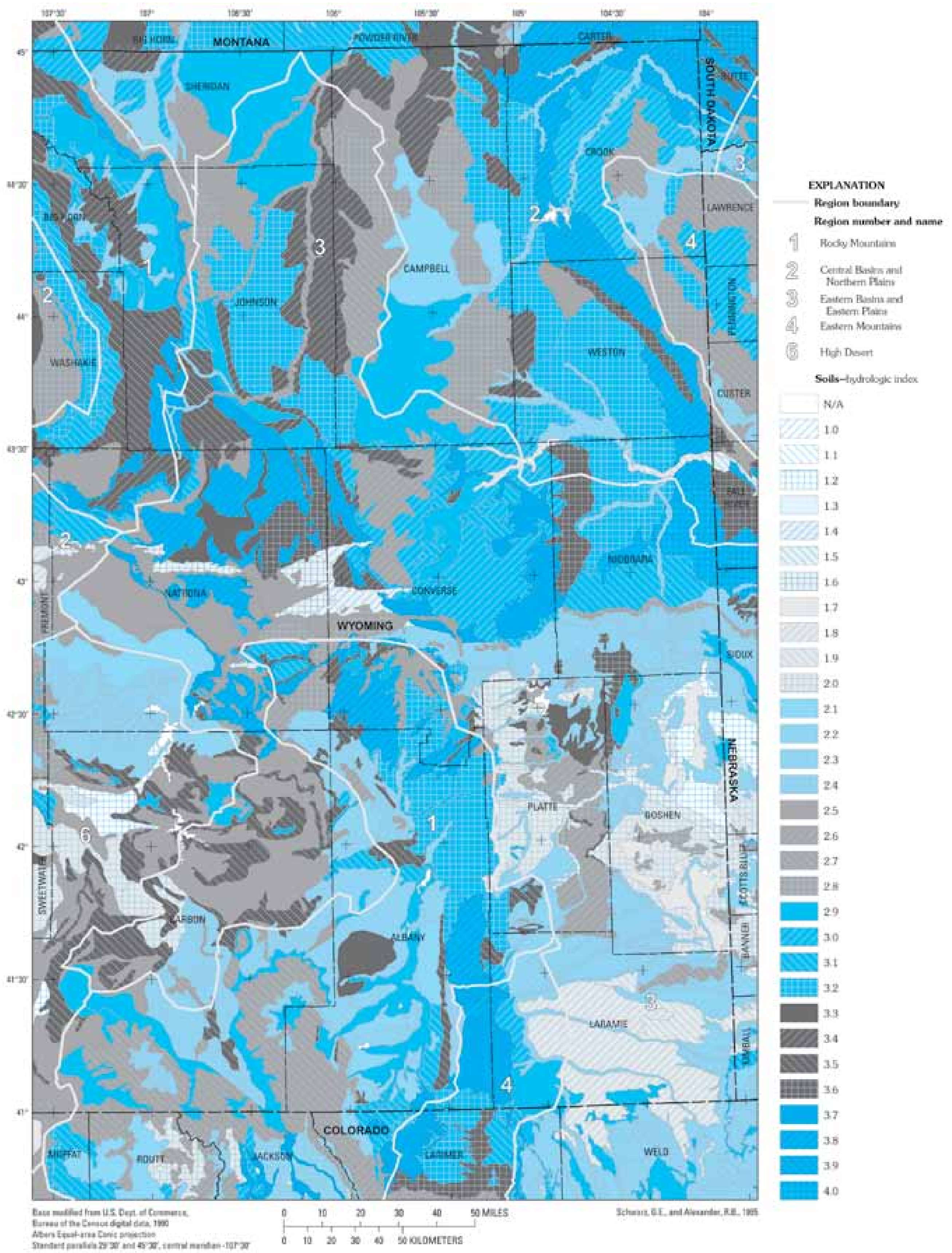
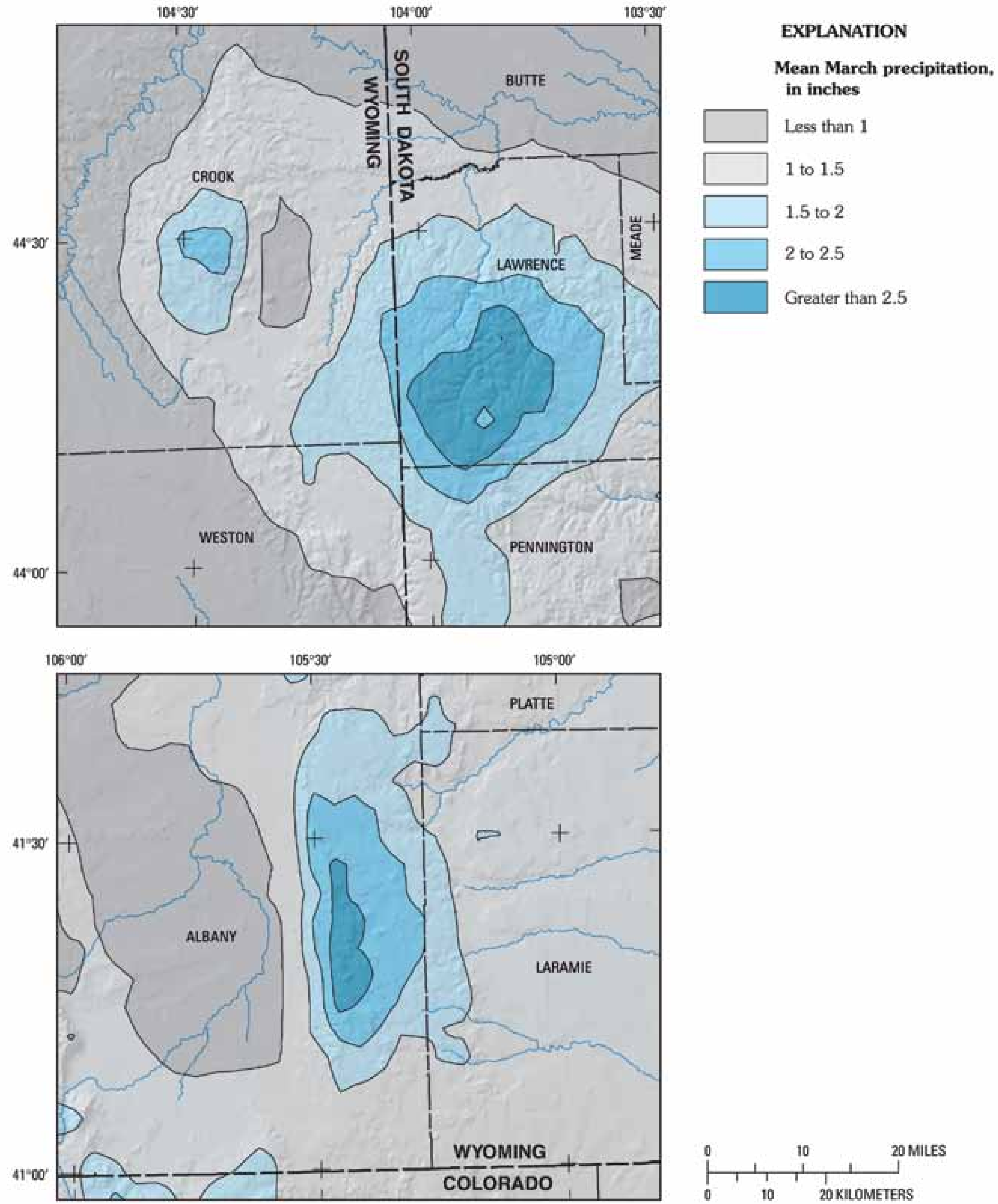


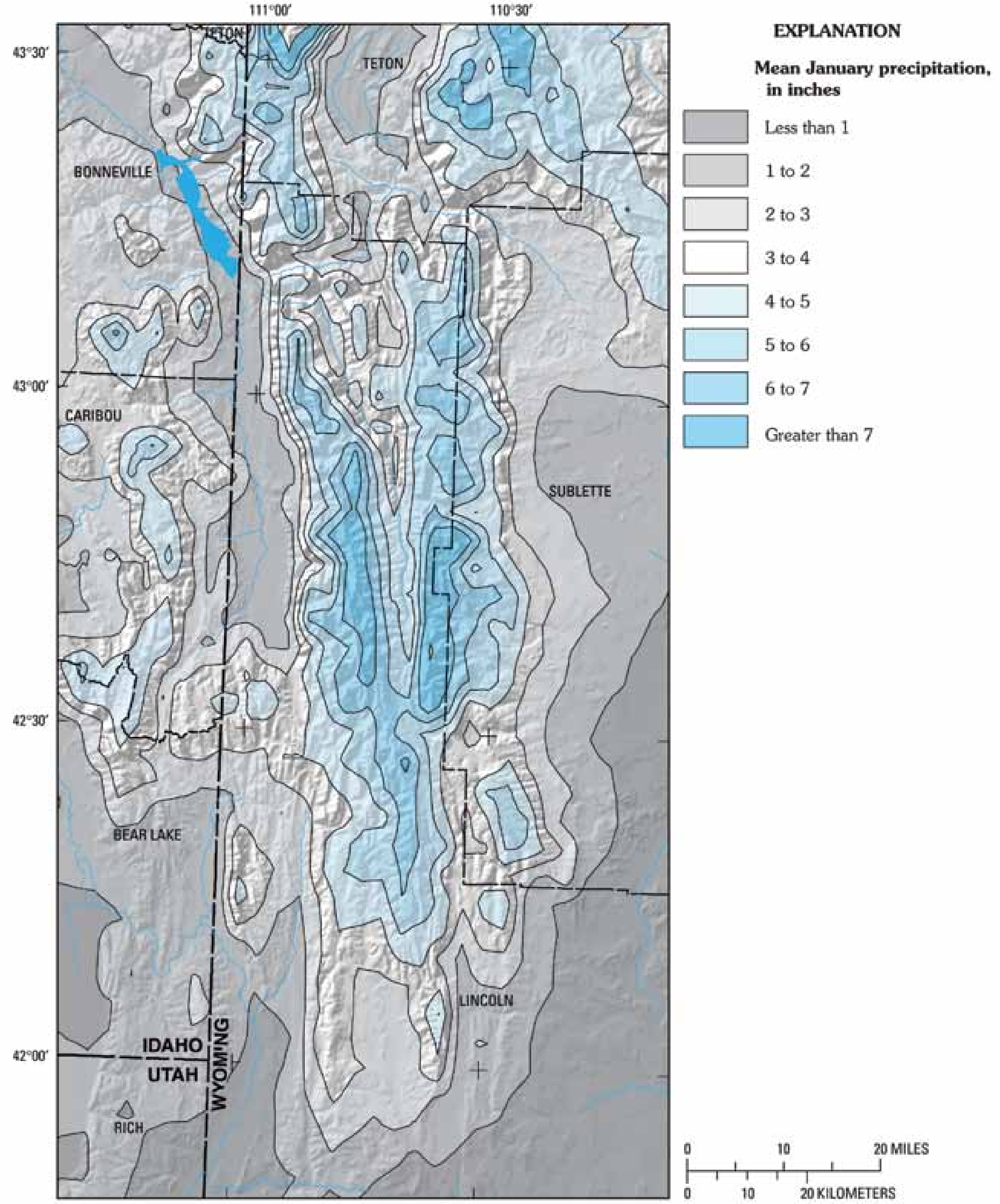
Figure C.26—Soil Hydrologic Index for Wyoming (Miller 2003).



Base modified from U.S. Dept. of Commerce,
Bureau of the Census digital data, 1990
Shaded relief map modified from U.S. Geological
Survey National Elevation Dataset digital data, 1999
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -107°30′

Oregon Climate Service, 1998b

Figure C.27—Mean March precipitation, Eastern Mountains Region, Wyoming (Miller 2003).



Base modified from U.S. Dept. of Commerce,
Bureau of the Census digital data, 1990
Shaded relief map modified from U.S. Geological
Survey National Elevation Dataset digital data, 1999
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -107°30′

Oregon Climate Service, 1998b

Figure C.28—Mean January precipitation, Overthrust Belt Region, Wyoming (Miller 2003).

Table C.1—Generalized least-squares regression equations for estimating regional flood-frequency relations for the High-Elevation Region 1 (Thomas and others 1997). Data were based on 165 stations. Average number of years of systematic record is 28.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 0.124\ \text{AREA}^{0.845}\text{PREC}^{1.44}$	59	0.16
5	$Q = 0.629\ \text{AREA}^{0.807}\text{PREC}^{1.12}$	52	0.62
10	$Q = 1.43\ \text{AREA}^{0.786}\text{PREC}^{0.958}$	48	1.34
25	$Q = 3.08\ \text{AREA}^{0.768}\text{PREC}^{0.811}$	46	2.50
50	$Q = 4.75\ \text{AREA}^{0.758}\text{PREC}^{0.732}$	46	3.37
100	$Q = 6.78\ \text{AREA}^{0.750}\text{PREC}^{0.668}$	46	4.19

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches

Table C.2—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Northwest Region 2 (Thomas and others 1997). Data were based on 108 stations. Average number of years of systematic record is 26.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 13.1\ \text{AREA}^{0.713}$	72	0.96
5	$Q = 22.4\ \text{AREA}^{0.723}$	66	1.80
10	$Q = 55.7\ \text{AREA}^{0.727}(\text{ELEV}/1{,}000)^{-0.353}$	61	3.07
25	$Q = 84.7\ \text{AREA}^{0.737}(\text{ELEV}/1{,}000)^{-0.438}$	61	4.64
50	$Q = 113\ \text{AREA}^{0.746}(\text{ELEV}/1{,}000)^{-0.511}$	64	5.47
100	$Q = 148\ \text{AREA}^{0.752}(\text{ELEV}/1{,}000)^{-0.584}$	68	6.05

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.3—Generalized least-squares regression equations for estimating regional flood-frequency relations for the South-Central Idaho Region 3 (Thomas and others 1997). Data were based on 35 stations. Average number of years of systematic record is 32.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 0.444\ \text{AREA}^{0.649}\text{PREC}^{1.15}$	86	0.29
5	$Q = 1.21\ \text{AREA}^{0.639}\text{PREC}^{0.995}$	83	0.49
10	$Q = 1.99\ \text{AREA}^{0.633}\text{PREC}^{0.924}$	80	0.77
25	$Q = 3.37\ \text{AREA}^{0.627}\text{PREC}^{0.849}$	78	1.23
50	$Q = 4.70\ \text{AREA}^{0.625}\text{PREC}^{0.802}$	77	1.57
100	$Q = 6.42\ \text{AREA}^{0.621}\text{PREC}^{0.757}$	78	1.92

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches

Table C.4—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Northeast Region 4 (Thomas and others 1997). Data were based on 108 stations. Average number of years of systematic record is 28.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 0.0405\ \text{AREA}^{0.701}(\text{ELEV}/1{,}000)^{2.91}$	64	0.39
5	$Q = 0.408\ \text{AREA}^{0.683}(\text{ELEV}/1{,}000)^{2.05}$	57	0.95
10	$Q = 1.26\ \text{AREA}^{0.674}(\text{ELEV}/1{,}000)^{1.64}$	53	1.76
25	$Q = 3.74\ \text{AREA}^{0.667}(\text{ELEV}/1{,}000)^{1.24}$	51	3.02
50	$Q = 7.04\ \text{AREA}^{0.664}(\text{ELEV}/1{,}000)^{1.02}$	52	3.89
100	$Q = 11.8\ \text{AREA}^{0.662}(\text{ELEV}/1{,}000)^{0.835}$	53	4.65

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.5—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Eastern Sierras Region 5 (Thomas and others 1997). Data were based on 37 stations. Average number of years of systematic record is 31.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 0.0333\ \text{AREA}^{0.853}(\text{ELEV}/1{,}000)^{2.68}[(\text{LAT}-28)/10]^{4.1}$	135	0.21
5	$Q = 2.42\ \text{AREA}^{0.823}(\text{ELEV}/1{,}000)^{1.01}[(\text{LAT}-28)/10]^{4.1}$	101	0.73
10	$Q = 28.0\ \text{AREA}^{0.826}[(\text{LAT}-28)/10]^{4.3}$	84	1.69
25	$Q = 426\ \text{AREA}^{0.812}(\text{ELEV}/1{,}000)^{-1.10}[(\text{LAT}-28)/10]^{4.3}$	87	2.62
50	$Q = 2{,}030\ \text{AREA}^{0.798}(\text{ELEV}/1{,}000)^{-1.71}[(\text{LAT}-28)/10]^{4.4}$	91	3.26
100	$Q = 7{,}000\ \text{AREA}^{0.782}(\text{ELEV}/1{,}000)^{-2.18}[(\text{LAT}-28)/10]^{4.6}$	95	3.80

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft; LAT, latitude of site, in decimal degrees

Table C.6—Hybrid equations for estimating regional flood-frequency relations for the Northern Great Basin Region 6 (Thomas and others 1997). Data were based on 80 stations. Average number of years of systematic record is 19.

Recurrence interval (yr)	Equation[a]	Estimated average standard error of regression[b] (log units)	Equivalent years of record
2	$Q = 0$	—[c]	—
5	$Q = 32\ \text{AREA}^{0.80}(\text{ELEV}/1{,}000)^{-0.66}$	1.47	0.233
10	$Q = 590\ \text{AREA}^{0.62}(\text{ELEV}/1{,}000)^{-1.6}$	1.12	0.748
25	$Q = 3{,}200\ \text{AREA}^{0.62}(\text{ELEV}/1{,}000)^{-2.1}$	0.796	2.52
50	$Q = 5{,}300\ \text{AREA}^{0.64}(\text{ELEV}/1{,}000)^{-2.1}$	1.10	1.75
100	$Q = 20{,}000\ \text{AREA}^{0.51}(\text{ELEV}/1{,}000)^{-2.3}$	1.84	0.794

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

[b] Estimated average standard error of regression for the hybrid method includes much of the within-station residual variance and therefore is not comparable to standard error of estimate from an ordinary least-squares regression.

[c] No data

Table C.7—Generalized least-squares regression equations for estimating regional flood-frequency relations for the South-Central Utah Region 7 (Thomas and others 1997). Data were based on 28 stations. Average number of years of systematic record is 23.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 0.0150\ \text{AREA}^{0.697}(\text{ELEV}/1{,}000)^{-3.16}$	56	0.25
5	$Q = 0.306\ \text{AREA}^{0.590}(\text{ELEV}/1{,}000)^{-2.22}$	45	1.56
10	$Q = 1.25\ \text{AREA}^{0.526}(\text{ELEV}/1{,}000)^{-1.83}$	45	3.07
25	$Q = 122\ \text{AREA}^{0.440}$	49	4.60
50	$Q = 183\ \text{AREA}^{0.390}$	53	5.27
100	$Q = 264\ \text{AREA}^{0.344}$	59	5.68

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.8—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Four Corners Region 8 (Thomas and others 1997). Data were based on 108 stations. Average number of years of systematic record is 27.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 598\ AREA^{0.501}(ELEV/1{,}000)^{-1.02}$	72	0.37
5	$Q = 2{,}620\ AREA^{0.449}(ELEV/1{,}000)^{-1.28}$	62	1.35
10	$Q = 5{,}310\ AREA^{0.425}(ELEV/1{,}000)^{-1.40}$	57	2.88
25	$Q = 10{,}500\ AREA^{0.403}(ELEV/1{,}000)^{-1.49}$	54	5.45
50	$Q = 16{,}000\ AREA^{0.390}(ELEV/1{,}000)^{-1.54}$	53	7.45
100	$Q = 23{,}300\ AREA^{0.377}(ELEV/1{,}000)^{-1.59}$	53	9.28

[a] Equation: *Q*, peak flow, in ft^3 sec^{-1}; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.9—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Western Colorado Region 9 (Thomas and others 1997). Data were based on 43 stations. Average number of years of systematic record is 28.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 0.0204\ AREA^{0.606}(ELEV/1{,}000)^{-3.5}$	68	0.14
5	$Q = 0.181\ AREA^{0.515}(ELEV/1{,}000)^{-2.9}$	55	0.77
10	$Q = 1.18\ AREA^{0.488}(ELEV/1{,}000)^{-2.2}$	52	1.70
25	$Q = 18.2\ AREA^{0.465}(ELEV/1{,}000)^{-1.1}$	53	2.81
50	$Q = 248\ AREA^{0.449}$	57	3.36
100	$Q = 292\ AREA^{0.444}$	59	3.94

[a] Equation: *Q*, peak flow, in ft^3 sec^{-1}; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.10—Hybrid equations for estimating regional flood-frequency relations for the Southern Great Basin Region 10 (Thomas and others 1997). Data were based on 104 stations. Average number of years of systematic record is 21.

Recurrence interval (yr)	Equation[a]	Estimated average standard error of regression[b] (log units)	Equivalent years of record
2	$Q = 12\ AREA^{0.58}$	1.14	0.618
5	$Q = 85\ AREA^{0.59}$	0.602	3.13
10	$Q = 200\ AREA^{0.62}$	0.675	3.45
25	$Q = 400\ AREA^{0.65}$	0.949	2.49
50	$Q = 590\ AREA^{0.67}$	0.928	3.22
100	$Q = 850\ AREA^{0.69}$	1.23	2.22

[a] Equation: *Q*, peak flow, in ft^3 sec^{-1}; AREA, drainage area, in mi^2

[b] Estimated average standard error of regression for the hybrid method includes much of the within-station residual variance and therefore is not comparable to standard error of estimate from an ordinary least-squares regression.

Table C.11—Hybrid equations for estimating regional flood-frequency relations for the Northeastern Arizona Region 11 (Thomas and others 1997). Data were based on 46 stations. Average number of years of systematic record is 20.

Recurrence interval (yr)	Equation[a]	Estimated average standard error of regression[b] (log units)	Equivalent years of record
2	$Q = 26\ AREA^{0.62}$	0.609	0.428
5	$Q = 130\ AREA^{0.56}$	0.309	2.79
10	$Q = 0.10\ AREA^{0.52}EVAP^{2.0}$	0.296	4.63
25	$Q = 0.17\ AREA^{0.52}EVAP^{2.0}$	0.191	17.1
50	$Q = 0.24\ AREA^{0.54}EVAP^{2.0}$	0.294	9.20
100	$Q = 0.27\ AREA^{0.58}EVAP^{2.0}$	0.863	1.32

[a] Equation: *Q*, peak flow, in ft^3 sec^{-1}; AREA, drainage area, in mi^2; EVAP, mean annual evaporation, in inches

[b] Estimated average standard error of regression for the hybrid method includes much of the within-station residual variance and therefore is not comparable to standard error of estimate from an ordinary least-squares regression.

Table C.12—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Central Arizona Region 12 (Thomas and others 1997). Data were based on 68 stations. Average number of years of systematic record is 21.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 41.1\,\text{AREA}^{0.629}$	105	0.23
5	$Q = 238\,\text{AREA}^{0.687}(\text{ELEV}/1{,}000)^{-0.358}$	68	1.90
10	$Q = 479\,\text{AREA}^{0.661}(\text{ELEV}/1{,}000)^{-0.398}$	52	6.24
25	$Q = 942\,\text{AREA}^{0.630}(\text{ELEV}/1{,}000)^{-0.383}$	40	17.8
50	$Q = 10^{(7.36-4.17\,AREA^{-0.08})}(\text{ELEV}/1{,}000)^{-0.440}$	37	27.5
100	$Q = 10^{(6.55-3.17\,AREA^{-0.11})}(\text{ELEV}/1{,}000)^{-0.454}$	39	32.1

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.13—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Southern Arizona Region 13 (Thomas and others 1997). Data were based on 73 stations. Average number of years of systematic record is 21.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 10^{(6.38-4.29\,AREA^{-0.06})}$	57	2.0
5	$Q = 10^{(5.78-3.31\,AREA^{-0.08})}$	40	6.25
10	$Q = 10^{(5.68-3.02\,AREA^{-0.09})}$	37	11.1
25	$Q = 10^{(5.64-2.78\,AREA^{-0.10})}$	39	15.0
50	$Q = 10^{(5.57-2.59\,AREA^{-0.11})}$	43	15.9
100	$Q = 10^{(5.52-2.42\,AREA^{-0.12})}$	48	16.1

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2

Table C.14—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Upper Gila Basin Region 14 (Thomas and others 1997). Data were based on 22 stations. Average number of years of systematic record is 26.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 583\,\text{AREA}^{0.588}(\text{ELEV}/1{,}000)^{-1.3}$	74	1.69
5	$Q = 618\,\text{AREA}^{0.524}(\text{ELEV}/1{,}000)^{-0.70}$	63	3.54
10	$Q = 361\,\text{AREA}^{0.464}$	65	4.95
25	$Q = 581\,\text{AREA}^{0.462}$	63	7.75
50	$Q = 779\,\text{AREA}^{0.462}$	64	9.65
100	$Q = 1{,}010\,\text{AREA}^{0.463}$	66	11.2

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft

Table C.15—Generalized least-squares regression equations for estimating regional flood-frequency relations for the Upper Rio Grande Basin Region 15 (Thomas and others 1997). Data were based on 17 stations. Average number of years of systematic record is 35.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
2	$Q = 18{,}700\ \text{AREA}^{0.730}(\text{ELEV}/1{,}000)^{-2.86}[(\text{LONG}-99)/10]^{2.8}$	64	0.13
5	$Q = 31{,}700\ \text{AREA}^{0.646}(\text{ELEV}/1{,}000)^{-2.67}[(\text{LONG}-99)/10]^{2.7}$	66	0.64
10	$Q = 26{,}000\ \text{AREA}^{0.582}(\text{ELEV}/1{,}000)^{-2.27}[(\text{LONG}-99)/10]^{2.7}$	68	1.24
25	$Q = 34{,}800\ \text{AREA}^{0.532}(\text{ELEV}/1{,}000)^{-2.15}[(\text{LONG}-99)/10]^{2.6}$	71	2.04
50	$Q = 44{,}200\ \text{AREA}^{0.501}(\text{ELEV}/1{,}000)^{-2.11}[(\text{LONG}-99)/10]^{2.5}$	73	2.60
100	$Q = 91{,}800\ \text{AREA}^{0.439}(\text{ELEV}/1{,}000)^{-2.22}[(\text{LONG}-99)/10]^{2.5}$	76	3.12

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft; LONG, longitude of site, in decimal degrees

Table C.16—Hybrid equations for estimating regional flood-frequency relations for the Southeast Region 16 (Thomas and others 1997). Data were based on 120 stations. Average number of years of systematic record is 30.

Recurrence interval (yr)	Equation[a]	Estimated average standard error of regression[b] (log units)	Equivalent years of record
2	$Q = 14\ \text{AREA}^{0.51}(\text{EVAP}-32)^{0.55}$	0.664	0.410
5	$Q = 37\ \text{AREA}^{0.48}(\text{EVAP}-32)^{0.63}$	0.269	3.77
10	$Q = 52\ \text{AREA}^{0.47}(\text{EVAP}-32)^{0.67}$	0.177	12.6
25	$Q = 70\ \text{AREA}^{0.48}(\text{EVAP}-32)^{0.74}$	0.425	3.20
50	$Q = 110\ \text{AREA}^{0.47}(\text{EVAP}-34)^{0.74}$	0.367	5.38
100	$Q = 400\ \text{AREA}^{0.50}(\text{EVAP}-37)^{0.45}$	0.442	4.54

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; EVAP, mean annual evaporation, in inches

[b] Estimated average standard error of regression for the hybrid method includes much of the within-station residual variance and therefore is not comparable to standard error of estimate from an ordinary least-squares regression.

Table C.17—Regression equations for estimating magnitude and frequency of floods for ungaged sites in California (Jennings and others 1994; Mann and others 2004; Waananen and Crippen 1977).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	North Coast Region (n^b = 125 to 141)	
2	$Q = 3.52\ \text{AREA}^{0.90}\text{PREC}^{0.89}\text{H}^{-0.47}$	26
5	$Q = 5.04\ \text{AREA}^{0.89}\text{PREC}^{0.91}\text{H}^{-0.35}$	24
10	$Q = 6.21\ \text{AREA}^{0.88}\text{PREC}^{0.93}\text{H}^{-0.27}$	24
25	$Q = 7.64\ \text{AREA}^{0.87}\text{PREC}^{0.94}\text{H}^{-0.17}$	24
50	$Q = 8.57\ \text{AREA}^{0.87}\text{PREC}^{0.96}\text{H}^{-0.08}$	25
100	$Q = 9.23\ \text{AREA}^{0.87}\text{PREC}^{0.97}$	26
	Northeast Region[c] (n = 20 to 31)	
2	$Q = 22\ \text{AREA}^{0.40}$	46
5	$Q = 46\ \text{AREA}^{0.45}$	38
10	$Q = 61\ \text{AREA}^{0.49}$	38
25	$Q = 84\ \text{AREA}^{0.54}$	40
50	$Q = 103\ \text{AREA}^{0.57}$	42
100	$Q = 125\ \text{AREA}^{0.59}$	45
	Sierra Region (n = 212 to 249)	
2	$Q = 0.24\ \text{AREA}^{0.88}\text{PREC}^{1.58}\text{H}^{-0.80}$	34
5	$Q = 1.20\ \text{AREA}^{0.82}\text{PREC}^{1.37}\text{H}^{-0.64}$	32
10	$Q = 2.63\ \text{AREA}^{0.80}\text{PREC}^{1.25}\text{H}^{-0.58}$	27
25	$Q = 6.55\ \text{AREA}^{0.79}\text{PREC}^{1.12}\text{H}^{-0.52}$	30
50	$Q = 10.4\ \text{AREA}^{0.78}\text{PREC}^{1.06}\text{H}^{-0.48}$	34
100	$Q = 15.7\ \text{AREA}^{0.77}\text{PREC}^{1.02}\text{H}^{-0.43}$	37
	Central Coast Region (n = 91 to 98)	
2	$Q = 0.0061\ \text{AREA}^{0.92}\text{PREC}^{2.54}\text{H}^{-1.10}$	47
5	$Q = 0.118\ \text{AREA}^{0.91}\text{PREC}^{1.95}\text{H}^{-0.79}$	39
10	$Q = 0.583\ \text{AREA}^{0.90}\text{PREC}^{1.61}\text{H}^{-0.64}$	35
25	$Q = 2.91\ \text{AREA}^{0.89}\text{PREC}^{1.26}\text{H}^{-0.50}$	35
50	$Q = 8.20\ \text{AREA}^{0.89}\text{PREC}^{1.03}\text{H}^{-0.41}$	38
100	$Q = 19.7\ \text{AREA}^{0.88}\text{PREC}^{0.84}\text{H}^{-0.33}$	41
	South Coast Region (n^b = 137 to 143)	
2	$Q = 0.14\ \text{AREA}^{0.72}\text{PREC}^{1.62}$	47
5	$Q = 0.40\ \text{AREA}^{0.77}\text{PREC}^{1.69}$	37
10	$Q = 0.63\ \text{AREA}^{0.79}\text{PREC}^{1.75}$	33
25	$Q = 1.10\ \text{AREA}^{0.81}\text{PREC}^{1.81}$	32
50	$Q = 1.50\ \text{AREA}^{0.82}\text{PREC}^{1.85}$	35
100	$Q = 1.95\ \text{AREA}^{0.83}\text{PREC}^{1.87}$	39
	South Lahontan–Colorado Desert Region[d] (n = 35 to 43)	
2	$Q = 7.3\ \text{AREA}^{0.30}$	60
5	$Q = 53\ \text{AREA}^{0.44}$	35
10	$Q = 150\ \text{AREA}^{0.53}$	31
25	$Q = 410\ \text{AREA}^{0.63}$	32
50	$Q = 700\ \text{AREA}^{0.68}$	33
100	$Q = 1{,}080\ \text{AREA}^{0.71}$	36

---

[a] Equation: Q, peak flow, in $\text{ft}^3\ \text{sec}^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches; H, altitude index, average of altitude taken at points 10% and 85% distance between point of interest and basin divide, in thousand ft (10^3 ft); in the North Coast Region, use a minimum value of 1.0 for H

[b] Number of stations used in the regression analysis

[c] Equations are defined only for basins of 25 mi^2 or less in the Northeast Region.

[d] Equations are defined only for basins of 25 mi^2 or less in the South Lahontan–Colorado Desert Region.

Table C.18—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Colorado (Vaill 2000). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (*Au/Ag*) if the drainage area ratio is between 0.5 and 1.5.

Hydrologic Region	Exponent, *x*
Mountains	0.69
Rio Grande	0.88
Southwest	0.71
Northwest	0.64
Plains	0.40

Table C.19—Regional flood-frequency equations for Colorado (Vaill 2000).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Mountain Region	
2	$Q = 11.0\ \text{AREA}^{0.663}(\text{BS}+1.0)^{3.465}$	52
5	$Q = 17.9\ \text{AREA}^{0.677}(\text{BS}+1.0)^{2.739}$	47
10	$Q = 23.0\ \text{AREA}^{0.685}(\text{BS}+1.0)^{2.364}$	45
25	$Q = 29.4\ \text{AREA}^{0.695}(\text{BS}+1.0)^{2.004}$	44
50	$Q = 34.5\ \text{AREA}^{0.700}(\text{BS}+1.0)^{1.768}$	44
100	$Q = 39.5\ \text{AREA}^{0.706}(\text{BS}+1.0)^{1.577}$	44
200	$Q = 44.6\ \text{AREA}^{0.710}(\text{BS}+1.0)^{1.408}$	45
500	$Q = 51.5\ \text{AREA}^{0.715}(\text{BS}+1.0)^{1.209}$	47
	Rio Grande Region	
2	$Q = 0.03\ \text{AREA}^{0.979}\text{PREC}^{1.615}$	61
5	$Q = 0.12\ \text{AREA}^{0.940}\text{PREC}^{1.384}$	55
10	$Q = 0.25\ \text{AREA}^{0.914}\text{PREC}^{1.277}$	53
25	$Q = 0.52\ \text{AREA}^{0.884}\text{PREC}^{1.117}$	51
50	$Q = 0.81\ \text{AREA}^{0.864}\text{PREC}^{1.121}$	50
100	$Q = 1.19\ \text{AREA}^{0.846}\text{PREC}^{1.074}$	49
200	$Q = 1.67\ \text{AREA}^{0.828}\text{PREC}^{1.036}$	49
500	$Q = 2.48\ \text{AREA}^{0.808}\text{PREC}^{0.995}$	49
	Southwest Region	
2	$Q = 28.7\ \text{AREA}^{0.699}$	62
5	$Q = 50.5\ \text{AREA}^{0.693}$	58
10	$Q = 66.0\ \text{AREA}^{0.697}$	57
25	$Q = 86.3\ \text{AREA}^{0.704}$	57
50	$Q = 102.0\ \text{AREA}^{0.709}$	58
100	$Q = 118.4\ \text{AREA}^{0.715}$	59
200	$Q = 135.5\ \text{AREA}^{0.720}$	60
500	$Q = 159.4\ \text{AREA}^{0.728}$	62
	Northwest Region	
2	$Q = 0.39\ \text{AREA}^{0.684}\text{PREC}^{1.304}$	62
5	$Q = 2.84\ \text{AREA}^{0.674}\text{PREC}^{0.833}$	58
10	$Q = 7.56\ \text{AREA}^{0.671}\text{PREC}^{0.601}$	56
25	$Q = 20.6\ \text{AREA}^{0.669}\text{PREC}^{0.362}$	56
50	$Q = 38.8\ \text{AREA}^{0.667}\text{PREC}^{0.210}$	56
100	$Q = 104.7\ \text{AREA}^{0.624}$	59
200	$Q = 118.5\ \text{AREA}^{0.624}$	60
500	$Q = 137.6\ \text{AREA}^{0.623}$	61

Table C.19—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Plains Region	
2	$Q = 39.0\ \mathrm{AREA}^{0.486}$	93
5	$Q = 195.8\ \mathrm{AREA}^{0.399}$	89
10	$Q = 364.6\ \mathrm{AREA}^{0.400}$	90
25	$Q = 725.3\ \mathrm{AREA}^{0.395}$	92
50	$Q = 1116\ \mathrm{AREA}^{0.392}$	95
100	$Q = 1640\ \mathrm{AREA}^{0.388}$	96
200	$Q = 2324\ \mathrm{AREA}^{0.385}$	98
500	$Q = 3534\ \mathrm{AREA}^{0.380}$	100

[a] Equation: Q, peak flow, in $\mathrm{ft}^3\ \mathrm{sec}^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches; BS, mean drainage-basin slope, in foot per foot

Table C.20—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Idaho (Berenbrock 2002). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (*Au/Ag*) if the drainage area ratio is between 0.5 and 1.5.

Hydrologic Region	Exponent, x
1	0.65
2	0.88
3	0.84
4	0.85
5	0.94
6	0.80
7a	0.77
7b	0.65
8	0.90

Table C.21—Flood-peak flow regression equations and associated statistics for ungaged sites on unregulated and undiverted streams in Idaho (Berenbrock 2002).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Region 1 (*n*[b] = 21)	
2	Q = 2.52 AREA$^{0.775}$(ELEV/1,000)$^{3.32}$(F+1)$^{-0.504}$	+78.4 to –43.9
5	Q = 23.0 AREA$^{0.720}$(ELEV/1,000)$^{3.36}$(F+1)$^{-0.885}$	+61.1 to –37.9
10	Q = 81.5 AREA$^{0.687}$(ELEV/1,000)$^{3.40}$(F+1)$^{-1.10}$	+56.8 to –36.2
25	Q = 339 AREA$^{0.649}$(ELEV/1,000)$^{3.44}$(F+1)$^{-1.36}$	+57.1 to –36.3
50	Q = 876 AREA$^{0.623}$(ELEV/1,000)$^{3.47}$(F+1)$^{-1.53}$	+60.1 to –37.6
100	Q = 2,080 AREA$^{0.597}$(ELEV/1,000)$^{3.49}$(F+1)$^{-1.68}$	+64.8 to –39.3
200	Q = 4,660 AREA$^{0.572}$(ELEV/1,000)$^{3.52}$(F+1)$^{-1.82}$	+70.8 to –41.4
500	Q = 12,600 AREA$^{0.540}$(ELEV/1,000)$^{3.56}$(F+1)$^{-2.00}$	+80.1 to –44.5
	Region 2 (*n* = 44)	
2	Q = 0.742 AREA$^{0.897}$PREC$^{0.935}$	+64.2 to –39.1
5	Q = 1.50 AREA$^{0.888}$(ELEV/1,000)$^{-0.330}$PREC$^{0.992}$	+64.3 to –39.1
10	Q = 2.17 AREA$^{0.884}$(ELEV/1,000)$^{-0.538}$PREC$^{1.04}$	+65.8 to –39.7
25	Q = 3.24 AREA$^{0.879}$(ELEV/1,000)$^{-0.788}$PREC$^{1.10}$	+68.7 to –40.7
50	Q = 4.22 AREA$^{0.876}$(ELEV/1,000)$^{-0.962}$PREC$^{1.14}$	+71.4 to –41.6
100	Q = 5.39 AREA$^{0.874}$(ELEV/1,000)$^{-1.13}$PREC$^{1.18}$	+74.1 to –42.6
200	Q = 6.75 AREA$^{0.872}$(ELEV/1,000)$^{-1.29}$PREC$^{1.21}$	+77.1 to –43.5
500	Q = 8.90 AREA$^{0.869}$(ELEV/1,000)$^{-1.49}$PREC$^{1.26}$	+81.3 to –44.8
	Region 3 (*n* = 26)	
2	Q = 26.3 AREA$^{0.864}$(ELEV/1,000)$^{-0.502}$	+86.4 to –46.4
5	Q = 127 AREA$^{0.842}$(ELEV/1,000)$^{-1.31}$	+58.6 to –36.9
10	Q = 265 AREA$^{0.837}$(ELEV/1,000)$^{-1.68}$	+51.8 to –34.1
25	Q = 504 AREA$^{0.833}$(ELEV/1,000)$^{-1.95}$	+50.3 to –33.5
50	Q = 719 AREA$^{0.832}$(ELEV/1,000)$^{-2.08}$	+51.9 to –34.2
100	Q = 965 AREA$^{0.831}$(ELEV/1,000)$^{-2.18}$	+55.1 to –35.5
200	Q = 1,240 AREA$^{0.831}$(ELEV/1,000)$^{-2.26}$	+59.4 to –37.3
500	Q = 1,660 AREA$^{0.832}$(ELEV/1,000)$^{-2.35}$	+66.2 to –39.8
	Region 3 (*n*[b] = 60)	
2	Q = 16.3 AREA$^{0.893}$(ELEV/1,000)$^{-0.121}$	+83.5 to –45.5
5	Q = 46.3 AREA$^{0.874}$(ELEV/1,000)$^{-0.459}$	+69.1 to –40.9
10	Q = 79.2 AREA$^{0.863}$(ELEV/1,000)$^{-0.628}$	+63.6 to –38.9
25	Q = 139 AREA$^{0.852}$(ELEV/1,000)$^{-0.801}$	+59.5 to –37.3
50	Q = 198 AREA$^{0.844}$(ELEV/1,000)$^{-0.910}$	+57.7 to –36.6
100	Q = 273 AREA$^{0.837}$(ELEV/1,000)$^{-1.01}$	+56.9 to –36.3
200	Q = 365 AREA$^{0.831}$(ELEV/1,000)$^{-1.10}$	+56.6 to –36.1
500	Q = 521 AREA$^{0.822}$(ELEV/1,000)$^{-1.20}$	+56.9 to –36.3
	Region 5 (n = 46)	
2	Q = 0.0297 AREA$^{0.995}$PREC2.20(NS$_{30}$+1)$^{-0.664}$	+46.7 to –31.8
5	Q = 0.0992 AREA$^{0.970}$PREC1.92(NS$_{30}$+1)$^{-0.602}$	+44.8 to –30.9
10	Q = 0.178 AREA$^{0.957}$PREC1.79(NS$_{30}$+1)$^{-0.571}$	+45.0 to –31.1
25	Q = 0.319 AREA$^{0.943}$PREC1.66(NS$_{30}$+1)$^{-0.538}$	+46.0 to –31.5
50	Q = 0.456 AREA$^{0.934}$PREC1.58(NS$_{30}$+1)$^{-0.517}$	+47.1 to –32.0
100	Q = 0.620 AREA$^{0.926}$PREC1.52(NS$_{30}$+1)$^{-0.499}$	+48.4 to –32.6
200	Q = 0.813 AREA$^{0.919}$PREC1.46(NS$_{30}$+1)$^{-0.483}$	+49.8 to –33.2
500	Q = 1.12 AREA$^{0.911}$PREC1.39(NS$_{30}$+1)$^{-0.464}$	+51.9 to –34.2
	Region 6 (n = 31)	
2	Q = 0.000258 AREA$^{0.893}$PREC$^{3.15}$	+76.5 to –43.4
5	Q = 0.00223 AREA$^{0.846}$PREC$^{2.68}$	+68.8 to –40.8
10	Q = 0.00632 AREA$^{0.824}$PREC$^{2.45}$	+67.9 to –40.4
25	Q = 0.0181 AREA$^{0.801}$PREC$^{2.22}$	+68.8 to –40.8
50	Q = 0.0346 AREA$^{0.787}$PREC$^{2.08}$	+70.2 to –41.2
100	Q = 0.0607 AREA$^{0.775}$PREC$^{1.96}$	+71.8 to –41.8
200	Q = 0.100 AREA$^{0.763}$PREC$^{1.85}$	+73.8 to –42.4
500	Q = 0.180 AREA$^{0.750}$PREC$^{1.73}$	+76.5 to –43.3

Table C.21—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Region 7a ($n^b = 28$)	
2	$Q = 2.28\ \mathrm{AREA}^{0.759}(\mathrm{ELEV}/1{,}000)^{0.769}$	+82.3 to –45.2
5	$Q = 27.3\ \mathrm{AREA}^{0.762}(\mathrm{ELEV}/1{,}000)^{-0.211}$	+66.6 to –40.0
10	$Q = 88.4\ \mathrm{AREA}^{0.766}(\mathrm{ELEV}/1{,}000)^{-0.669}$	+62.2 to –38.3
25	$Q = 286\ \mathrm{AREA}^{0.771}(\mathrm{ELEV}/1{,}000)^{-1.12}$	+60.6 to –37.7
50	$Q = 592\ \mathrm{AREA}^{0.774}(\mathrm{ELEV}/1{,}000)^{-1.41}$	+61.4 to –38.0
100	$Q = 1{,}120\ \mathrm{AREA}^{0.778}(\mathrm{ELEV}/1{,}000)^{-1.65}$	+63.3 to –38.8
200	$Q = 1{,}970\ \mathrm{AREA}^{0.781}(\mathrm{ELEV}/1{,}000)^{-1.87}$	+66.2 to –39.8
500	$Q = 3{,}860\ \mathrm{AREA}^{0.784}(\mathrm{ELEV}/1{,}000)^{-2.13}$	+71.1 to –41.5
	Region 7b ($n = 17$)	
2	$Q = 10.2\ \mathrm{AREA}^{0.611}$	+143 to –58.8
5	$Q = 17.1\ \mathrm{AREA}^{0.624}$	+104 to –50.9
10	$Q = 22.4\ \mathrm{AREA}^{0.633}$	+86.9 to –46.5
25	$Q = 29.9\ \mathrm{AREA}^{0.644}$	+73.5 to –42.3
50	$Q = 35.7\ \mathrm{AREA}^{0.653}$	+68.0 to –40.5
100	$Q = 41.6\ \mathrm{AREA}^{0.662}$	+66.1 to –39.8
200	$Q = 47.5\ \mathrm{AREA}^{0.672}$	+66.9 to –40.1
500	$Q = 55.5\ \mathrm{AREA}^{0.686}$	+71.8 to –41.8
	Region 8 ($n = 60$)	
2	$Q = 1.49\ \mathrm{AREA}^{0.942}\mathrm{BS\%}^{1.15}(\mathrm{S30}+1)^{-0.563}$	+86.9 to –46.5
5	$Q = 1.93\ \mathrm{AREA}^{0.915}\mathrm{BS\%}^{1.53}(\mathrm{S30}+1)^{-0.862}$	+79.8 to –44.4
10	$Q = 2.10\ \mathrm{AREA}^{0.903}\mathrm{BS\%}^{1.75}(\mathrm{S30}+1)^{-1.03}$	+78.3 to –43.9
25	$Q = 2.22\ \mathrm{AREA}^{0.892}\mathrm{BS\%}^{1.99}(\mathrm{S30}+1)^{-1.21}$	+78.2 to –43.9
50	$Q = 2.26\ \mathrm{AREA}^{0.886}\mathrm{BS\%}^{2.15}(\mathrm{S30}+1)^{-1.33}$	+78.9 to –44.1
100	$Q = 2.27\ \mathrm{AREA}^{0.882}\mathrm{BS\%}^{2.31}(\mathrm{S30}+1)^{-1.44}$	+79.9 to –44.4
200	$Q = 2.25\ \mathrm{AREA}^{0.878}\mathrm{BS\%}^{2.45}(\mathrm{S30}+1)^{-1.54}$	+81.2 to –44.8
500	$Q = 2.22\ \mathrm{AREA}^{0.874}\mathrm{BS\%}^{2.62}(\mathrm{S30}+1)^{-1.67}$	+83.2 to –45.4

[a] Equation: Q, peak flow, in $\mathrm{ft}^3\ \mathrm{sec}^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft; F, percentage of basin covered by forest; PREC, mean annual precipitation, in inches; NS_{30}, percentage of north-facing slopes greater than 30%; $\mathrm{BS}_{\%}$, average basin slope, in percent; S_{30}, percentage of slopes greater than 30%

[b] Number of stations used in the regression analysis

Table C.22—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Montana (Omang 1992). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (*Au/Ag*) if the drainage area ratio is between 0.5 and 1.5.

	Hydrologic Regions of Montana							
Ta (yr)	**West**	**Northwest**	**Southwest**	**Upper Yellowstone Central Mountain**	**Northwest Foothills**	**Northeast Plains**	**East-Central Plains**	**Southeast Plains**
2	0.94	0.94	0.87	0.85	0.49	0.69	0.55	0.55
5	0.90	0.87	0.82	0.79	0.48	0.65	0.53	0.53
10	0.89	0.84	0.78	0.77	0.47	0.63	0.52	0.52
25	0.87	0.81	0.72	0.74	0.46	0.61	0.50	0.51
50	0.86	0.79	0.70	0.72	0.47	0.60	0.49	0.50
100	0.85	0.74	0.68	0.70	0.48	0.59	0.49	0.50
500	0.83	0.67	0.64	0.65	0.50	0.57	0.47	0.49

[a] Recurrence interval

Table C.23—Regional flood-frequency equations for Montana based on drainage-basin characteristics (Omang 1992).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	West Region		
2	$Q = 0.042\ \mathrm{AREA}^{0.94}\mathrm{PREC}^{1.49}$	52	1
5	$Q = 0.140\ \mathrm{AREA}^{0.90}\mathrm{PREC}^{1.31}$	47	2
10	$Q = 0.235\ \mathrm{AREA}^{0.89}\mathrm{PREC}^{1.25}$	45	2
25	$Q = 0.379\ \mathrm{AREA}^{0.87}\mathrm{PREC}^{1.19}$	45	3
50	$Q = 0.496\ \mathrm{AREA}^{0.86}\mathrm{PREC}^{1.17}$	46	3
100	$Q = 0.615\ \mathrm{AREA}^{0.85}\mathrm{PREC}^{1.15}$	48	4
500	$Q = 0.874\ \mathrm{AREA}^{0.83}\mathrm{PREC}^{1.14}$	55	4
	Northwest Region		
2	$Q = 0.266\ \mathrm{AREA}^{0.94}\mathrm{PREC}^{1.12}$	44	2
5	$Q = 2.34\ \mathrm{AREA}^{0.87}\mathrm{PREC}^{0.75}$	34	8
10	$Q = 7.84\ \mathrm{AREA}^{0.84}\mathrm{PREC}^{0.54}$	31	13
25	$Q = 23.1\ \mathrm{AREA}^{0.81}\mathrm{PREC}^{0.40}$	27	26
50	$Q = 25.4\ \mathrm{AREA}^{0.79}\mathrm{PREC}^{0.46}$	26	39
100	$Q = 38.9\ \mathrm{AREA}^{0.74}\mathrm{PREC}^{0.50}$	38	24
500	$Q = 87.1\ \mathrm{AREA}^{0.67}\mathrm{PREC}^{0.49}$	59	18
	Southwest Region		
2	$Q = 2.48\ \mathrm{AREA}^{0.87}(\mathrm{HE}+10)^{0.19}$	88	1
5	$Q = 24.8\ \mathrm{AREA}^{0.82}(\mathrm{HE}+10)^{-0.16}$	69	2
10	$Q = 81.5\ \mathrm{AREA}^{0.78}(\mathrm{HE}+10)^{-0.32}$	63	3
25	$Q = 297\ \mathrm{AREA}^{0.72}(\mathrm{HE}+10)^{-0.49}$	60	4
50	$Q = 695\ \mathrm{AREA}^{0.70}(\mathrm{HE}+10)^{-0.62}$	63	5
100	$Q = 1{,}520\ \mathrm{AREA}^{0.68}(\mathrm{HE}+10)^{-0.74}$	66	5
500	$Q = 7{,}460\ \mathrm{AREA}^{0.64}(\mathrm{HE}+10)^{-0.99}$	80	5
	Upper Yellowstone–Central Mountain Region		
2	$Q = 0.117\ \mathrm{AREA}^{0.85}(\mathrm{ELEV}/1{,}000)^{3.57}(\mathrm{HE}+10)^{-0.57}$	72	2
5	$Q = 0.960\ \mathrm{AREA}^{0.79}(\mathrm{ELEV}/1{,}000)^{3.44}(\mathrm{HE}+10)^{-0.82}$	53	7
10	$Q = 2.71\ \mathrm{AREA}^{0.77}(\mathrm{ELEV}/1{,}000)^{3.36}(\mathrm{HE}+10)^{-0.94}$	46	12
25	$Q = 8.54\ \mathrm{AREA}^{0.74}(\mathrm{ELEV}/1{,}000)^{3.16}(\mathrm{HE}+10)^{-1.03}$	44	14
50	$Q = 19.0\ \mathrm{AREA}^{0.72}(\mathrm{ELEV}/1{,}000)^{2.95}(\mathrm{HE}+10)^{-1.05}$	46	14
100	$Q = 41.6\ \mathrm{AREA}^{0.70}(\mathrm{ELEV}/1{,}000)^{2.72}(\mathrm{HE}+10)^{-1.07}$	50	14
500	$Q = 205\ \mathrm{AREA}^{0.65}(\mathrm{ELEV}/1{,}000)^{2.17}(\mathrm{HE}+10)^{-1.07}$	63	15
	Northwest Foothills Region		
2	$Q = 0.653\ \mathrm{AREA}^{0.49}(\mathrm{ELEV}/1{,}000)^{2.60}$	88	4
5	$Q = 3.70\ \mathrm{AREA}^{0.48}(\mathrm{ELEV}/1{,}000)^{2.22}$	52	13
10	$Q = 8.30\ \mathrm{AREA}^{0.47}(\mathrm{ELEV}/1{,}000)^{2.10}$	48	19
25	$Q = 20.3\ \mathrm{AREA}^{0.46}(\mathrm{ELEV}/1{,}000)^{1.95}$	50	25
50	[b]$Q = 47.7\ \mathrm{AREA}^{0.47}(\mathrm{ELEV}/1{,}000)^{1.62}$	54	28
100	[b]$Q = 79.8\ \mathrm{AREA}^{0.48}(\mathrm{ELEV}/1{,}000)^{1.40}$	62	28
500	[b]$Q = 344\ \mathrm{AREA}^{0.50}(\mathrm{ELEV}/1{,}000)^{0.98}$	75	31
	Northeast Plains Region		
2	$Q = 15.4\ \mathrm{AREA}^{0.69}(\mathrm{ELEV}/1{,}000)^{-0.39}$	85	3
5	$Q = 77.0\ \mathrm{AREA}^{0.65}(\mathrm{ELEV}/1{,}000)^{-0.71}$	63	6
10	$Q = 161\ \mathrm{AREA}^{0.63}(\mathrm{ELEV}/1{,}000)^{-0.84}$	56	10
25	$Q = 343\ \mathrm{AREA}^{0.61}(\mathrm{ELEV}/1{,}000)^{-1.00}$	53	14
50	$Q = 543\ \mathrm{AREA}^{0.60}(\mathrm{ELEV}/1{,}000)^{-1.09}$	53	17
100	$Q = 818\ \mathrm{AREA}^{0.59}(\mathrm{ELEV}/1{,}000)^{-1.19}$	56	18
500	$Q = 1{,}720\ \mathrm{AREA}^{0.57}(\mathrm{ELEV}/1{,}000)^{-1.37}$	68	18
	East–Central Plains Region		
2	$Q = 141\ \mathrm{AREA}^{0.55}(\mathrm{ELEV}/1{,}000)^{-1.88}$	99	3
5	$Q = 509\ \mathrm{AREA}^{0.53}(\mathrm{ELEV}/1{,}000)^{-1.92}$	75	5
10	$Q = 911\ \mathrm{AREA}^{0.52}(\mathrm{ELEV}/1{,}000)^{-1.88}$	66	8
25	$Q = 1{,}545\ \mathrm{AREA}^{0.50}(\mathrm{ELEV}/1{,}000)^{-1.79}$	62	11
50	$Q = 2{,}100\ \mathrm{AREA}^{0.49}(\mathrm{ELEV}/1{,}000)^{-1.72}$	62	14
100	$Q = 2{,}620\ \mathrm{AREA}^{0.49}(\mathrm{ELEV}/1{,}000)^{-1.62}$	65	15
500	$Q = 3{,}930\ \mathrm{AREA}^{0.47}(\mathrm{ELEV}/1{,}000)^{-1.44}$	75	16

Table C.23—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Southeast Plains Region		
2	$Q = 537\ AREA^{0.55}(ELEV/1{,}000)^{-2.91}$	134	1
5	$Q = 1{,}350\ AREA^{0.53}(ELEV/1{,}000)^{-2.75}$	88	3
10	$Q = 2{,}050\ AREA^{0.52}(ELEV/1{,}000)^{-2.64}$	73	5
25	$Q = 3{,}240\ AREA^{0.51}(ELEV/1{,}000)^{-2.55}$	63	9
50	$Q = 4{,}160\ AREA^{0.50}(ELEV/1{,}000)^{-2.47}$	59	12
100	$Q = 5{,}850\ AREA^{0.50}(ELEV/1{,}000)^{-2.51}$	62	13
500	$Q = 8{,}250\ AREA^{0.49}(ELEV/1{,}000)^{-2.33}$	67	15

[a] Equation: Q, peak flow, in $ft^3\ sec^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches; ELEV, mean basin elevation, in ft; HE, percentage of basin above 6,000 ft elevation

[b] Equation is not valid if the ungaged stream originates in the Northwest Region

Table C.24—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Montana (Parrett and Johnson 2004). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (*Au/Ag*) if the drainage area ratio is between 0.5 and 1.5.

	Hydrologic Regions of Montana							
T[a] (yr)	West Region	Northwest Region	Northwest Foothills Region	Northeast Plains Region	East-Central Plains Region	Southeast Plains Region	Upper Yellowstone Central Mountain Region	Southwest Region
2	0.851	0.884	0.609	0.620	0.464	0.516	0.877	0.894
5	0.818	0.822	0.587	0.564	0.459	0.478	0.768	0.776
10	0.798	0.789	0.577	0.536	0.454	0.458	0.712	0.720
25	0.776	0.747	0.566	0.506	0.446	0.433	0.656	0.661
50	0.761	0.722	0.560	0.486	0.439	0.418	0.618	0.622
100	0.747	0.700	0.555	0.469	0.432	0.403	0.587	0.585
200	0.734	0.685	0.551	0.453	0.426	0.389	0.557	0.550
500	0.717	0.665	0.547	0.433	0.417	0.371	0.523	0.510

[a] Recurrence interval

Table C.25—Regression equations for Montana based on basin characteristics (Parrett and Johnson 2004).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	West Region (n[b] = 96)		
2	$Q = 0.268\ \mathrm{AREA}^{0.927}\mathrm{PREC}^{1.60}(\mathrm{F}+1)^{-0.508}$	60.5	0.9
5	$Q = 1.54\ \mathrm{AREA}^{0.884}\mathrm{PREC}^{1.36}(\mathrm{F}+1)^{-0.577}$	55.4	1.4
10	$Q = 3.63\ \mathrm{AREA}^{0.860}\mathrm{PREC}^{1.25}(\mathrm{F}+1)^{-0.605}$	54.3	1.9
25	$Q = 8.50\ \mathrm{AREA}^{0.835}\mathrm{PREC}^{1.14}(\mathrm{F}+1)^{-0.639}$	54.6	2.7
50	$Q = 13.2\ \mathrm{AREA}^{0.823}\mathrm{PREC}^{1.09}(\mathrm{F}+1)^{-0.652}$	56.0	3.1
100	$Q = 18.7\ \mathrm{AREA}^{0.812}\mathrm{PREC}^{1.06}(\mathrm{F}+1)^{-0.664}$	58.5	3.4
200	$Q = 24.7\ \mathrm{AREA}^{0.804}\mathrm{PREC}^{1.04}(\mathrm{F}+1)^{-0.674}$	62.2	3.6
500	$Q = 35.4\ \mathrm{AREA}^{0.792}\mathrm{PREC}^{1.02}(\mathrm{F}+1)^{-0.690}$	67.9	3.7
	Northwest Region (n = 35)		
2	$Q = 0.128\ \mathrm{AREA}^{0.918}\mathrm{PREC}^{1.33}$	49.2	—[c]
5	$Q = 1.19\ \mathrm{AREA}^{0.846}\mathrm{PREC}^{0.954}$	39.2	—
10	$Q = 4.10\ \mathrm{AREA}^{0.807}\mathrm{PREC}^{0.720}$	38.4	—
25	$Q = 15.8\ \mathrm{AREA}^{0.760}\mathrm{PREC}^{0.510}$	38.4	—
50	$Q = 31.2\ \mathrm{AREA}^{0.733}\mathrm{PREC}^{0.445}$	37.4	—
100	$Q = 56.4\ \mathrm{AREA}^{0.710}\mathrm{PREC}^{0.403}$	40.2	—
200	$Q = 97.0\ \mathrm{AREA}^{0.694}\mathrm{PREC}^{0.364}$	46.0	—
500	$Q = 175\ \mathrm{AREA}^{0.674}\mathrm{PREC}^{0.374}$	56.9	—
	Northwest Foothills Region (n = 24)		
2	$Q = 14.2\ \mathrm{AREA}^{0.598}$	99.5	2.7
5	$Q = 53.6\ \mathrm{AREA}^{0.546}$	59.6	8.7
10	$Q = 105\ \mathrm{AREA}^{0.546}$	51.3	15.5
25	$Q = 208\ \mathrm{AREA}^{0.538}$	50.8	22.2
50	$Q = 318\ \mathrm{AREA}^{0.536}$	55.0	23.8
100	$Q = 462\ \mathrm{AREA}^{0.537}$	61.0	23.8
200	$Q = 649\ \mathrm{AREA}^{0.540}$	68.2	23.1
500	$Q = 977\ \mathrm{AREA}^{0.544}$	79.0	21.8
	Northeast Plains Region (n[b] = 57)		
2	$Q = 30.5\ \mathrm{AREA}^{0.601}(\mathrm{ELEV}/1{,}000)^{-0.913}$	91.0	3.0
5	$Q = 143\ \mathrm{AREA}^{0.547}(\mathrm{ELEV}/1{,}000)^{-1.12}$	80.3	4.3
10	$Q = 293\ \mathrm{AREA}^{0.520}(\mathrm{ELEV}/1{,}000)^{-1.19}$	81.3	5.5
25	$Q = 579\ \mathrm{AREA}^{0.493}(\mathrm{ELEV}/1{,}000)^{-1.21}$	87.2	6.6
50	$Q = 860\ \mathrm{AREA}^{0.477}(\mathrm{ELEV}/1{,}000)^{-1.21}$	93.9	7.2
100	$Q = 1{,}190\ \mathrm{AREA}^{0.462}(\mathrm{ELEV}/1{,}000)^{-1.20}$	101.4	7.5
200	$Q = 1{,}570\ \mathrm{AREA}^{0.450}(\mathrm{ELEV}/1{,}000)^{-1.17}$	109.9	7.7
500	$Q = 2{,}130\ \mathrm{AREA}^{0.435}(\mathrm{ELEV}/1{,}000)^{-1.13}$	123.2	7.7
	East–Central Plains Region (n = 85)		
2	$Q = 141\ \mathrm{AREA}^{0.495}(\mathrm{ELEV}/1{,}000)^{-1.85}$	99.9	3.1
5	$Q = 661\ \mathrm{AREA}^{0.490}(\mathrm{ELEV}/1{,}000)^{-2.09}$	76.0	5.7
10	$Q = 1{,}300\ \mathrm{AREA}^{0.482}(\mathrm{ELEV}/1{,}000)^{-2.11}$	71.4	8.3
25	$Q = 2{,}360\ \mathrm{AREA}^{0.470}(\mathrm{ELEV}/1{,}000)^{-2.05}$	73.4	10.7
50	$Q = 3{,}240\ \mathrm{AREA}^{0.462}(\mathrm{ELEV}/1{,}000)^{-1.96}$	78.6	11.6
100	$Q = 4{,}120\ \mathrm{AREA}^{0.454}(\mathrm{ELEV}/1{,}000)^{-1.84}$	85.7	12.0
200	$Q = 4{,}950\ \mathrm{AREA}^{0.446}(\mathrm{ELEV}/1{,}000)^{-1.72}$	94.3	11.9
500	$Q = 5{,}940\ \mathrm{AREA}^{0.435}(\mathrm{ELEV}/1{,}000)^{-1.53}$	107.8	11.6
	Southeast Plains Region (n = 69)		
2	$Q = 29.0\ \mathrm{AREA}^{0.600}(\mathrm{F}+1)^{-0.424}$	134.1	1.5
5	$Q = 83.1\ \mathrm{AREA}^{0.547}(\mathrm{F}+1)^{-0.352}$	103.9	2.6
10	$Q = 142\ \mathrm{AREA}^{0.517}(\mathrm{F}+1)^{-0.309}$	94.3	4.0
25	$Q = 249\ \mathrm{AREA}^{0.483}(\mathrm{F}+1)^{-0.264}$	88.9	6.0
50	$Q = 355\ \mathrm{AREA}^{0.461}(\mathrm{F}+1)^{-0.236}$	89.1	7.3
100	$Q = 486\ \mathrm{AREA}^{0.441}(\mathrm{F}+1)^{-0.212}$	91.6	8.3
200	$Q = 645\ \mathrm{AREA}^{0.422}(\mathrm{F}+1)^{-0.190}$	96.1	9.0
500	$Q = 905\ \mathrm{AREA}^{0.401}(\mathrm{F}+1)^{-0.166}$	105.5	9.3

Table C.25—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Upper Yellowstone–Central Mountain Region (n[b] = 92)		
2	$Q = 5.84\ \mathrm{AREA}^{0.832}(\mathrm{HE}+1)^{0.098}$	94.9	1.5
5	$Q = 21.7\ \mathrm{AREA}^{0.782}(\mathrm{HE}+1)^{-0.0295}$	72.7	3.2
10	$Q = 42.3\ \mathrm{AREA}^{0.758}(\mathrm{HE}+1)^{0.0915}$	63.4	5.6
25	$Q = 82.6\ \mathrm{AREA}^{0.733}(\mathrm{HE}+1)^{-0.148}$	57.1	9.5
50	$Q = 126\ \mathrm{AREA}^{0.716}(\mathrm{HE}+1)^{-0.182}$	55.9	12.2
100	$Q = 181\ \mathrm{AREA}^{0.702}(\mathrm{HE}+1)^{-0.211}$	56.8	14.2
200	$Q = 252\ \mathrm{AREA}^{0.689}(\mathrm{HE}+1)^{-0.238}$	59.5	15.4
500	$Q = 375\ \mathrm{AREA}^{0.674}(\mathrm{HE}+1)^{-0.271}$	65.2	15.9
	Southwest Region (n = 44)		
2	$Q = 3.02\ \mathrm{AREA}^{0.881}(\mathrm{HE}+1)^{0.0981}$	94.4	0.9
5	$Q = 17.1\ \mathrm{AREA}^{0.800}(\mathrm{HE}+1)^{-0.104}$	79.0	1.7
10	$Q = 41.9\ \mathrm{AREA}^{0.765}(\mathrm{HE}+1)^{-0.214}$	75.9	2.4
25	$Q = 109\ \mathrm{AREA}^{0.728}(\mathrm{HE}+1)^{-0.332}$	75.6	3.4
50	$Q = 201\ \mathrm{AREA}^{0.704}(\mathrm{HE}+1)^{-0.408}$	77.4	4.0
100	$Q = 351\ \mathrm{AREA}^{0.682}(\mathrm{HE}+1)^{-0.476}$	80.3	4.5
200	$Q = 582\ \mathrm{AREA}^{0.660}(\mathrm{HE}+1)^{-0.537}$	83.8	4.9
500	$Q = 1{,}060\ \mathrm{AREA}^{0.636}(\mathrm{HE}+1)^{-0.611}$	89.9	5.3

[a] Equation: Q, peak flow, in $\mathrm{ft}^3\ \mathrm{sec}^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches; ELEV, mean basin elevation, in ft; HE, percentage of basin above 6,000 ft elevation; F, percentage of basin covered by forest

[b] Number of stations used in the regression analysis

[c] Not applicable

Table C.26—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in New Mexico (Mason and others 2000; Waltemeyer 1996). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (A_u/A_g) if the drainage area ratio is between 0.5 and 1.5.

	Hydrologic Regions of New Mexico								
Recurrence interval (yr)	**Region 1 Northeast Plains**	**Region 2 Northwest Plateau**	**Region 3 Southeast Mountain**	**Region 4 Southeast Plains**	**Region 5 Northern Mountain**	**Region 6 Central Valley Mountain**	**Region 7 Southwest Desert**	**Region 8 Southwest Mountain**	**Statewide small basin[a]**
2	0.53	0.47	0.60	0.51	0.83	0.50	0.46	0.19	0.39
5	0.50	0.46	0.67	0.54	0.81	0.47	0.48	0.23	0.42
10	0.49	0.46	0.70	0.55	0.81	0.46	0.49	0.25	0.43
25	0.48	0.45	0.75	0.57	0.80	0.44	0.50	0.27	0.44
50	0.48	0.45	0.78	0.58	0.80	0.43	0.51	0.29	0.45
100	0.48	0.45	0.81	0.59	0.80	0.42	0.52	0.30	0.46
500	0.48	0.45	0.87	0.62	0.80	0.40	0.55	0.32	0.47

[a] Statewide small basin has basin size of 10 mi^2 or less, and mean basin elevation of less than 7,500 ft

Table C.27—Flood-peak flow regression equations and associated statistics for streams that drain rural areas in New Mexico (Mason and others 2000; Waltemeyer 1996).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Northeast Plains Region (Hydrologic Region 1 in New Mexico)	
2	$Q = 114\ \text{AREA}^{0.53}$	96
5	$Q = 307\ \text{AREA}^{0.50}$	78
10	$Q = 508\ \text{AREA}^{0.49}$	75
25	$Q = 853\ \text{AREA}^{0.48}$	72
50	$Q = 1{,}180\ \text{AREA}^{0.48}$	72
100	$Q = 1{,}580\ \text{AREA}^{0.48}$	75
500	$Q = 2{,}800\ \text{AREA}^{0.48}$	82
	Northwest Plateau Region (Hydrologic Region 2 in New Mexico)	
2	$Q = 84.7\ \text{AREA}^{0.47}$	111
5	$Q = 197\ \text{AREA}^{0.46}$	82
10	$Q = 306\ \text{AREA}^{0.46}$	72
25	$Q = 486\ \text{AREA}^{0.45}$	66
50	$Q = 654\ \text{AREA}^{0.45}$	63
100	$Q = 853\ \text{AREA}^{0.45}$	63
500	$Q = 1{,}450\ \text{AREA}^{0.45}$	66
	Southeast Mountain Region (Hydrologic Region 3 in New Mexico)	
2	$Q = 8{,}540{,}000\ \text{AREA}^{0.60}(\text{ELEV}/1{,}000)^{-5.96}$	36
5	$Q = 71{,}400{,}000\ \text{AREA}^{0.67}(\text{ELEV}/1{,}000)^{-6.69}$	38
10	$Q = 160{,}000{,}000\ \text{AREA}^{0.70}(\text{ELEV}/1{,}000)^{-6.94}$	41
25	$Q = 304{,}000{,}000\ \text{AREA}^{0.75}(\text{ELEV}/1{,}000)^{-7.10}$	43
50	$Q = 415{,}000{,}000\ \text{AREA}^{0.78}(\text{ELEV}/1{,}000)^{-7.16}$	46
100	$Q = 521{,}000{,}000\ \text{AREA}^{0.81}(\text{ELEV}/1{,}000)^{-7.19}$	49
500	$Q = 711{,}000{,}000\ \text{AREA}^{0.87}(\text{ELEV}/1{,}000)^{-7.20}$	60
	Southeast Plains Region (Hydrologic Region 4 in New Mexico)	
2	$Q = 81.7\ \text{AREA}^{0.51}$	192
5	$Q = 236\ \text{AREA}^{0.54}$	124
10	$Q = 407\ \text{AREA}^{0.55}$	103
25	$Q = 721\ \text{AREA}^{0.57}$	88
50	$Q = 1{,}040\ \text{AREA}^{0.58}$	78
100	$Q = 1{,}430\ \text{AREA}^{0.59}$	72
500	$Q = 2{,}720\ \text{AREA}^{0.62}$	66

Table C.27—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Northern Mountain Region (Hydrologic Region 5 in New Mexico)	
2	$Q = 854\ \mathrm{AREA}^{0.83}(\mathrm{ELEV}/1{,}000)^{-2.22}I_{25}^{0.31}$	92
5	$Q = 7{,}390\ \mathrm{AREA}^{0.81}(\mathrm{ELEV}/1{,}000)^{-3.01}I_{25}^{0.63}$	82
10	$Q = 21{,}900\ \mathrm{AREA}^{0.81}(\mathrm{ELEV}/1{,}000)^{-3.41}I_{25}^{0.81}$	78
25	$Q = 69{,}000\ \mathrm{AREA}^{0.80}(\mathrm{ELEV}/1{,}000)^{-3.85}I_{25}^{1.03}$	75
50	$Q = 144{,}000\ \mathrm{AREA}^{0.80}(\mathrm{ELEV}/1{,}000)^{-4.13}I_{25}^{1.18}$	78
100	$Q = 280{,}000\ \mathrm{AREA}^{0.80}(\mathrm{ELEV}/1{,}000)^{-4.40}I_{25}^{1.33}$	82
500	$Q = 1{,}100{,}000\ \mathrm{AREA}^{0.80}(\mathrm{ELEV}/1{,}000)^{-4.95}I_{25}^{1.64}$	92
	Central Mountain Valley Region (Hydrologic Region 6 in New Mexico)	
2	$Q = 747{,}000\ \mathrm{AREA}^{0.50}(\mathrm{CE}/1{,}000)^{-5.28}I_{10}^{1.18}$	103
5	$Q = 257{,}000\ \mathrm{AREA}^{0.47}(\mathrm{CE}/1{,}000)^{-4.49}I_{10}^{1.76}$	69
10	$Q = 153{,}000\ \mathrm{AREA}^{0.46}(\mathrm{CE}/1{,}000)^{-4.09}I_{10}^{2.06}$	57
25	$Q = 88{,}900\ \mathrm{AREA}^{0.44}(\mathrm{CE}/1{,}000)^{-3.67}I_{10}^{2.37}$	46
50	$Q = 61{,}100\ \mathrm{AREA}^{0.43}(\mathrm{CE}/1{,}000)^{-3.38}I_{10}^{2.57}$	43
100	$Q = 41{,}800\ \mathrm{AREA}^{0.42}(\mathrm{CE}/1{,}000)^{-3.09}I_{10}^{2.74}$	41
500	$Q = 17{,}800\ \mathrm{AREA}^{0.40}(\mathrm{CE}/1{,}000)^{-2.45}I_{10}^{3.03}$	43
	Southwest Desert Region (Hydrologic Region 7 in New Mexico)	
2	$Q = 128\ \mathrm{AREA}^{0.46}$	57
5	$Q = 246\ \mathrm{AREA}^{0.48}$	51
10	$Q = 345\ \mathrm{AREA}^{0.49}$	51
25	$Q = 491\ \mathrm{AREA}^{0.50}$	54
50	$Q = 615\ \mathrm{AREA}^{0.51}$	57
100	$Q = 751\ \mathrm{AREA}^{0.52}$	60
500	$Q = 1{,}120\ \mathrm{AREA}^{0.55}$	72
	Southwest Mountain Region (Hydrologic Region 8 in New Mexico)	
2	$Q = 25{,}800{,}000\ \mathrm{AREA}^{0.19}(\mathrm{CE}/1{,}000)^{-6.10}$	88
5	$Q = 14{,}900{,}000\ \mathrm{AREA}^{0.23}(\mathrm{CE}/1{,}000)^{-5.53}$	85
10	$Q = 10{,}300{,}000\ \mathrm{AREA}^{0.25}(\mathrm{CE}/1{,}000)^{-5.19}$	85
25	$Q = 6{,}530{,}000\ \mathrm{AREA}^{0.27}(\mathrm{CE}/1{,}000)^{-4.80}$	88
50	$Q = 4{,}690{,}000\ \mathrm{AREA}^{0.29}(\mathrm{CE}/1{,}000)^{-4.52}$	92
100	$Q = 3{,}400{,}000\ \mathrm{AREA}^{0.30}(\mathrm{CE}/1{,}000)^{-4.25}$	96
500	$Q = 1{,}660{,}000\ \mathrm{AREA}^{0.32}(\mathrm{CE}/1{,}000)^{-3.68}$	116
	Statewide small basin, less than 10 mi^2 and less than 7,500 ft mean basin elevation	
2	$Q = 107\ \mathrm{AREA}^{0.39}$	120
5	$Q = 243\ \mathrm{AREA}^{0.42}$	88
10	$Q = 374\ \mathrm{AREA}^{0.43}$	75
25	$Q = 591\ \mathrm{AREA}^{0.44}$	69
50	$Q = 792\ \mathrm{AREA}^{0.45}$	66
100	$Q = 1{,}030\ \mathrm{AREA}^{0.46}$	63
500	$Q = 1{,}730\ \mathrm{AREA}^{0.47}$	63

[a] Equation: Q, peak flow, in ft^3 sec^{-1}; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft; CE, average channel elevation, in ft above sea level; I_{10}, maximum precipitation intensity, 24-hour precipitation intensity, in inches, with a recurrence interval of 10 years; I_{25}, maximum precipitation intensity, 24-hour precipitation intensity, in inches, with a recurrence interval of 25 years

Table C.28—Regression equations for estimating magnitude and frequency of floods for ungaged sites in western Oregon (Harris and others 1979; Jennings and others 1994).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Coast Region (n[b] = 40)	
2	$Q = 4.59\ AREA^{0.96}(ST+1)^{-0.45}I_2^{1.91}$	33
5	$Q = 6.27\ AREA^{0.95}(ST+1)^{-0.45}I_2^{1.95}$	32
10	$Q = 7.32\ AREA^{0.94}(ST+1)^{-0.45}I_2^{1.97}$	33
25	$Q = 8.71\ AREA^{0.93}(ST+1)^{-0.45}I_2^{1.99}$	34
50	$Q = 9.73\ AREA^{0.93}(ST+1)^{-0.44}I_2^{2.01}$	35
100	$Q = 10.7\ AREA^{0.92}(ST+1)^{-0.44}I_2^{2.02}$	37
	Willamette Region (n = 111)	
2	$Q = 8.70\ AREA^{0.87}I_2^{1.71}$	33
5	$Q = 15.6\ AREA^{0.88}I_2^{1.55}$	33
10	$Q = 21.5\ AREA^{0.88}I_2^{1.46}$	33
25	$Q = 30.3\ AREA^{0.88}I_2^{1.37}$	34
50	$Q = 38.0\ AREA^{0.88}I_2^{1.31}$	36
100	$Q = 46.9\ AREA^{0.88}I_2^{1.25}$	37
	Rogue–Umpqua Region (n = 60)	
2	$Q = 24.2\ AREA^{0.86}(ST+1)^{-1.16}I_2^{1.15}$	44
5	$Q = 36.0\ AREA^{0.88}(ST+1)^{-1.25}I_2^{1.15}$	43
10	$Q = 44.8\ AREA^{0.88}(ST+1)^{-1.28}I_2^{1.14}$	44
25	$Q = 56.9\ AREA^{0.89}(ST+1)^{-1.31}I_2^{1.12}$	46
50	$Q = 66.7\ AREA^{0.90}(ST+1)^{-1.33}I_2^{1.10}$	49
100	$Q = 77.3\ AREA^{0.90}(ST+1)^{-1.34}I_2^{1.08}$	51
	High Cascades Region (n = 28)	
2	$Q = 4.75\ AREA^{0.90}(ST+1)^{-0.62}(101-F)^{0.11}I_2^{1.17}$	55
5	$Q = 8.36\ AREA^{0.86}(ST+1)^{-0.81}(101-F)^{0.08}I_2^{1.30}$	50
10	$Q = 11.3\ AREA^{0.85}(ST+1)^{-0.92}(101-F)^{0.07}I_2^{1.37}$	53
25	$Q = 15.4\ AREA^{0.83}(ST+1)^{-1.03}(101-F)^{0.05}I_2^{1.46}$	59
50	$Q = 18.8\ AREA^{0.82}(ST+1)^{-1.10}(101-F)^{0.04}I_2^{1.52}$	66
100	$Q = 22.6\ AREA^{0.81}(ST+1)^{-1.17}(101-F)^{0.03}I_2^{1.57}$	72

[a] Equation: Q, peak flow, in $ft^3\ sec^{-1}$; AREA, drainage area, in mi^2; ST, storage, area of lakes and ponds, in percent; I_2, maximum precipitation intensity, 24-hour precipitation intensity, in inches, with a recurrence interval of 2 years (fig. C.14); F, percentage of basin covered by forest

[b] Number of stations used in the regression analysis

Table C.29—Regression equations for estimating magnitude and frequency of floods for ungaged sites in eastern Oregon (Harris and Hubbard 1983; Jennings and others 1994).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	North Central Region	
2	$Q = 0.00013\ AREA^{0.80}PREC^{1.24}MnJT^{2.53}$	41 to 51
5	$Q = 0.00068\ AREA^{0.76}PREC^{0.90}MnJT^{2.64}$	
10	$Q = 0.00134\ AREA^{0.74}PREC^{0.73}MnJT^{2.73}$	
25	$Q = 0.00325\ AREA^{0.72}PREC^{0.55}MnJT^{2.78}$	
50	$Q = 0.00533\ AREA^{0.70}PREC^{0.44}MnJT^{2.83}$	
100	$Q = 0.00863\ AREA^{0.69}PREC^{0.35}MnJT^{2.86}$	
	East Cascade Region	
2	$Q = 0.017\ CL^{1.72}PREC^{1.32}$	41 to 51
5	$Q = 0.118\ CL^{1.59}PREC^{1.01}$	
10	$Q = 0.319\ CL^{1.53}PREC^{0.85}$	
25	$Q = 0.881\ CL^{1.46}PREC^{0.68}$	
50	$Q = 1.67\ CL^{1.42}PREC^{0.58}$	
100	$Q = 2.92\ CL^{1.39}PREC^{0.49}$	

Table C.29—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)
	Southeast Region	
2	$Q = 0.105\ AREA^{0.79}MnJT^{1.67}$	41 to 51
5	$Q = 0.328\ AREA^{0.77}MnJT^{1.52}$	
10	$Q = 0.509\ AREA^{0.77}MnJT^{1.50}$	
25	$Q = 0.723\ AREA^{0.75}MnJT^{1.52}$	
50	$Q = 0.872\ AREA^{0.76}MnJT^{1.52}$	
100	$Q = 0.960\ AREA^{0.75}MnJT^{1.57}$	
	Northeast Region	
2	$Q = 0.508\ AREA^{0.82}PREC^{1.36}(1+F)^{-0.27}$	41 to 51
5	$Q = 2.44\ AREA^{0.79}PREC^{1.09}(1+F)^{-0.30}$	
10	$Q = 5.28\ AREA^{0.78}PREC^{0.96}(1+F)^{-0.32}$	
25	$Q = 11.8\ AREA^{0.77}PREC^{0.83}(1+F)^{-0.35}$	
50	$Q = 19.8\ AREA^{0.76}PREC^{0.75}(1+F)^{-0.36}$	
100	$Q = 30.7\ AREA^{0.76}PREC^{0.68}(1+F)^{-0.38}$	

[a] Equation: Q, peak flow, in $ft^3\ sec^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches; MnJT, mean minimum January air temperature, in degrees Fahrenheit; CL, main channel length, in miles; F, percentage of basin covered by forest

Table C.30—Prediction equations for estimating peak flow for ungaged watershed in western Oregon (Cooper 2005).

Recurrence interval (yr)	Equation[a]	Average prediction error (%)	Equivalent years of record
	Region 1: Coastal watersheds		
2	$Q = 0.05056\ AREA^{0.9489}I_2^{1.360}MxJT^{1.280}SC^{-0.4421}SP^{-0.1576}$	26.8	2.4
5	$Q = 0.01316\ AREA^{0.9385}I_2^{1.272}MxJT^{1.738}SC^{-0.5026}SP^{-0.2234}$	25.3	3.7
10	$Q = 0.008041\ AREA^{0.9324}I_2^{1.226}MxJT^{1.926}SC^{-0.5267}SP^{-0.2552}$	25.6	5.0
25	$Q = 0.005122\ AREA^{0.9258}I_2^{1.179}MxJT^{2.109}SC^{-0.5484}SP^{-0.2888}$	26.6	6.4
50	$Q = 0.003888\ AREA^{0.9215}I_2^{1.151}MxJT^{2.223}SC^{-0.5605}SP^{-0.3111}$	27.8	7.2
100	$Q = 0.003048\ AREA^{0.9176}I_2^{1.126}MxJT^{2.325}SC^{-0.5701}SP^{-0.3319}$	29.1	7.9
500	$Q = 0.001890\ AREA^{0.9099}I_2^{1.078}MxJT^{2.527}SC^{-0.5855}SP^{-0.3770}$	32.6	8.9
	Region 2A: Western interior watersheds with mean elevations greater than 3,000 ft		
2	$Q = 0.003119\ AREA^{1.021}BS_o^{0.8124}I_2^{2.050}MnJT^{3.541}MxJT^{-1.867}$	38.7	2.2
5	$Q = 0.007824\ AREA^{1.020}BS_o^{0.9022}I_2^{1.649}MnJT^{3.611}MxJT^{-2.017}$	33.8	4.2
10	$Q = 0.01546\ AREA^{1.021}BS_o^{0.9506}I_2^{1.471}MnJT^{3.620}MxJT^{-2.137}$	32.5	6.1
25	$Q = 0.03353\ AREA^{1.021}BS_o^{0.9930}I_2^{1.321}MnJT^{3.624}MxJT^{-2.278}$	32.5	8.6
50	$Q = 0.05501\ AREA^{1.022}BS_o^{1.014}I_2^{1.243}MnJT^{3.624}MxJT^{-2.366}$	33.2	10.3
100	$Q = 0.08492\ AREA^{1.022}BS_o^{1.030}I_2^{1.182}MnJT^{3.621}MxJT^{-2.440}$	34.4	11.6
500	$Q = 0.1974\ AREA^{1.023}BS_o^{1.053}I_2^{1.079}MnJT^{3.601}MxJT^{-2.566}$	37.9	13.6
	Region 2B: Western interior watersheds with mean elevations less than 3,000 ft		
2	$Q = 9.136\ AREA^{0.9004}BS_o^{0.4695}I_2^{0.8481}$	32.6	2.0
5	$Q = 14.54\ AREA^{0.9042}BS_o^{0.4735}I_2^{0.7355}$	32.4	2.8
10	$Q = 18.49\ AREA^{0.9064}BS_o^{0.4688}I_2^{0.6937}$	33.0	3.6
25	$Q = 23.72\ AREA^{0.9086}BS_o^{0.4615}I_2^{0.6578}$	34.1	4.8
50	$Q = 27.75\ AREA^{0.9101}BS_o^{0.4559}I_2^{0.6390}$	35.1	5.5
100	$Q = 31.85\ AREA^{0.9114}BS_o^{0.4501}I_2^{0.6252}$	36.2	6.2
500	$Q = 41.72\ AREA^{0.9141}BS_o^{0.4365}I_2^{0.6059}$	39.1	7.5

[a] Equation: Q, peak flow, in $ft^3\ sec^{-1}$; AREA, drainage area, in mi^2; BS_o, average basin slope, in degrees (fig. C.15); I_2, maximum precipitation intensity, 24-hour precipitation intensity, in inches, with a recurrence interval of 2 years (fig. C.14); MnJT, mean minimum January temperature, in degrees Fahrenheit (fig. C.16); MxJT, mean maximum January temperature, in degrees Fahrenheit (fig. C.17); SC, soil storage capacity, in inches (fig. C.18); SP, soil permeability, in inches per hour (fig. C.19)

[b] Number of stations used in the regression analysis

Table C.31—Exponent coefficients and description of hydrologic sub-regions for estimation of peak flow of ungaged sites near gaged sites on the same stream in South Dakota (Sando 1998). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (A_u/A_g) if the drainage area ratio is between 0.75 and 1.5.

Sub-region	Description	Exponent, x
A	Minnesota-Red River Lowland, Coteau des Prairies, and eastern part of the Southern Plateaus physical divisions of Flint (1955).	0.529
B	Lake Dakota Plain, James River Lowland and Highlands, and Coteau du Missouri physical divisions of Flint (1955); part of the Coteau du Missouri in central South Dakota that has topography typical of Great Plains "breaks" sites was excluded from this sub-region.	0.615
C	Great Plains physiographic division of Fenneman (1946), excluding the Sand Hills influenced area in south-central South Dakota, and areas with topography typical of "breaks" sites, primarily in Cheyenne, Bad, and White River basins.	0.569
D	Includes areas in the Great Plains physiographic division of Fenneman (1946) with topography typical of "breaks" sites.	0.545
E	Generally corresponds to the Sand Hills physical division of Flint (1955).	0.691
F	Generally corresponds to the northeast exterior part of the Black Hills physical division of Flint (1955).	0.654
G	Generally corresponds to the southwest interior part of the Black Hills physical division of Flint (1955).	0.689

Table C.32—Regional regression equations for South Dakota based on basin and climate characteristics (Sando 1998).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Sub-region A (n[b] = 55)		
2	$Q = 30.9\ \mathrm{AREA}^{0.513} I_{\mathrm{II}}^{6.14}$	59	4.5
5	$Q = 85.5\ \mathrm{AREA}^{0.509} I_{\mathrm{II}}^{5.45}$	54	6.1
10	$Q = 137\ \mathrm{AREA}^{0.510} I_{\mathrm{II}}^{5.12}$	54	7.8
25	$Q = 218\ \mathrm{AREA}^{0.513} I_{\mathrm{II}}^{4.80}$	56	9.8
50	$Q = 287\ \mathrm{AREA}^{0.517} I_{\mathrm{II}}^{4.62}$	58	11.0
100	$Q = 362\ \mathrm{AREA}^{0.521} I_{\mathrm{II}}^{4.47}$	61	11.9
500	$Q = 553\ \mathrm{AREA}^{0.531} I_{\mathrm{II}}^{4.22}$	69	13.0
	Sub-region B (n = 43)		
2	$Q = 18.6\ \mathrm{AREA}^{0.425} I_{\mathrm{II}}^{1.10}$	67	5.4
5	$Q = 51.6\ \mathrm{AREA}^{0.508} I_{\mathrm{II}}^{0.835}$	64	7.1
10	$Q = 86.8\ \mathrm{AREA}^{0.546} I_{\mathrm{II}}^{0.764}$	67	8.7
25	$Q = 148\ \mathrm{AREA}^{0.584} I_{\mathrm{II}}^{0.730}$	72	10.6
50	$Q = 206\ \mathrm{AREA}^{0.606} I_{\mathrm{II}}^{0.728}$	76	11.6
100	$Q = 275\ \mathrm{AREA}^{0.625} I_{\mathrm{II}}^{0.742}$	81	12.4
500	$Q = 480\ \mathrm{AREA}^{0.661} I_{\mathrm{II}}^{0.811}$	93	13.6
	Sub-region C		
2	$Q = 25.0\ \mathrm{AREA}^{0.569}$ (n = 48)	108	1.8
5	$Q = 72.5\ \mathrm{AREA}^{0.578}$ (n = 48)	67	4.8
10	$Q = 125\ \mathrm{AREA}^{0.579}$ (n = 48)	58	8.3
25	$Q = 207\ \mathrm{AREA}^{0.573}$ (n = 46)	53	12.0
50	$Q = 286\ \mathrm{AREA}^{0.570}$ (n = 46)	53	14.9
100	$Q = 379\ \mathrm{AREA}^{0.566}$ (n = 46)	55	16.5
500	$Q = 664\ \mathrm{AREA}^{0.556}$ (n = 46)	65	16.6

Table C.32—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Sub-region D (n^b = 17)		
2	$Q = 78.5 \text{ AREA}^{0.357}$	109	2.3
5	$Q = 230 \text{ AREA}^{0.455}$	61	7.4
10	$Q = 395 \text{ AREA}^{0.515}$	44	17.9
25	$Q = 676 \text{ AREA}^{0.585}$	34	39.1
50	$Q = 944 \text{ AREA}^{0.627}$	33	52.5
100	$Q = 1{,}270 \text{ AREA}^{0.663}$	34	59.2
500	$Q = 2{,}300 \text{ AREA}^{0.732}$	41	57.5
	Sub-region E (n = 10)		
2	$Q = 12.1 \text{ AREA}^{0.555}$	44	4.3
5	$Q = 18.9 \text{ AREA}^{0.611}$	28	16.0
10	$Q = 22.6 \text{ AREA}^{0.653}$	26	27.0
25	$Q = 27.0 \text{ AREA}^{0.702}$	30	30.2
50	$Q = 30.3 \text{ AREA}^{0.737}$	36	27.4
100	$Q = 33.6 \text{ AREA}^{0.769}$	42	24.2
500	$Q = 41.4 \text{ AREA}^{0.840}$	60	18.5
	Sub-region F (n = 17)		
2	$Q = 0.937 \text{ AREA}^{0.676}\text{CS}^{0.447}$	107	2.6
5	$Q = 0.591 \text{ AREA}^{0.779}\text{CS}^{0.745}$	83	6.0
10	$Q = 0.471 \text{ AREA}^{0.832}\text{CS}^{0.907}$	73	10.5
25	$Q = 0.406 \text{ AREA}^{0.888}\text{CS}^{1.06}$	66	18.4
50	$Q = 0.381 \text{ AREA}^{0.925}\text{CS}^{1.16}$	64	24.6
100	$Q = 0.352 \text{ AREA}^{0.960}\text{CS}^{1.25}$	64	29.4
500	$Q = 0.243 \text{ AREA}^{1.04}\text{CS}^{1.47}$	78	31.2
	Sub-region G (n^b = 7)		
2	$Q = 3.46 \text{ AREA}^{0.650}$	51	3.9
5	$Q = 7.70 \text{ AREA}^{0.654}$	71	3.2
10	$Q = 11.3 \text{ AREA}^{0.673}$	87	3.2
25	$Q = 16.5 \text{ AREA}^{0.704}$	108	3.3
50	$Q = 21.0 \text{ AREA}^{0.731}$	126	3.3
100	$Q = 25.8 \text{ AREA}^{0.759}$	144	3.4
500	$Q = 38.5 \text{ AREA}^{0.826}$	193	3.5

[a] Equation: Q, peak flow, in $\text{ft}^3 \text{ sec}^{-1}$; AREA, drainage area, in mi^2; I_{II}, precipitation intensity index, 24-hour precipitation intensity, in inches, with a recurrence interval of 2 years (fig. C.21; estimated from U.S. Weather Bureau 1961)

[b] Number of stations used in the regression analysis

Table C.33—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Utah (Kenney and others 2007). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (A_u/A_g) if the drainage area ratio is between 0.5 and 1.5.

Hydrologic Region	Exponent, x
1	0.49
2	0.51
3	0.21
4	0.84
5	0.53
6	0.31
7	0.45

Table C.34-Predictive regression equations and their associated uncertainty in estimating peak flows for natural streams in Utah (Kenney and others 2007).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Region 1 (n[b] = 46)		
2	$Q = 1.52\ \mathrm{AREA}^{0.677} 1.39^{(\mathrm{ELEV}/1{,}000)}$	62	0.97
5	$Q = 5.49\ \mathrm{AREA}^{0.614} 1.30^{(\mathrm{ELEV}/1{,}000)}$	54	1.49
10	$Q = 10.3\ \mathrm{AREA}^{0.581} 1.25^{(\mathrm{ELEV}/1{,}000)}$	53	2.00
25	$Q = 19.7\ \mathrm{AREA}^{0.547} 1.21^{(\mathrm{ELEV}/1{,}000)}$	55	2.59
50	$Q = 29.4\ \mathrm{AREA}^{0.524} 1.19^{(\mathrm{ELEV}/1{,}000)}$	57	2.92
100	$Q = 40.4\ \mathrm{AREA}^{0.512} 1.17^{(\mathrm{ELEV}/1{,}000)}$	58	3.34
200	$Q = 58.3\ \mathrm{AREA}^{0.483} 1.15^{(\mathrm{ELEV}/1{,}000)}$	63	3.35
500	$Q = 85.4\ \mathrm{AREA}^{0.457} 1.13^{(\mathrm{ELEV}/1{,}000)}$	68	3.50
	Region 2 (n = 32)		
2	$Q = 0.585\ \mathrm{AREA}^{0.847} 1.07^{\mathrm{PREC}}$	71	0.91
5	$Q = 1.56\ \mathrm{AREA}^{0.747} 1.07^{\mathrm{PREC}}$	58	1.62
10	$Q = 2.51\ \mathrm{AREA}^{0.703} 1.06^{\mathrm{PREC}}$	53	2.46
25	$Q = 4.00\ \mathrm{AREA}^{0.661} 1.06^{\mathrm{PREC}}$	51	3.70
50	$Q = 5.36\ \mathrm{AREA}^{0.635} 1.06^{\mathrm{PREC}}$	50	4.59
100	$Q = 6.92\ \mathrm{AREA}^{0.613} 1.06^{\mathrm{PREC}}$	50	5.38
200	$Q = 8.79\ \mathrm{AREA}^{0.592} 1.05^{\mathrm{PREC}}$	51	6.06
500	$Q = 12.0\ \mathrm{AREA}^{0.555} 1.05^{\mathrm{PREC}}$	52	6.84
	Region 3 (n = 14)		
2	$Q = 14.5\ \mathrm{AREA}^{0.328}$	357	0.60
5	$Q = 47.6\ \mathrm{AREA}^{0.287}$	194	1.40
10	$Q = 83.7\ \mathrm{AREA}^{0.289}$	152	2.49
25	$Q = 148\ \mathrm{AREA}^{0.298}$	130	4.21
50	$Q = 215\ \mathrm{AREA}^{0.302}$	128	5.28
100	$Q = 300\ \mathrm{AREA}^{0.303}$	136	5.89
200	$Q = 411\ \mathrm{AREA}^{0.301}$	150	6.13
500	$Q = 599\ \mathrm{AREA}^{0.299}$	177	6.10
	Region 4 (n[b] = 42)		
2	$Q = 0.083\ \mathrm{AREA}^{0.822} 2.72^{0.656\ (\mathrm{ELEV}/1{,}000) - 0.039\ \mathrm{BS}\%}$	49	1.35
5	$Q = 0.359\ \mathrm{AREA}^{0.816} 2.72^{0.537\ (\mathrm{ELEV}/1{,}000) - 0.035\ \mathrm{BS}\%}$	37	2.60
10	$Q = 0.753\ \mathrm{AREA}^{0.811} 2.72^{0.500\ (\mathrm{ELEV}/1{,}000) - 0.032\ \mathrm{BS}\%}$	35	3.84
25	$Q = 1.64\ \mathrm{AREA}^{0.804} 2.72^{0.414\ (\mathrm{ELEV}/1{,}000) - 0.030\ \mathrm{BS}\%}$	35	5.07
50	$Q = 2.68\ \mathrm{AREA}^{0.798} 2.72^{0.373\ (\mathrm{ELEV}/1{,}000) - 0.028\ \mathrm{BS}\%}$	37	5.56
100	$Q = 4.18\ \mathrm{AREA}^{0.792} 2.72^{0.334\ (\mathrm{ELEV}/1{,}000) - 0.023\ \mathrm{BS}\%}$	39	5.72
200	$Q = 6.29\ \mathrm{AREA}^{0.786} 2.72^{0.299\ (\mathrm{ELEV}/1{,}000) - 0.021\ \mathrm{BS}\%}$	43	5.69
500	$Q = 10.5\ \mathrm{AREA}^{0.778} 2.72^{0.256\ (\mathrm{ELEV}/1{,}000) - 0.018\ \mathrm{BS}\%}$	47	5.47
	Region 5 (n = 35)		
2	$Q = 4.32\ \mathrm{AREA}^{0.623} (\mathrm{HERB}+1)^{0.503}$	99	1.08
5	$Q = 11.7\ \mathrm{AREA}^{0.575} (\mathrm{HERB}+1)^{0.425}$	60	3.27
10	$Q = 18.4\ \mathrm{AREA}^{0.555} (\mathrm{HERB}+1)^{0.388}$	50	6.11
25	$Q = 28.8\ \mathrm{AREA}^{0.538} (\mathrm{HERB}+1)^{0.352}$	49	8.91
50	$Q = 38.4\ \mathrm{AREA}^{0.536} (\mathrm{HERB}+1)^{0.331}$	53	9.35
100	$Q = 50.2\ \mathrm{AREA}^{0.515} (\mathrm{HERB}+1)^{0.316}$	61	8.79
200	$Q = 64.7\ \mathrm{AREA}^{0.504} (\mathrm{HERB}+1)^{0.300}$	71	7.99
500	$Q = 88.3\ \mathrm{AREA}^{0.489} (\mathrm{HERB}+1)^{0.285}$	86	7.05
	Region 6 (n = 99)		
2	$Q = 4{,}150\ \mathrm{AREA}^{0.553} (\mathrm{ELEV}/1{,}000)^{-2.45}$	108	1.44
5	$Q = 13{,}100\ \mathrm{AREA}^{0.479} (\mathrm{ELEV}/1{,}000)^{-2.44}$	80	3.01
10	$Q = 24{,}700\ \mathrm{AREA}^{0.444} (\mathrm{ELEV}/1{,}000)^{-2.47}$	70	5.06
25	$Q = 49{,}500\ \mathrm{AREA}^{0.411} (\mathrm{ELEV}/1{,}000)^{-2.51}$	62	8.43
50	$Q = 77{,}400\ \mathrm{AREA}^{0.391} (\mathrm{ELEV}/1{,}000)^{-2.54}$	60	10.95
100	$Q = 115{,}000\ \mathrm{AREA}^{0.391} (\mathrm{ELEV}/1{,}000)^{-2.58}$	61	12.97
200	$Q = 166{,}000\ \mathrm{AREA}^{0.361} (\mathrm{ELEV}/1{,}000)^{-2.61}$	62	14.42
500	$Q = 258{,}000\ \mathrm{AREA}^{0.344} (\mathrm{ELEV}/1{,}000)^{-2.65}$	66	15.40

Table C.34-*Continued.*

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Region 7 (n[b] = 25)		
2	$Q = 18.4\ AREA^{0.630}$	76	2.71
5	$Q = 67.4\ AREA^{0.539}$	95	2.46
10	$Q = 134\ AREA^{0.487}$	110	2.62
25	$Q = 278\ AREA^{0.429}$	132	2.85
50	$Q = 446\ AREA^{0.390}$	149	2.99
100	$Q = 683\ AREA^{0.355}$	166	3.13
200	$Q = 1{,}010\ AREA^{0.321}$	185	3.23
500	$Q = 1{,}620\ AREA^{0.280}$	211	3.35

[a] Equation: Q, peak flow, in $ft^3\ sec^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft; PREC, mean annual precipitation, in inches; $BS_{\%}$, average basin slope, in percent; HERB, area covered by herbaceous upland, in percent

[b] Number of stations used in the regression analysis

Table C.35—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Washington (Knowles and Sumioka 2001; Sumioka and others 1998). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (A_u/A_g) if the drainage area ratio is between 0.5 and 1.5.

	Hydrologic Regions of Washington								
Recurrence interval (yr)	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9
2	0.923	0.877	0.877	0.880	0.815	0.719	0.629	0.761	0.672
10	0.921	0.868	0.875	0.856	0.787	0.716	0.587	0.706	0.597
25	0.921	0.864	0.874	0.850	0.779	0.714	0.574	0.687	0.570
50	0.921	0.862	0.872	0.845	0.774	0.713	0.566	0.676	0.553
100	0.922	0.861	0.871	0.842	0.769	0.713	0.558	0.666	0.538

Table C.36—Flood-peak flow regression equations and associated statistics for hydrologic regions in Washington (Knowles and Sumioka 2001; Sumioka and others 1998).

Recurrence interval (yr)	Equation[a]	Standard error of prediction (%)	Equivalent years of record
	Region 1 (n[b] = 61)		
2	$Q = 0.350\ \mathrm{AREA}^{0.923}\mathrm{PREC}^{1.24}$	32	1
10	$Q = 0.502\ \mathrm{AREA}^{0.921}\mathrm{PREC}^{1.26}$	33	2
25	$Q = 0.590\ \mathrm{AREA}^{0.921}\mathrm{PREC}^{1.26}$	34	3
50	$Q = 0.666\ \mathrm{AREA}^{0.921}\mathrm{PREC}^{1.26}$	36	3
100	$Q = 0.745\ \mathrm{AREA}^{0.922}\mathrm{PREC}^{1.26}$	37	4
	Region 2 (n = 202)		
2	$Q = 0.090\ \mathrm{AREA}^{0.877}\mathrm{PREC}^{1.51}$	56	1
10	$Q = 0.129\ \mathrm{AREA}^{0.868}\mathrm{PREC}^{1.57}$	53	1
25	$Q = 0.148\ \mathrm{AREA}^{0.864}\mathrm{PREC}^{1.59}$	53	2
50	$Q = 0.161\ \mathrm{AREA}^{0.862}\mathrm{PREC}^{1.61}$	53	2
100	$Q = 0.174\ \mathrm{AREA}^{0.861}\mathrm{PREC}^{1.62}$	54	3
	Region 3 (n = 63)		
2	$Q = 0.817\ \mathrm{AREA}^{0.877}\mathrm{PREC}^{1.02}$	57	1
10	$Q = 0.845\ \mathrm{AREA}^{0.875}\mathrm{PREC}^{1.14}$	55	1
25	$Q = 0.912\ \mathrm{AREA}^{0.874}\mathrm{PREC}^{1.17}$	54	2
50	$Q = 0.808\ \mathrm{AREA}^{0.872}\mathrm{PREC}^{1.23}$	54	2
100	$Q = 0.801\ \mathrm{AREA}^{0.871}\mathrm{PREC}^{1.26}$	55	3
	Region 4 (n = 60)		
2	$Q = 0.025\ \mathrm{AREA}^{0.880}\mathrm{PREC}^{1.70}$	82	1
10	$Q = 0.179\ \mathrm{AREA}^{0.856}\mathrm{PREC}^{1.37}$	84	1
25	$Q = 0.341\ \mathrm{AREA}^{0.850}\mathrm{PREC}^{1.26}$	87	1
50	$Q = 0.505\ \mathrm{AREA}^{0.845}\mathrm{PREC}^{1.20}$	90	2
100	$Q = 0.703\ \mathrm{AREA}^{0.842}\mathrm{PREC}^{1.15}$	92	2
	Region 5 (n[b] = 19)		
2	$Q = 14.7\ \mathrm{AREA}^{0.815}$	96	1
10	$Q = 35.2\ \mathrm{AREA}^{0.787}$	63	2
25	$Q = 48.2\ \mathrm{AREA}^{0.779}$	56	3
50	$Q = 59.1\ \mathrm{AREA}^{0.774}$	53	5
100	$Q = 71.2\ \mathrm{AREA}^{0.769}$	52	6
	Region 6 (n = 23)		
2	$Q = 2.24\ \mathrm{AREA}^{0.719}\mathrm{PREC}^{0.833}$	63	1
10	$Q = 17.8\ \mathrm{AREA}^{0.716}\mathrm{PREC}^{0.487}$	69	2
25	$Q = 38.6\ \mathrm{AREA}^{0.714}\mathrm{PREC}^{0.359}$	72	2
50	$Q = 63.6\ \mathrm{AREA}^{0.713}\mathrm{PREC}^{0.276}$	74	3
100	$Q = 100\ \mathrm{AREA}^{0.713}\mathrm{PREC}^{0.201}$	77	3
	Region 7 (n = 17)		
2	$Q = 8.77\ \mathrm{AREA}^{0.629}$	128	2
10	$Q = 50.9\ \mathrm{AREA}^{0.587}$	63	7
25	$Q = 91.6\ \mathrm{AREA}^{0.574}$	54	12
50	$Q = 131\ \mathrm{AREA}^{0.566}$	53	15
100	$Q = 179\ \mathrm{AREA}^{0.558}$	56	16
	Region 8 (n = 23)		
2	$Q = 12.0\ \mathrm{AREA}^{0.761}$	133	<1
10	$Q = 32.6\ \mathrm{AREA}^{0.706}$	111	1
25	$Q = 46.2\ \mathrm{AREA}^{0.687}$	114	1
50	$Q = 57.3\ \mathrm{AREA}^{0.676}$	119	1
100	$Q = 69.4\ \mathrm{AREA}^{0.666}$	126	1
	Region 9 (n[b] = 36)		
2	$Q = 0.803\ \mathrm{AREA}^{0.672}\mathrm{PREC}^{1.16}$	80	2
10	$Q = 15.4\ \mathrm{AREA}^{0.597}\mathrm{PREC}^{0.662}$	57	6
25	$Q = 41.1\ \mathrm{AREA}^{0.570}\mathrm{PREC}^{0.508}$	55	8
50	$Q = 74.7\ \mathrm{AREA}^{0.553}\mathrm{PREC}^{0.420}$	55	10
100	$Q = 126\ \mathrm{AREA}^{0.538}\mathrm{PREC}^{0.344}$	56	12

[a] Equation: Q, peak flow, in $\mathrm{ft}^3\ \mathrm{sec}^{-1}$; AREA, drainage area, in mi^2; PREC, mean annual precipitation, in inches

[b] Number of stations used in the regression analysis

Table C.37—Exponent coefficients for estimation of peak flow of ungaged sites near gaged sites on the same stream in Wyoming (Miller 2003). Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites (A_u/A_g) if the drainage area ratio is between 0.75 and 1.5.

	Hydrologic Regions of Wyoming					
Recurrence interval (yr)	Region 1 Rocky Mountains	Region 2 Central Basins and Northern Plains	Region 3 Eastern Basins and Eastern Plains	Region 4 Eastern Mountains	Region 5 Overthrust Belt	Region 6 High Desert
1.5	0.885	0.486	0.401	0.518	0.871	0.626
2	0.866	0.475	0.402	0.506	0.869	0.608
2.33	0.858	0.470	0.403	0.503	0.868	0.600
5	0.829	0.455	0.407	0.506	0.864	0.567
10	0.810	0.447	0.410	0.518	0.861	0.544
25	0.790	0.439	0.416	0.536	0.857	0.520
50	0.776	0.434	0.423	0.549	0.853	0.504
100	0.764	0.430	0.432	0.562	0.850	0.489
200	0.752	0.427	0.441	0.573	0.847	0.476
500	0.738	0.425	0.454	0.585	0.842	0.459

Table C.38—Regression equations for Wyoming based on basin characteristics (Miller 2003).

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Rocky Mountains (Region 1)		
1.5	$Q = 0.126\ \mathrm{AREA}^{0.885}\left(\frac{ELEV-3,000}{1,000}\right)^{2.56}(\mathrm{LONG\text{-}100})^{0.032}$	56	1.0
2	$Q = 0.313\ \mathrm{AREA}^{0.866}\left(\frac{ELEV-3,000}{1,000}\right)^{2.32}(\mathrm{LONG\text{-}100})^{-0.069}$	50	1.2
2.33	$Q = 0.458\ \mathrm{AREA}^{0.858}\left(\frac{ELEV-3,000}{1,000}\right)^{2.22}(\mathrm{LONG\text{-}100})^{-0.110}$	47	1.3
5	$Q = 1.89\ \mathrm{AREA}^{0.829}\left(\frac{ELEV-3,000}{1,000}\right)^{1.85}(\mathrm{LONG\text{-}100})^{-0.262}$	39	2.4
10	$Q = 4.71\ \mathrm{AREA}^{0.810}\left(\frac{ELEV-3,000}{1,000}\right)^{1.60}(\mathrm{LONG\text{-}100})^{-0.357}$	36	3.8
25	$Q = 12.1\ \mathrm{AREA}^{0.790}\left(\frac{ELEV-3,000}{1,000}\right)^{1.34}(\mathrm{LONG\text{-}100})^{-0.451}$	35	5.4
50	$Q = 22.3\ \mathrm{AREA}^{0.776}\left(\frac{ELEV-3,000}{1,000}\right)^{1.16}(\mathrm{LONG\text{-}100})^{-0.510}$	36	6.3
100	$Q = 38.6\ \mathrm{AREA}^{0.764}\left(\frac{ELEV-3,000}{1,000}\right)^{1.00}(\mathrm{LONG\text{-}100})^{-0.562}$	38	6.9
200	$Q = 64.3\ \mathrm{AREA}^{0.752}\left(\frac{ELEV-3,000}{1,000}\right)^{0.857}(\mathrm{LONG\text{-}100})^{-0.611}$	40	7.2
500	$Q = 120\ \mathrm{AREA}^{0.738}\left(\frac{ELEV-3,000}{1,000}\right)^{0.674}(\mathrm{LONG\text{-}100})^{-0.670}$	43	7.3
	Central Basins and Northern Plains (Hydrologic Region 2 in Wyoming)		
1.5	$Q = 17.8\ \mathrm{AREA}^{0.486}$	135	1.4
2	$Q = 29.9\ \mathrm{AREA}^{0.475}$	113	1.6
2.33	$Q = 37.1\ \mathrm{AREA}^{0.470}$	105	1.7
5	$Q = 80.9\ \mathrm{AREA}^{0.455}$	81	3.4
10	$Q = 134\ \mathrm{AREA}^{0.447}$	69	5.9
25	$Q = 225\ \mathrm{AREA}^{0.439}$	60	10.4
50	$Q = 311\ \mathrm{AREA}^{0.434}$	57	13.9
100	$Q = 415\ \mathrm{AREA}^{0.430}$	56	16.9
200	$Q = 536\ \mathrm{AREA}^{0.427}$	57	19.0
500	$Q = 728\ \mathrm{AREA}^{0.425}$	61	20.1
	Eastern Basins and Eastern Plains (Hydrologic Region 3 in Wyoming)		
1.5	$Q = 1.12\ \mathrm{AREA}^{0.401}\mathrm{SHI}^{3.01}$	127	2.0
2	$Q = 2.28\ \mathrm{AREA}^{0.402}\mathrm{SHI}^{2.90}$	98	2.6
2.33	$Q = 3.10\ \mathrm{AREA}^{0.403}\mathrm{SHI}^{2.84}$	89	3.1
5	$Q = 10.1\ \mathrm{AREA}^{0.407}\mathrm{SHI}^{2.60}$	61	7.7
10	$Q = 21.9\ \mathrm{AREA}^{0.410}\mathrm{SHI}^{2.44}$	51	14.4
25	$Q = 48.8\ \mathrm{AREA}^{0.416}\mathrm{SHI}^{2.27}$	46	23.6
50	$Q = 80.9\ \mathrm{AREA}^{0.423}\mathrm{SHI}^{2.16}$	48	28.0
100	$Q = 127\ \mathrm{AREA}^{0.432}\mathrm{SHI}^{2.05}$	51	29.5
200	$Q = 193\ \mathrm{AREA}^{0.441}\mathrm{SHI}^{1.94}$	56	28.9
500	$Q = 323\ \mathrm{AREA}^{0.454}\mathrm{SHI}^{1.80}$	66	26.6

Table C.38—*Continued*.

Recurrence interval (yr)	Equation[a]	Average standard error of prediction (%)	Equivalent years of record
	Eastern Mountains (Hydrologic Region 4 in Wyoming)		
1.5	$Q = 4.27\ \mathrm{AREA}^{0.518}\mathrm{MAR}^{1.42}(\mathrm{LAT}\text{-}40)^{-0.435}$	53	3.4
2	$Q = 6.26\ \mathrm{AREA}^{0.506}\mathrm{MAR}^{1.33}(\mathrm{LAT}\text{-}40)^{-0.315}$	53	3.2
2.33	$Q = 7.27\ \mathrm{AREA}^{0.503}\mathrm{MAR}^{1.30}(\mathrm{LAT}\text{-}40)^{-0.262}$	53	3.3
5	$Q = 12.2\ \mathrm{AREA}^{0.506}\mathrm{MAR}^{1.19}(\mathrm{LAT}\text{-}40)^{-0.048}$	53	4.6
10	$Q = 16.9\ \mathrm{AREA}^{0.518}\mathrm{MAR}^{1.12}(\mathrm{LAT}\text{-}40)^{0.107}$	54	6.3
25	$Q = 23.5\ \mathrm{AREA}^{0.536}\mathrm{MAR}^{1.05}(\mathrm{LAT}\text{-}40)^{0.283}$	54	8.9
50	$Q = 29.1\ \mathrm{AREA}^{0.549}\mathrm{MAR}^{1.01}(\mathrm{LAT}\text{-}40)^{0.403}$	54	11.0
100	$Q = 35.3\ \mathrm{AREA}^{0.562}\mathrm{MAR}^{0.963}(\mathrm{LAT}\text{-}40)^{0.517}$	54	13.1
200	$Q = 42.2\ \mathrm{AREA}^{0.573}\mathrm{MAR}^{0.922}(\mathrm{LAT}\text{-}40)^{0.626}$	55	15.1
500	$Q = 52.5\ \mathrm{AREA}^{0.585}\mathrm{MAR}^{0.873}(\mathrm{LAT}\text{-}40)^{0.766}$	56	17.5
	Overthrust Belt (Hydrologic Region 5 in Wyoming)		
1.5	$Q = 2.08\ \mathrm{AREA}^{0.871}\mathrm{JAN}^{1.02}$	63	0.8
2	$Q = 3.07\ \mathrm{AREA}^{0.869}\mathrm{JAN}^{0.884}$	61	0.7
2.33	$Q = 3.58\ \mathrm{AREA}^{0.868}\mathrm{JAN}^{0.831}$	61	0.6
5	$Q = 6.19\ \mathrm{AREA}^{0.864}\mathrm{JAN}^{0.643}$	61	0.8
10	$Q = 8.71\ \mathrm{AREA}^{0.861}\mathrm{JAN}^{0.529}$	62	1.0
25	$Q = 12.3\ \mathrm{AREA}^{0.857}\mathrm{JAN}^{0.415}$	64	1.2
50	$Q = 15.2\ \mathrm{AREA}^{0.853}\mathrm{JAN}^{0.346}$	66	1.4
100	$Q = 18.3\ \mathrm{AREA}^{0.850}\mathrm{JAN}^{0.287}$	68	1.6
200	$Q = 21.6\ \mathrm{AREA}^{0.847}\mathrm{JAN}^{0.235}$	69	1.7
500	$Q = 26.2\ \mathrm{AREA}^{0.842}\mathrm{JAN}^{0.176}$	72	1.9
	High Desert (Hydrologic Region 6 in Wyoming)		
1.5	$Q = 12.7\ \mathrm{AREA}^{0.626}(\mathrm{LAT}\text{-}40)^{-1.18}$	72	3.2
2	$Q = 22.2\ \mathrm{AREA}^{0.608}(\mathrm{LAT}\text{-}40)^{-1.24}$	66	3.2
2.33	$Q = 28.1\ \mathrm{AREA}^{0.600}(\mathrm{LAT}\text{-}40)^{-1.26}$	64	3.3
5	$Q = 66.4\ \mathrm{AREA}^{0.567}(\mathrm{LAT}\text{-}40)^{-1.35}$	59	4.7
10	$Q = 116\ \mathrm{AREA}^{0.544}(\mathrm{LAT}\text{-}40)^{-1.40}$	57	6.4
25	$Q = 204\ \mathrm{AREA}^{0.520}(\mathrm{LAT}\text{-}40)^{-1.44}$	58	8.5
50	$Q = 290\ \mathrm{AREA}^{0.504}(\mathrm{LAT}\text{-}40)^{-1.46}$	60	9.7
100	$Q = 394\ \mathrm{AREA}^{0.489}(\mathrm{LAT}\text{-}40)^{-1.47}$	63	10.4
200	$Q = 519\ \mathrm{AREA}^{0.476}(\mathrm{LAT}\text{-}40)^{-1.48}$	67	10.9
500	$Q = 719\ \mathrm{AREA}^{0.459}(\mathrm{LAT}\text{-}40)^{-1.49}$	73	11.1

[a] Equation: Q, peak flow, in $ft^3\ sec^{-1}$; AREA, drainage area, in mi^2; ELEV, mean basin elevation, in ft; LONG, longitude of basin outlet location, in decimal degrees; LAT, latitude of basin outlet location, in decimal degrees; SHI, mean basin Soils Hydrologic Index (fig. C.26), unitless; JAN, mean January precipitation, in inches; MAR, mean March precipitation, in inches

Appendix D—NRCS Curve Number Method

The curve number method was developed by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), to estimate runoff and peak flow. The following steps were modified from SCS Engineering Field Handbook: Chapter 2—Estimating Runoff (USDA SCS 1991) and used to apply the NRCS curve number method for estimation of post-fire peak flow.

1. Determine rainfall type among type I, IA, II, and III (fig. 4) and design storm recurrence interval (e.g., 2-, 5-, 10-, 25-, 50-, and 100-year), based on the location of the watershed. The rainfall amount (P) is determined using NOAA Atlas (NOAA 2008).
2. Classify the watershed soil among soil groups (A, B, C, and D) (table 14).
3. Determine the average watershed slope, which is the slope of the land, not the water course. The following relationship can be used, or any adequate method can be used:

$$Y = \frac{100CI}{A} \qquad \text{(Eq. D.1)}$$

Where:

Y = average watershed slope in percent
C = total contour length in feet
I = contour interval in feet
A = drainage area in square feet

4. Determine the runoff curve number (CN), based on cover type, treatment, hydrologic conditions, and hydrologic soil group determined above (table D.2; table D.3; fig. D.1). A representative curve number for a watershed can be estimated by area weighting with different curve numbers.
5. Estimate time of concentration using the following empirical relationship:

$$T_c = \frac{\left[\left(\frac{1000}{CN}\right) - 9\right]^{0.7}}{1140Y^{0.5}} \qquad \text{(Eq. D.2)}$$

Where:

T_c = time of concentration in hours
l = flow length in feet
CN = runoff curve number
Y = average watershed slope in percent

6. Calculate potential maximum retention after runoff begins, in inches (S), using the following relationship:

$$S = \frac{1000}{CN} - 10 \qquad \text{(Eq. D.3)}$$

7. Calculate the runoff (Q) in inches, with a given total rainfall amount (P) in inches, and the S-value calculated above using figure D.2 or the following relationship:

$$Q = \frac{\left(P - 0.2S\right)^2}{P + 0.8S} \qquad \text{(Eq. D.4)}$$

8. Calculate initial abstraction (I_a) in inches, which includes the portion of the rainfall that is not available for either infiltration or runoff and is used to wet surfaces prior to reaching the ground (interception). The initial abstraction is generally returned to the atmosphere by evaporation (Chin 2000). The initial abstraction is found to be approximated by table D.4 or the following equation:

$$I_a = 0.2\ S \qquad \text{(Eq. D.5)}$$

9. Calculate I_a/P using the values determined above.
10. Determine unit peak flow (q_u) in cfs/acre/inch, using T_c and I_a/P in figure D.3 to D.6.
11. Estimate peak flow (q_p) using the following relationship:

$$q_p = \frac{q_u \times A \times Q}{43{,}560} \qquad \text{(Eq. D.6)}$$

Where:

q_p = peak flow in cfs
q_u = unit peak flow in cfs/ac/in
A = drainage area in square feet
Q = runoff in inches

Limitations and notations for using the NRCS curve number method are as follows:

- This method only considers rainfall-generated runoff, and not runoff generated from snowmelt. Runoff and peak flow from snowmelt or rain on frozen ground cannot be estimated.
- The watershed drainage area must be greater than 1.0 acre and less than 2,000 acres (3.1 mi^2).
- The watershed must be hydrologically similar; i.e., able to represented by a weighted CN. Land use, soils, and cover are distributed uniformly throughout the watershed. The land use must be primarily rural. The NRCS curve number method is not applicable if urban conditions represent more than 10 percent of the watershed.
- The computed time of concentration (T_c) should be less than 10 hours. If the computed T_c is less than 0.1 hour, 0.1 hour is used.

- The flow length (*l*) should be greater than 200 ft and less than 26,000 ft.
- Potholes (storage) should be less than one third of the total drainage area and should not intercept the drainage.
- The average watershed slope should be greater than 0.5 percent and less than 64 percent.
- The weighted CN should be greater than 40 and less than 98.
- If I_a/P is less than 0.1, 0.1 is used; if I_a/P is greater than 0.5, 0.5 is used.

Table D.1—Runoff depth for selected CN/s and rainfall amounts[a] (USDA SCS 1991).

	Runoff (*Q*) for curve number of											
Rainfall	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**
Inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39

[a] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Table D.2—Runoff curve numbers for other agricultural lands[a] (USDA SCS 1991).

Cover description		**Curve numbers for Hydrologic Soil Group—**			
Cover type	**Hydrologic condition**	**A**	**B**	**C**	**D**
Bare soil	—	77	86	91	94
Pasture, grassland, or range-continuous forage for grazing[b]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush-brush-weed-grass mixture with brush the major element[c]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[d]	48	65	73
Woods-grass combination (orchard or tree farm)[e]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[f]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[d]	55	70	77
Farmsteads-buildings, lanes, driveways, and surrounding lots	—	59	74	82	86

[a] Average runoff condition

[b] *Poor*: <50% ground cover or heavily grazed with no mulch
Fair: 50 to 75% ground cover and not heavily grazed
Good: >75% ground cover and lightly or only occasionally grazed

[c] *Poor*: <50%
Fair: 50 to 75% ground cover
Good: >75% ground cover

[d] Actual curve number is less than 30; use CN = 30 for runoff computations.

[e] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[f] *Poor*: Forest, litter, small trees, and brush have been destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table D.3—Runoff curve numbers for arid and semiarid rangelands[a] (USDA SCS 1991).

Cover description		Curve numbers for Hydrologic Soil Group			
Cover type	**Hydrologic Condition[b]**	**A[c]**	**B**	**C**	**D**
Herbaceous-mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen-mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper-pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	86
	Fair		51	63	70
	Good		35	47	55
Desert shrub-major plants include saltbush greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[a] Average runoff condition. For rangelands in humid regions, use table D.2

[b] *Poor*: <30% ground cover (litter, grass, and brush overstory)
Fair: 30 to 70% ground cover
Good: >70% ground cover

[c] Curve numbers for group A were developed only for desert shrub.

Table D.4—I_a values for runoff curve numbers (USDA SCS 1991).

Curve number	I_a	Curve number	I_a
	(inch)		(inch)
40	3.000	68	0.941
41	2.878	69	0.899
42	2.762	70	0.857
43	2.651	71	0.817
44	2.545	72	0.778
45	2.444	73	0.740
46	2.348	74	0.703
47	2.255	75	0.667
48	2.167	76	0.632
49	2.082	77	0.597
50	2.000	78	0.564
51	1.922	79	0.532
52	1.846	80	0.500
53	1.774	81	0.469
54	1.704	82	0.439
55	1.636	83	0.410
56	1.571	84	0.381
57	1.509	85	0.353
58	1.448	86	0.326
59	1.390	87	0.299
60	1.333	88	0.273
61	1.279	89	0.247
62	1.226	90	0.222
63	1.175	91	0.198
64	1.125	92	0.174
65	1.077	93	0.151
66	1.030	94	0.128
67	0.985	95	0.105

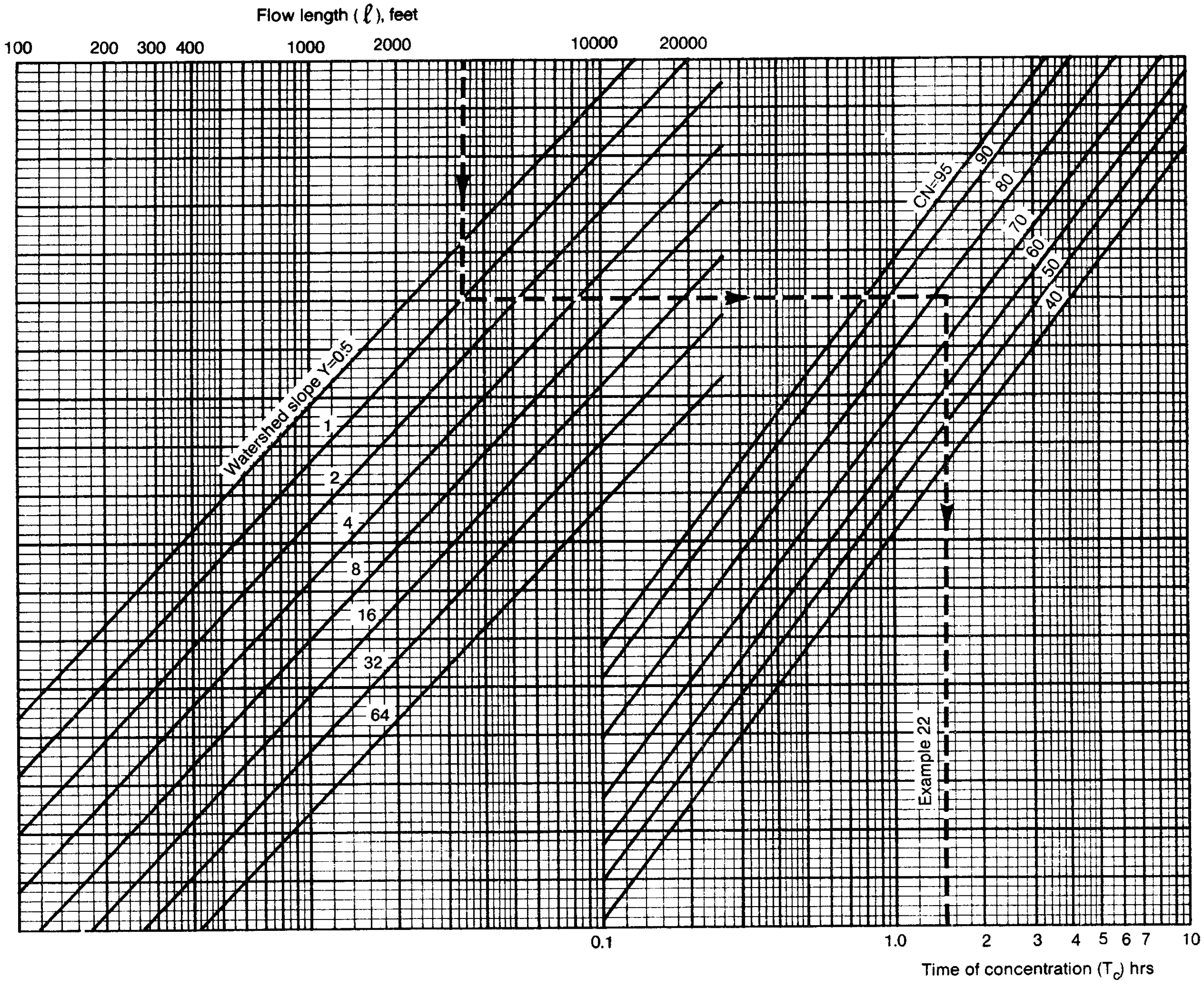


Figure D.1—Time of concentration (Tc) nomograph (USDA SCS 1991).

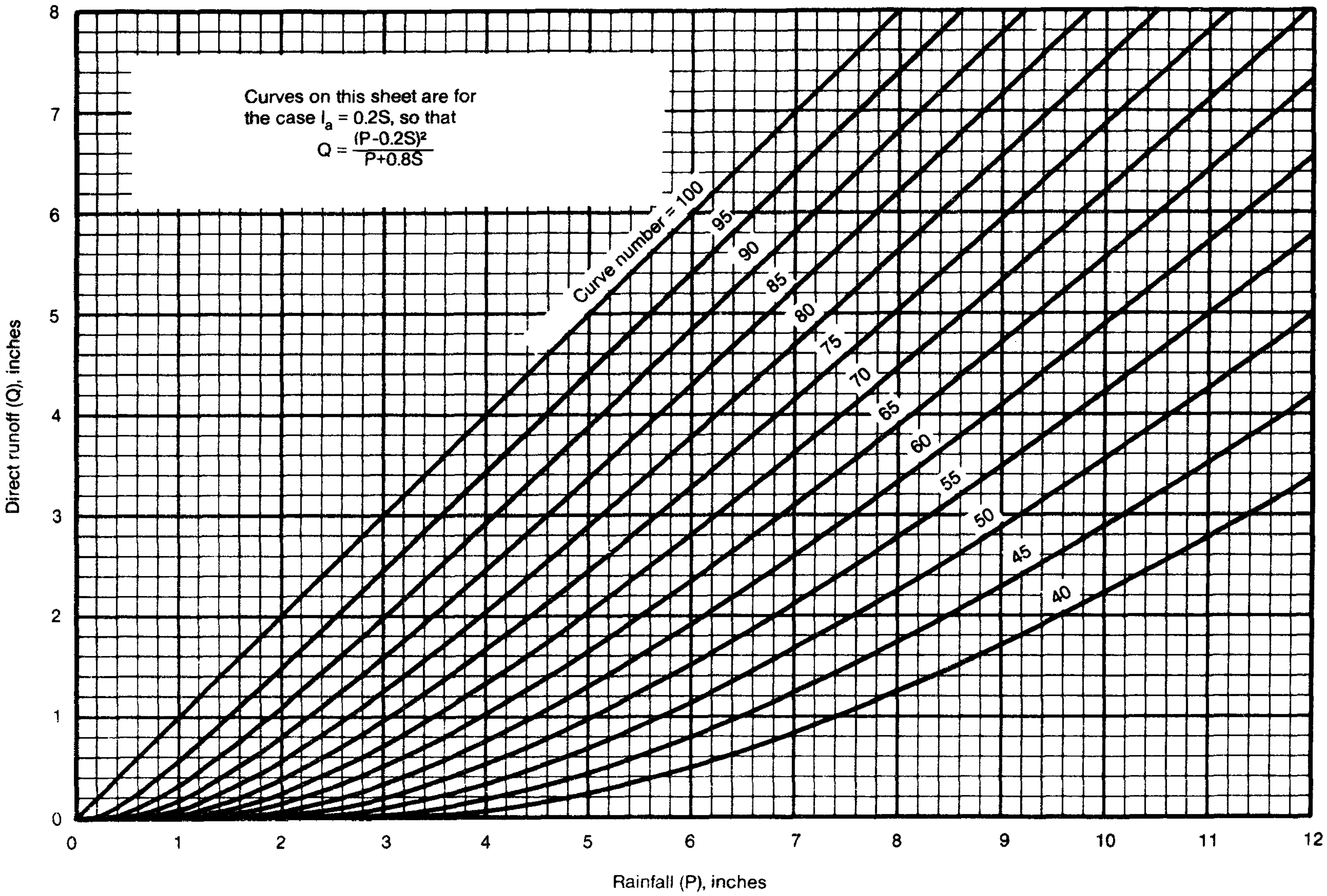


Figure D.2—Solution for runoff equation (USDA SCS 1991).

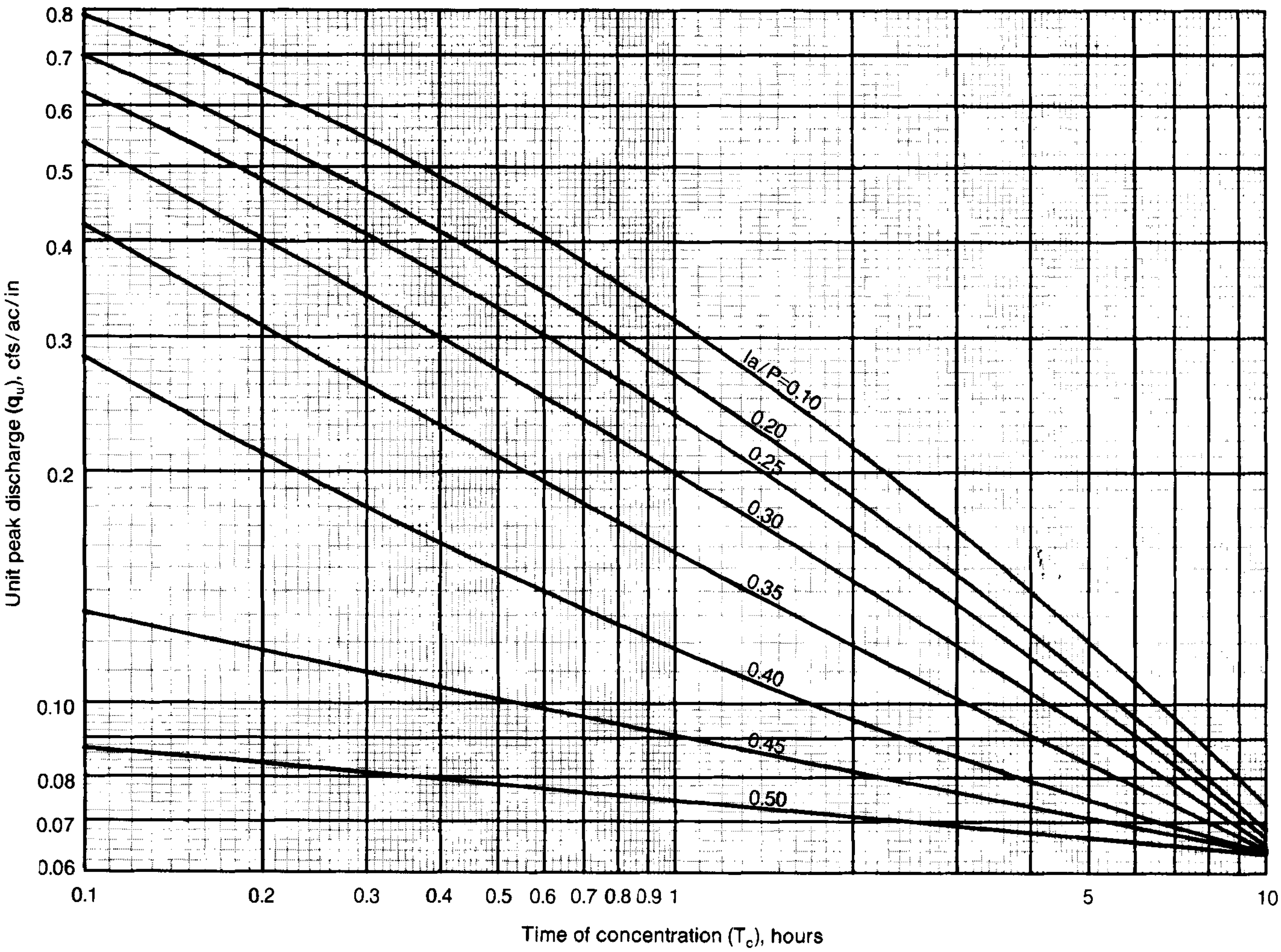


Figure D.3—Unit peak flow (qu) for SCS Type I rainfall distribution (USDA SCS 1991).

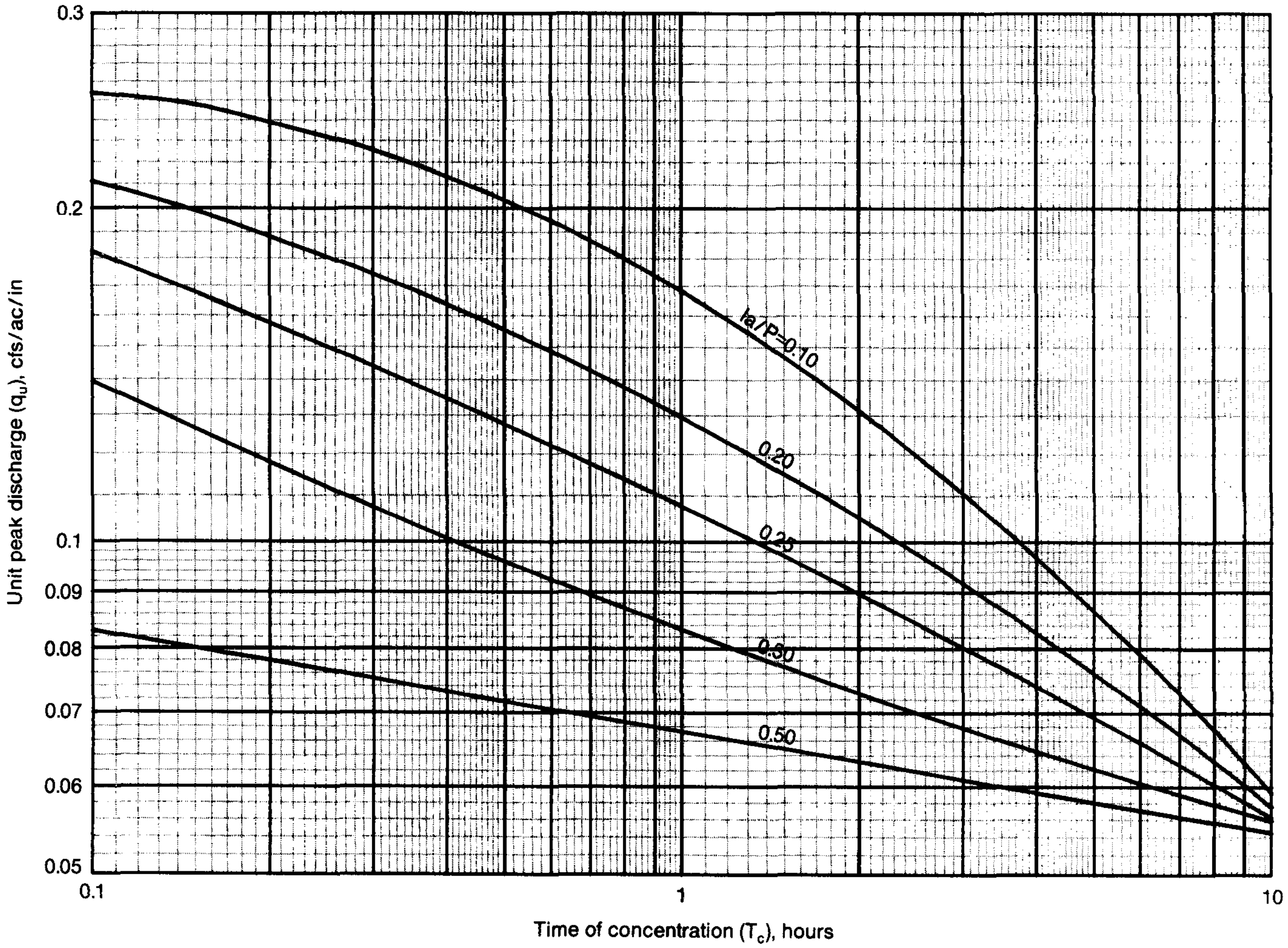


Figure D.4—Unit peak flow (qu) for SCS Type IA rainfall distribution (USDA SCS 1991).

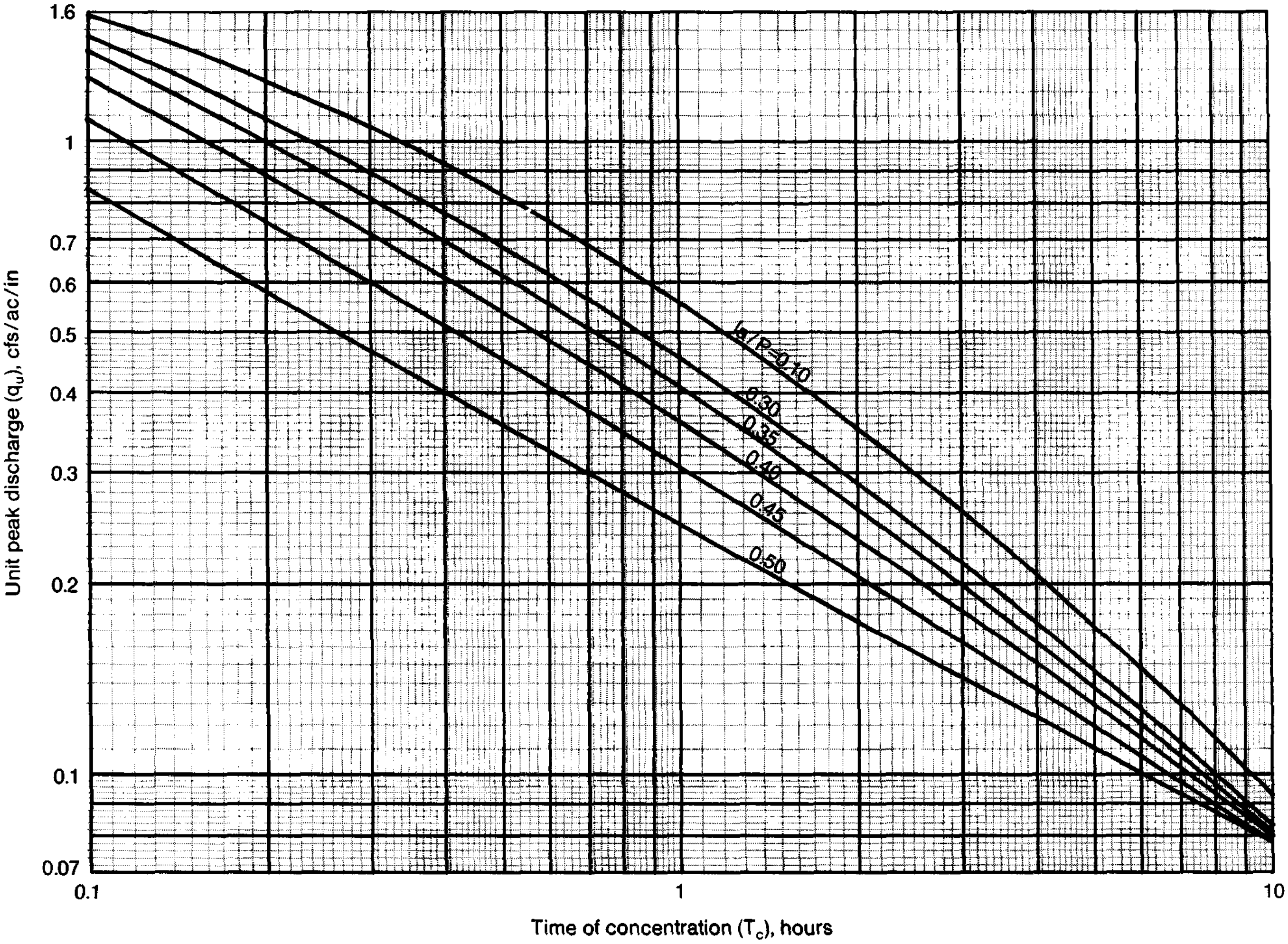


Figure D.5—Unit peak flow (qu) for SCS Type II rainfall distribution (USDA SCS 1991).

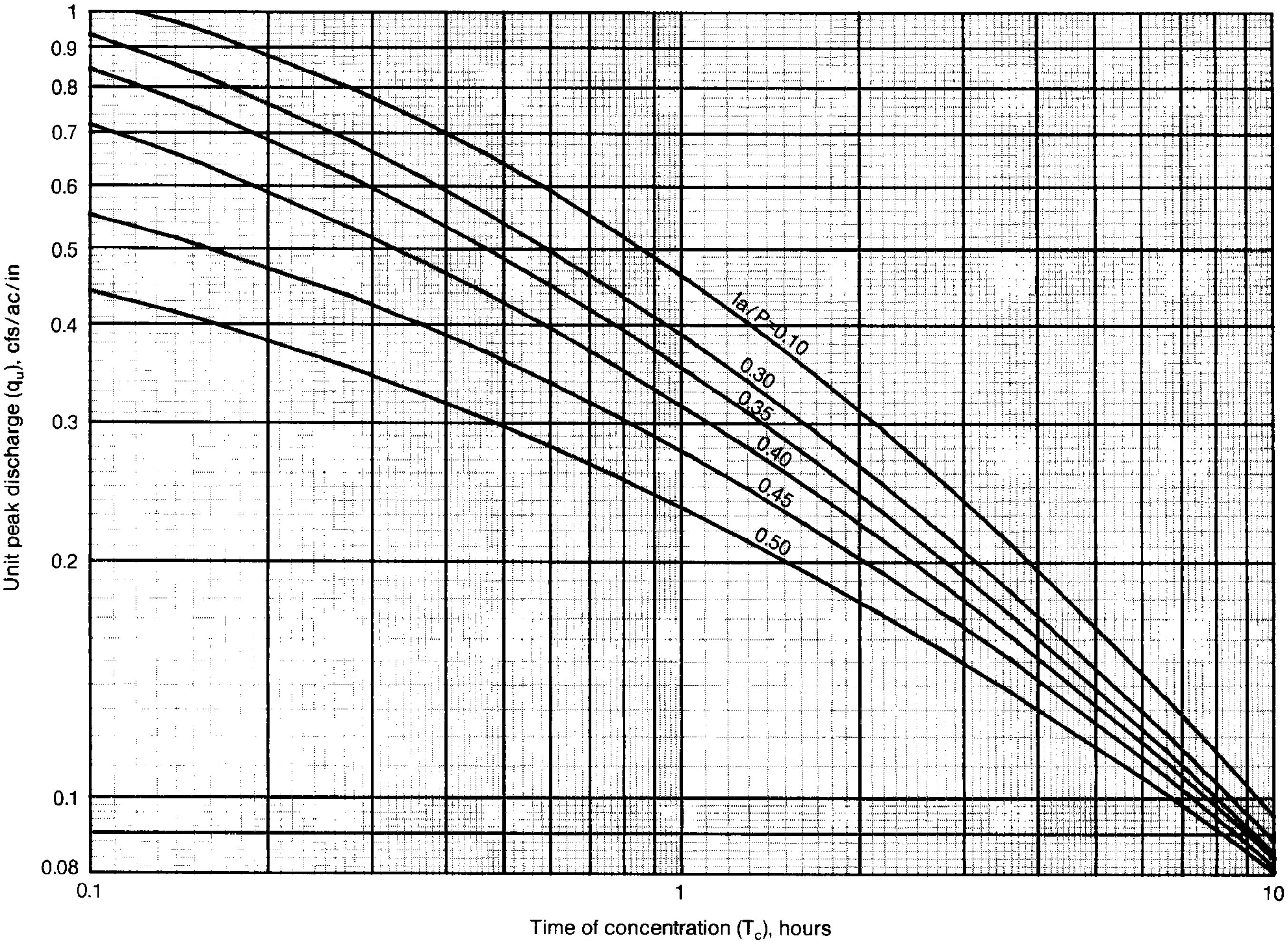


Figure D.6—Unit peak flow (qu) for SCS Type III rainfall distribution (USDA SCS 1991).

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Station Headquarters
Rocky Mountain Research Station
240 W Prospect Road
Fort Collins, CO 80526
(970) 498-1100

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah