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Determination of 100-Year Floodplain Elevations at Los Alamos National Laboratory

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DETERMINATION OF 100-YEAR FLOODPLAIN ELEVATIONS AT LOS ALAMOS NATIONAL LABORATORY

by

Stephen G. McLin

ABSTRACT

Under existing permit requirements, the US Environmental Protection Agency stipulates that facilities regulated by the Resource Conservation and Recovery Act must delineate all 100-yr floodplain elevations within their boundaries. At Los Alamos these floodplains are located within ungaged watersheds that drain Pajarito Plateau. This report documents the floodplain computational mapping procedure and, along with supporting maps, is intended to satisfy this permit requirement.

The floodplain mapping procedure outlined here uses topographic data from AUTOGIS Mapping Overlay Statistical System (AUTOGIS-MOSS), a graphical information system database. About 65% of the Laboratory has 2-ft topographic contour interval coverage, while 35% has 10-ft coverage. Targeted stream channel segments are initially specified in the MOSS system, and topographic profiles of stream channel cross sections at user-designated intervals are extracted automatically. Each 2-D profile is stored as a 3-D MOSS line feature using New Mexico state plane coordinates. This procedure is initiated at a convenient downstream location within each watershed and is continued upstream to a selected termination point. These 3-D line features are then exported in a format that satisfies the US Army Corps of Engineers' (COE's) Water-Surface Profiles (HEC-2) input data requirements.

The COE's computer-based Flood Hydrograph Package (HEC-1) and HEC-2 were used on a PC-type microcomputer to perform floodplain hydrology simulations. HEC-1 generates storm hydrographs at selected channel locations within each ungaged watershed. This information, along with the stream channel geometry extracted from the MOSS system, is then used by HEC-2 to define each floodplain. The approach used here employs a 100-yr, 6-h design storm event for Los Alamos, but alternative floodplain elevations produced by different storm events are easily computed.

The HEC-2-computed water-surface elevations for each channel section, along with the left and right channel stations where this water surface intersects the ground, are read back into the MOSS system. This information is then transformed within MOSS to determine local geographically referenced coordinates that uniquely define the 100-yr floodpool. Finally, these paired coordinates are linked together as MOSS-area features to identify each watershed floodplain. In this particular application, 11 separate watersheds traverse LANL lands; individual channels range up to 9 mi in length. The 100-yr floodplain was defined on each channel segment at 250-ft intervals, and detailed 1:4800-scale maps were generated.

I. INTRODUCTION

The US Environmental Protection Agency (EPA) stipulates that all regulated hazardous waste treatment, storage, and disposal facilities must apply for a Resource Conservation and Recovery Act (RCRA) operating permit. Under EPA authority, the New Mexico Environment Department issued the US Department of Energy (DOE) and Los Alamos National Laboratory (LANL) a RCRA hazardous waste facility operating permit in November 1989. The EPA issued DOE and LANL the Hazardous and Solid Waste Amendments (HSWA) portion of that permit in March 1990. As a condition to the HSWA portion of the permit, LANL was required to define all 100-yr floodplain elevations within the facility boundary [40 CFR 270.14(b)(11)(iii)]. These floodplain elevations must be consistent with National Flood Insurance Program maps produced for the Federal Insurance Administration (FIA), or must use an equivalent method of mapping. Before this HSWA permit condition was mandated, these floodplain boundary locations had never been completely mapped within the LANL complex. This report describes a methodology that is recognized by the EPA and others (i.e., FIA, US Army Corps of Engineers (COE), US Bureau of Reclamation, and US Soil Conservation Service) as being an approved technique for defining floodplain elevations in ungaged watersheds.

Actual floodplain-modeling efforts used the COE Hydrologic Engineering Center (HEC) computer-based Flood Hydrograph model (HEC-1) and the Water-Surface Profiles model (HEC-2). Both the HEC-1 and HEC-2 computer programs are classified as single-event simulation models, as opposed to continuous-simulation streamflow models like the Stanford or Kentucky Watershed Models. Continuous-simulation models require extensive system observation, which is not available at LANL. Event-simulation models, on the other hand, allow greater flexibility in using distributed parameters and short time increments. They also require considerably less field observation to support input data requirements. In addition, the HEC-1 and HEC-2 event-simulation models are recognized by the EPA and COE as state-of-the-art simulation models for ungaged watershed applications.

HEC-1 is used to simulate either real or hypothetical storm hydrographs in ungaged or gaged watersheds in response to user-specified rainfall hyetographs. As used here, HEC-1 employs a traditional 100-yr, 6-h design storm event for Los Alamos, although any alternative return-period event can easily be incorporated. A representative 100-yr, 6-h design storm event is recommended by the COE for defining 100-yr floodplains in northern New Mexico (M. Magnuson, US Army COE Albuquerque, personal communication, 1989). Predicted HEC-1 hydrograph peaks at various stream channel locations, along with stream channel geometry and watershed basin characteristics, are used by HEC-2 to compute 100-yr floodplain elevations.

Topographic profiles of stream channel cross sections at various locations were obtained from LANL's AUTOGIS computer-based Mapping Overlay Statistical System (AUTOGIS-MOSS), a graphic information system database copyrighted by Autometric, Inc. About 65% of LANL has 2-ft topographic-contour interval coverage, while 35% has 10-ft coverage. Targeted stream channel segments were initially specified in the MOSS system, and topographic profiles of cross sections at user-designated intervals along segments were extracted automatically. Each 2-D topographic profile was stored as a 3-D MOSS line feature using New Mexico state plane coordinates. This procedure was initiated at the intersection of the eastern DOE-LANL facility boundary and each watershed stream channel and was continued upstream to the western facility boundary. These 3-D line features were then exported in a format satisfying HEC-2 model input data requirements. Appendix A describes how to use the AUTOGIS-MOSS data extraction programs developed for this project; actual source code listings (LA-CC 91-3) are contained in Disk No. 1 attached to this report.

HEC-2 is used to compute floodplain elevations that are associated with user-specified hydrograph peaks. Floodplain elevations for 11 separate watersheds that included all major tributaries were defined at 250-ft intervals along stream channels within the DOE-LANL boundary. These watersheds are depicted in Fig. 1; they were subdivided into 52 separate subbasins. Peak floods were also defined with HEC-1 for two additional watersheds having a total of eight separate subbasins; however, these later watersheds do not cross the DOE-LANL facility boundary. The HEC-1

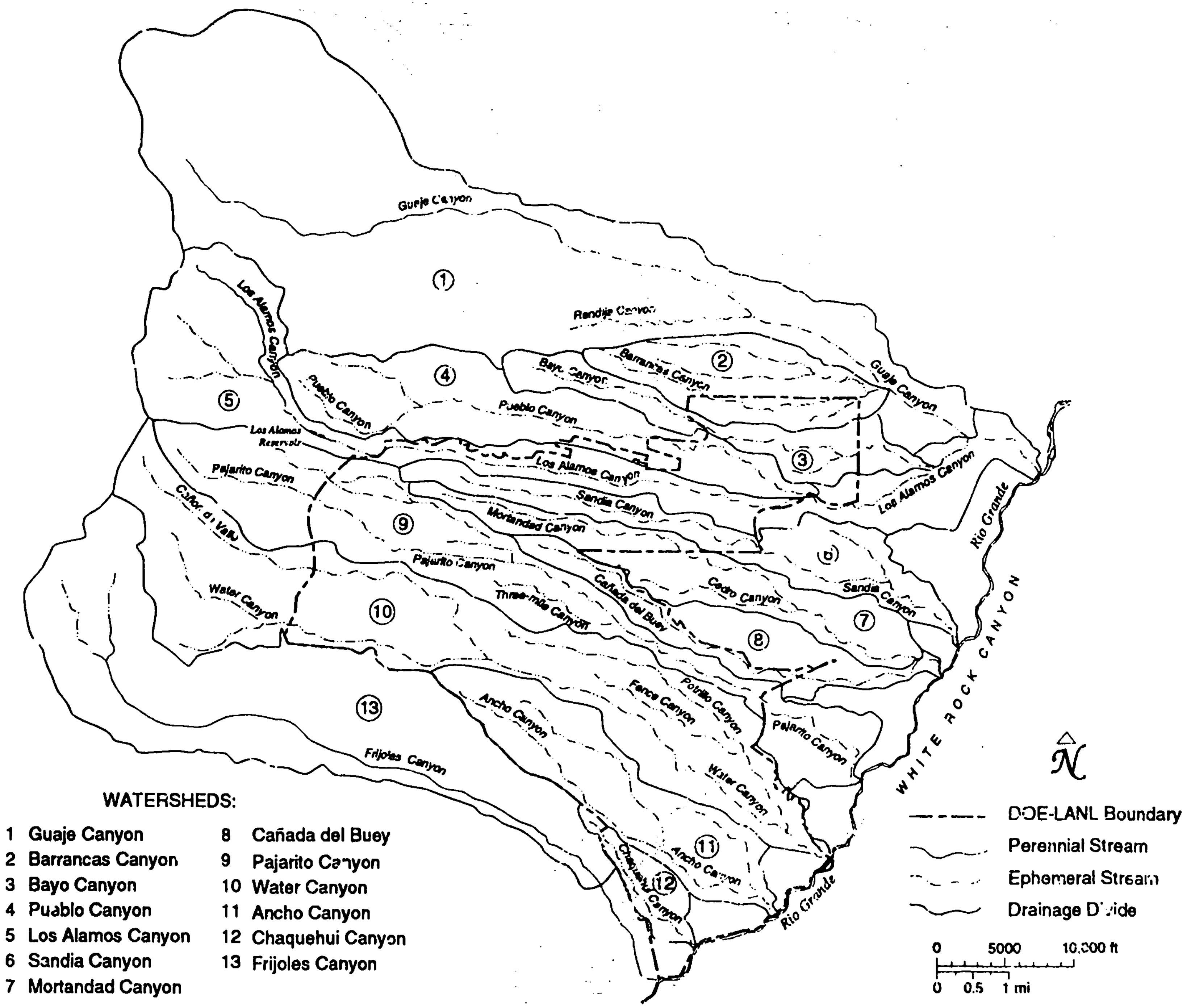

Fig. 1. Major watersheds at Los Alamos (see Table 1).

and HEC-2 input data files used to generate these hydrograph peaks and floodplain elevations are contained on disks numbered 1 and 2 attached to this report. Parameter estimation procedures and construction of input data files, including the AUTOGIS-MOSS data extraction technique used to define topographical profiles of stream channel cross sections, are described in the sections below. Once all floodplains had been defined by HEC-2, then this information was read back into the MOSS system. These data were then transformed within MOSS to determine New Mexico state plane geographically referenced coordinates that uniquely define the 100-yr floodpool at each stream cross section. Finally 1:4800-scale maps depicting the DOE-LANL boundary and all 100-yr floodplains were prepared. This packet of maps is maintained on file in LANL's Facilities Engineering Planning Group office (ENG-2 File Number R-7160) and in the Geology and Geochemistry Group office (EES-1). This report documents the identification of these floodplain elevations and, along with the above-referenced maps, is intended to satisfy the RCRA/HSWA permit requirement that all 100-yr floodplains within the DOE-LANL facility be mapped.

II. COMPUTATIONAL METHODOLOGY

Predicting peak discharge rates and synthesizing complete discharge hydrographs for use in defining floodplain areas within ungaged watersheds are two challenging tasks in engineering hydrology. Most designs involve hydrologic analyses based upon a critical flood that imitates some hypothetical future storm event. Ideally these analyses are based on long-term rainfall-runoff observations. At LANL sufficient stream flow records are not available to support these analyses, although an extensive rain gage network with a lengthy precipitation record lends support (Bowen 1990). Hence, one may be tempted to employ some regional analysis technique, or use empirical-correlative methods. However these approaches may not accurately simulate the rainfall-runoff process. An example illustrates this point.

The US Geological Survey (USGS) has produced probabilistic techniques to estimate peak discharges in New Mexico's streams (Waltemeyer 1986; Thomas and Gold 1982; Scott 1971; and Borland 1970). These USGS studies define the regional magnitude and flood frequency within New Mexico stream channels using multiple regression techniques for the 2-, 5-, 10-, 25-, 50-, and 100-yr storm events. The empirical equations used are valid for specific watersheds under a wide range of climatic basin conditions that are considerably different from those at Los Alamos. Furthermore, these USGS studies yield significant errors in applications for which gaging records are available for direct comparison. Finally, these techniques were not intended to satisfy the RCRA/HSWA permit condition requiring floodplain definition. A direct comparison between the USGS and HEC-1 hydrograph peaks is presented later in this report.

Other analytical tools are also available to perform floodplain analyses; Viessman, et al. (1977) have summarized many of these approaches. However, the LANL site is contained within a system of ungaged, interconnected, watersheds with ephemeral stream drainage. Hence, most of these alternative approaches would not produce acceptable results. The reason for this centers around the general shape of watersheds within the LANL complex. These watersheds are elongated in the east/west direction along Pajarito Plateau, but they are extremely narrow in the north/south direction. This atypical watershed shape, coupled with variability in surficial soil type and vegetation cover, yields fairly typical rainfall-runoff time-of-concentration values for each subbasin within an individual watershed. Here, time of concentration is defined as the flow time from the most remote point in a drainage subbasin area to its outlet point. However, as one moves downstream these subbasin time-of-concentration values and unusual watershed configurations combine to yield hydrograph peaks that are atypically amplified. Hence, one tends to actually observe longer-duration runoff events with lower corresponding hydrograph peaks than some simple models would predict.

When one considers the particular application at LANL, the deterministic approach using unit hydrograph theory commonly employed by the US Army COE, the US Soil Conservation Service (SCS), and US Bureau of Reclamation is clearly appropriate. This approach is incorporated into the HEC-1 model and generates stream hydrographs at specific channel locations. An entire watershed is represented by an interconnected group of subbasins. Each subbasin generates an individual unit hydrograph that simulates important hydrologic rainfall-runoff relationships, which are reflected by average subbasin characteristics. Individual subbasin hydrographs are then hydraulically routed downstream and combined with other stream-connected, subbasin hydrographs. These HEC-1 peak hydrograph values are subsequently read into the HEC-2 model as a function of channel distance. HEC-2 then simulates the 100-yr water-surface elevation using a steady, gradually varied flow approximation. An iterative, standard-step method was used to compute this water-surface elevation as a function of channel distance.

Several key HEC-1 parameters represent average nonlinear temporal and spatial processes within each subbasin; they include antecedent moisture conditions, soil types, and land cover. HEC-1 also requires that a design rainfall amount and temporal distribution be specified as input data. Hence, the unit hydrograph approach is quite flexible. In addition, the HEC-1 and HEC-2 models also require basic watershed topographic and geometric characteristics, topographic profiles of stream cross sections, and bed-roughness factors as a function of channel length. All of this information for LANL watersheds was available from the MOSS mapping system or was readily obtained during short field investigations.

III. HEC-1 FLOOD HYDROGRAPH PACKAGE

A. General Model Description

HEC-1 is the most widely accepted method for systematically computing runoff hydrographs in complex watersheds. It is a general-purpose model consisting of a calling program and six subroutines. Two of the subroutines determine the optimal unit hydrograph, channel loss rate, and streamflow-routing parameters. Other subroutines perform snowmelt-runoff, unit hydrograph, hydrograph-routing, and combination computations and hydrograph-balancing operations. HEC-1 is capable of simulating a single-storm rainfall-runoff process or computing multiple floods for the same watershed during planning studies. It can be used to forecast both pre- and post-construction flooding impacts associated with development activities. Output from the model includes design storm hydrographs at specified channel locations within the watershed. HEC-1 output is then used by the HEC-2 model as input data.

Table 1 summarizes major watersheds draining the DOE-LANL facility complex. Figure 1 shows approximate watershed locations; detailed maps are referenced later in this report. Because watershed basins within the facility complex are ungaged, the SCS synthetic unit hydrograph technique was used to characterize the relationship between rainfall-runoff and flood peak discharges. Although HEC-1 can use either the Clark, Snyder, or SCS synthetic unit hydrograph approach, the latter was selected for reasons listed below. Furthermore, the SCS rainfall-abstraction rate was also used, as this paper will describe later. Finally, by using a variety of techniques, including modified Puls, Muskingum, kinematic wave, working R&D, and level-pool reservoir routing, HEC-1 can route computed flood flows through downstream subbasins. The Muskingum method was selected for channel routing because channel losses and flood wave attenuations in individual watersheds have not been fully characterized. Hence, these losses were assumed to be zero, even though they are known to be relatively high in certain stream channel segments. It should be emphasized that a relatively conservative design philosophy was followed here; whenever specific observational data were not available, an approach that would tend to yield larger peak hydrographs at a particular channel location was taken. It should also be noted that the HEC-1 model is extremely flexible; however, only those particular features that were used in this study are explained in detail. The interested reader is referred to the HEC-1 user's manual (US Army COE 1990) for additional model descriptions and to Viessman et al. (1977) for general hydrologic principles. Finally, it should be noted that the June 1988 FORTRAN version of HEC-1, published as PROHEC1 (March 1990 release) by Dodson & Associates, Inc., of Houston, Texas, was used in this study.

Table 1. Watersheds draining the eastern DOE-LANL boundary. See Figure 1 for approximate locations.

MAJOR WATERSHED NAME	TECH AREAS WITHIN WATERSHED
1. GUAJE CANYON WATERSHED	Outside DOE-LANL Boundary, Guaje municipal well field.
2. BARRANCAS CANYON WATERSHED	None.
3. BAYO CANYON WATERSHED	None.
4. PUEBLO CANYON WATERSHED	Historic LANL Sites, O-1 water well, and airport.
5. LOS ALAMOS CANYON WATERSHED a. Canada Bonito Tributary b. Quemazon Canyon Tributary	Historic LANL Sites, 3, 43, 41, 2, 21, 53, airport, O-4 water well, and Los Alamos municipal well field.
6. SANDIA CANYON WATERSHED	3, 53, municipal landfill, PM-1 and PM-3 water wells.
7. MORTANDAD CANYON WATERSHED a. Ten Site Canyon Tributary	3, 48, 55, 42, 50, 35, 52, and 5.
8. CANADA DEL BUEY WATERSHED	52, 5, 46, 51, 54, and PM-4 and PM-5 water wells.
9. PAJARITO CANYON WATERSHED a. Two-Mile Canyon Tributary b. Three-Mile Canyon Tributary	3, 58, 6, 8, 9, 22, 59, 69, 14, 15, 51, 18, 54, and PM-2 water supply well.
10. WATER CANYON WATERSHED a. Ski Lodge Canyon Tributary b. Canon de Valle Tributary	16, 9, 14, 11, 37, 28, 49, and 15.
c. Potrillo Canyon Tributary	15 and 36.
d. Fence Canyon Tributary	
11. ANCHO CANYON WATERSHED a. Unnamed Tributary at State Road 4 b. Unnamed Tributary near Rio Grande	49, 33, and 39.
12. CHAQUEHUI CANYON WATERSHED	33.
13. FRIJOLES CANYON WATERSHED	Outside DOE-LANL Boundary

B. Design Storm Events for Los Alamos

Obviously, a particular storm hydrograph for a given watershed is intimately related to the spatial and temporal storm distribution pattern generating that hydrograph. Hence, in this report we describe the 100-yr, 6-h design storm event that produces the 100-year floodplain for Los Alamos. The reader should note that other 100-yr storm durations (for example, the 100-yr, 24-h event) may produce different 100-yr floodplain definitions. Each of these aspects is described below.

Establishing a design storm event requires several important steps. These include specification of (1) storm frequency or return period; (2) storm duration, total rainfall depth, and watershed area adjustment; and (3) storm temporal distribution and duration of rainfall excess. The EPA stipulates that RCRA-permitted facilities must use the 100-yr storm to define all floodplains [40 CFR 270.14(b)(11)(iii)]. The US Army COE recommends that a 6-h storm event be used in 100-yr HEC-1 flood simulations for northern New Mexico. In addition, rainfall depths have been tabulated for Los Alamos County (Bowen 1989). Owing to the small size of individual subbasin watersheds within the Laboratory complex (typically less than 5 sq mi), no areal adjustment was made for these rainfall depths. Hence factors (1) and (2) above are fixed by institutional constraints and system observations. The recommended design rationale for factor (3) is described below.

A representative rainfall hyetograph that is based on either the worst-possible storm distribution pattern or on recorded storm distribution patterns must be selected. This hyetograph will significantly affect the shape and peak value of the resulting runoff hydrograph for a given watershed. Precipitation depths have been measured daily in Los Alamos since 1911 (Bowen 1990). Individual storm patterns have been recorded in 15-min intervals since 1979. These data were used to develop intensity/duration/frequency (IDF) relationships for Los Alamos. These IDF curves were then used to establish individual 6-h design storm distributions for the 2-, 5-, 10-, 25-, 50-, and 100-yr events. A comparison with the SCS 6-h design storm distribution (SCS, 1968) shows that the SCS curve produces a slightly more uniform rainfall distribution and somewhat lower corresponding hydrograph peaks.

Since standard IDF curves had not been developed previously for Los Alamos, they were constructed for this study using precipitation data from Bowen (1990, p. 156). Intensity is the time rate of precipitation, expressed in inches per hour (in./h). Here, average intensity is given by the expression

$$i = P/T = c/(T^e + f), \qquad \text{(III-1)}$$

where i is average intensity (in./h) over time T; P is the precipitation depth (in.) listed in Bowen (1990); T is rainfall duration (min); and c, e, and f are coefficients that vary with location and return period (Tr). Plots of i versus T are shown in Fig. 2; for Los Alamos, these IDF curves have the following coefficients:

Tr (yr)	c	e	f
2	88.441	1.011	21.953
5	85.513	0.962	10.752
10	80.908	0.931	6.123
25	82.730	0.912	3.281
50	81.414	0.893	1.580
100	85.050	0.888	0.617

Once these IDF curves had been constructed, a hyetograph of a 6-h design storm was developed for each return-period event using the alternating-block method (Chow et al. 1988, pp. 454–466). Results for the 2- and 100-yr storm events are shown in Fig. 3. Figure 4 shows the cumulative 100-yr, 6-h design storm for Los Alamos and the SCS 6-h design storm for comparison. The Los Alamos cumulative 6-h design storm patterns for the 2-, 5-, 10-, 25-, 50-, and 100-yr events are listed in Table 2; note that these distributions are in dimensionless form. These hyetographs were used throughout this study in all HEC-1 simulations.

It should be noted that each of the Los Alamos storm distributions listed in Table 2 contains all of the shorter-duration events with the same recurrence interval. For example, the 100-yr, 6-h design storm contains the 100-yr, 15-min storm in its central 15-min interval. Likewise, the 100-yr, 30-min storm is contained within the central 30-min interval of the 100-yr, 6-h design distribution. Similar comments apply to the 2-, 5-, 10-, 25-, and 50-yr design storm events listed in Table 2.

While many theoretical storm distributions are available for midwestern and eastern watersheds, it was felt that none of these would adequately reflect conditions at Los Alamos. In other words, these

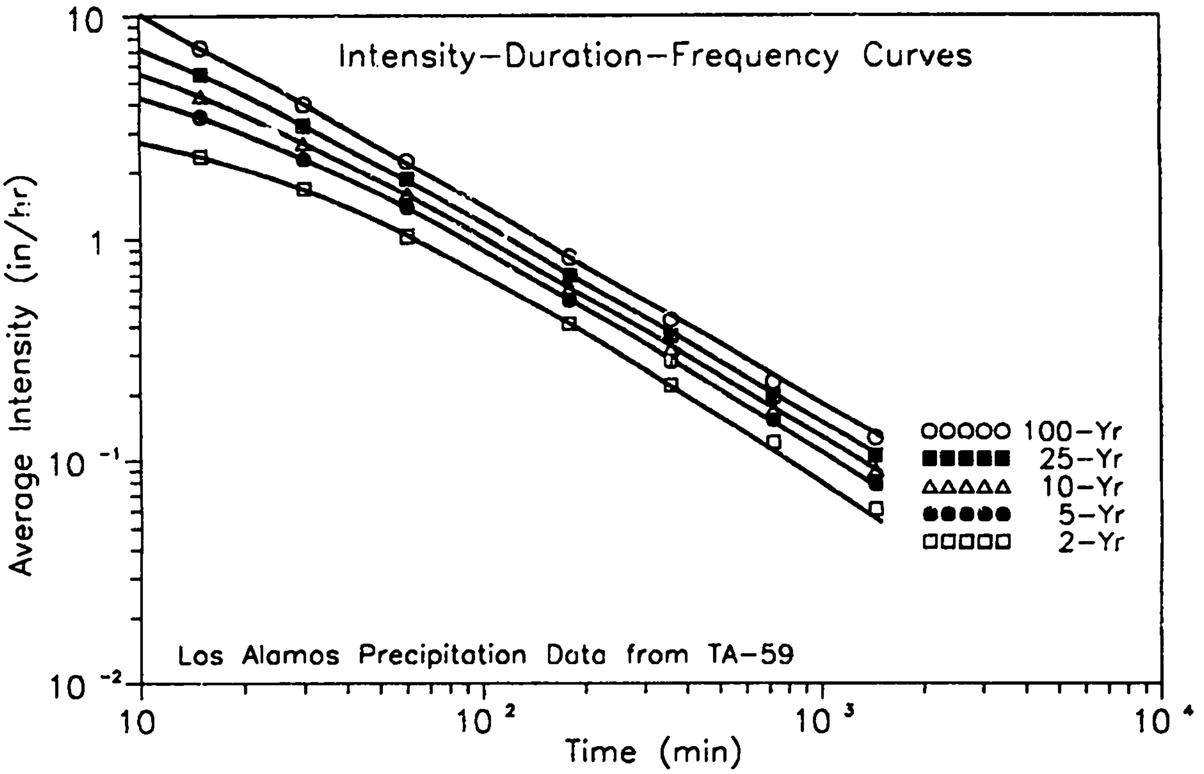

Fig. 2. Intensity-duration-frequency curves for Los Alamos County.

midwestern and eastern storm patterns tend to yield smaller peak hydrographs than those obtained from Los Alamos storm patterns. Note that one may also use instantaneous rainfall increments (Hoggan, 1989, p. 239; US Army COE, 1959; USBR, 1977, pp. 86–89) in HEC-1 simulations; however, this option was not used here. Instead, cumulative storm distribution patterns were used in all HEC-1 simulations; furthermore, they were adjusted for total rainfall depths in individual subbasin watersheds. It can be inferred from Fig. 3 that all of the 6-h design storm distribution patterns used in this study have a midpoint peak intensity near 3 h. Figure 3 also implies that gradually increasing and decreasing intensities precede and follow these peak values. This general worst-possible design storm pattern essentially satisfies abstractions with low rainfall intensity early in the storm. As a result, this design pattern yields higher hydrographs in response to higher rainfall intensities at later times. It should be added that observed New Mexico summer thunderstorms typically result from intense prefrontal squall lines moving south to north. While an observed 100-yr 6-h storm has never been recorded at Los Alamos, its characteristic distribution would probably show the highest rainfall intensities in the first hour and gradually decreasing rainfall intensities over the next 5 h. Furthermore, observed thunderstorms are exceptionally localized events and rarely cover an entire watershed. However, each subbasin's design storm was assumed to occur simultaneously with all other subbasin events in HEC-1 simulations. Hence, the Los Alamos design storm distribution patterns are conservative and tend to yield larger hydrograph peaks than would likely be obtained from observed hyetographs. Finally, it should be noted that observed rainfall data were obtained from Bowen (1989, Table 9.1) and are summarized here in Table 3. Linear interpolation was used to adjust these precipitation depth values for elevation differences between rain gages at Technical Areas 54 and 59 (TA-54 and TA-59) and individual elevations of subbasin centroids (Tables 4 and 5). Centroid elevations were obtained from 7.5-min-series USGS topographic maps. Precipitation depths listed in these tables were assumed to be uniformly distributed over their

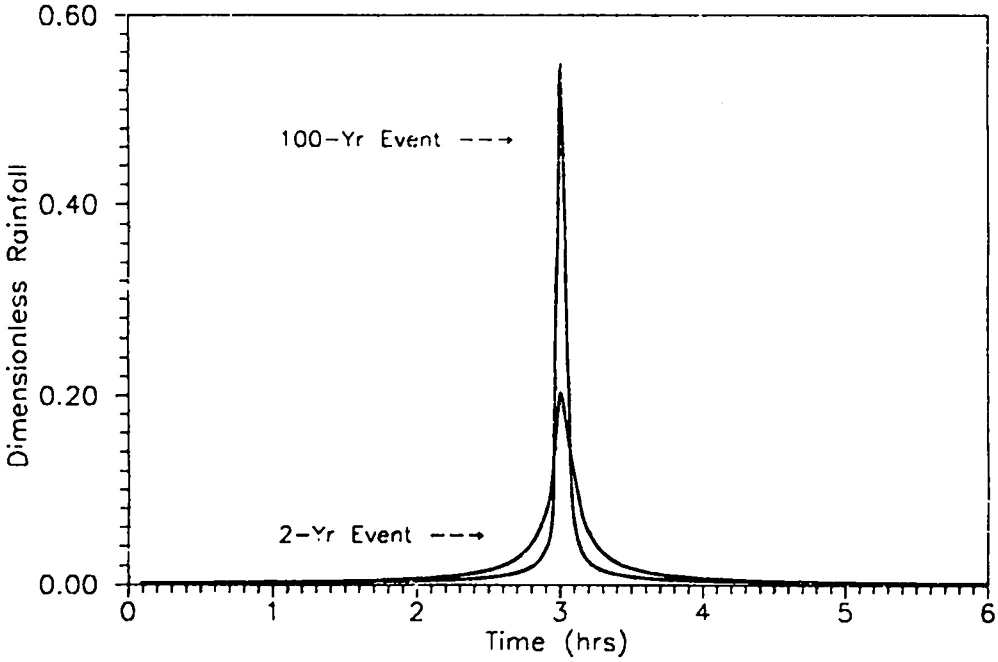

Fig. 3. Six-hour design storms for Los Alamos County.

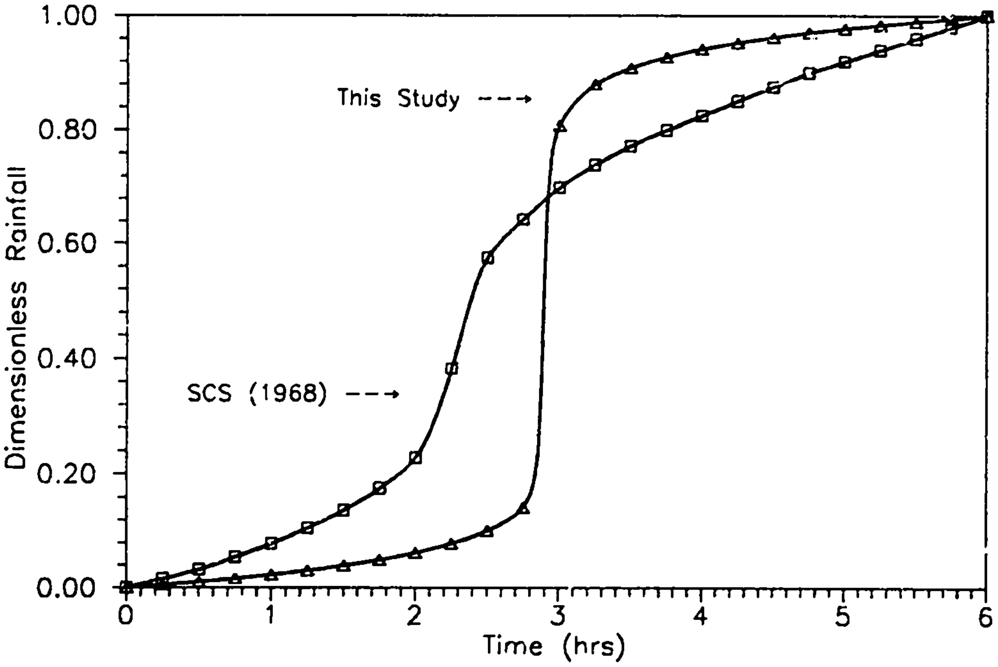

Fig. 4. Cumulative 100-yr, 6-h design storm distributions.

Table 2. Individual 6-hour design storm distributions for Los Alamos County. See Figures 1 through 3.

Time (min)	Time (hr)	Cumulative Storm Distribution (dimensionless) 2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
0	0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.25	0.0021	0.0033	0.0041	0.0045	0.0051	0.0051
30	0.50	0.0046	0.0071	0.0087	0.0095	0.0106	0.0106
45	0.75	0.0078	0.0114	0.0139	0.0151	0.0167	0.0167
60	1.00	0.0118	0.0165	0.0199	0.0213	0.0235	0.0234
75	1.25	0.0169	0.0227	0.0268	0.0285	0.0312	0.0310
90	1.50	0.0238	0.0303	0.0351	0.0369	0.0401	0.0397
105	1.75	0.0334	0.0402	0.0454	0.0471	0.0507	0.0499
120	2.00	0.0476	0.0537	0.0588	0.0599	0.0637	0.0624
135	2.25	0.0704	0.0739	0.0778	0.0774	0.0808	0.0784
150	2.50	0.1125	0.1087	0.1088	0.1045	0.1060	0.1012
165	2.75	0.2121	0.1894	0.1770	0.1608	0.1542	0.1424
180	3.00	0.6644	0.7017	0.7289	0.7617	0.7833	0.8081
195	3.25	0.8493	0.8598	0.8637	0.8718	0.8726	0.8797
210	3.50	0.9113	0.9100	0.9070	0.9087	0.9057	0.9090
225	3.75	0.9416	0.9358	0.9307	0.9300	0.9260	0.9278
240	4.00	0.9594	0.9521	0.9465	0.9448	0.9408	0.9418
255	4.25	0.9709	0.9636	0.9581	0.9562	0.9525	0.9530
270	4.50	0.9790	0.9722	0.9673	0.9654	0.9622	0.9624
285	4.75	0.9849	0.9790	0.9749	0.9731	0.9704	0.9705
300	5.00	0.9894	0.9846	0.9813	0.9798	0.9776	0.9777
315	5.25	0.9930	0.9893	0.9868	0.9857	0.9841	0.9840
330	5.50	0.9958	0.9934	0.9917	0.9909	0.9899	0.9898
345	5.75	0.9981	0.9969	0.9961	0.9957	0.9951	0.9951
360	6.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

respective subbasins in all HEC-1 simulations. These depths were also assumed to have the temporal distributions listed in Table 2 using 15-min rainfall increments.

C. SCS Unit Hydrograph

Obviously, not all rainfall from a storm contributes to direct runoff, because some is lost during the overland flow process. Four theoretical rainfall-abstraction calculation techniques are incorporated in HEC-1; these include the initial and uniform, the exponential, the SCS, and the Holtan techniques. However, the SCS calculation method is the only one which provides reasonably good estimates when geographic watershed characteristics are used to estimate time-of-concentration or basin lag time values. Here, basin lag time is defined as the time between the centroid of excess rainfall and the resulting stream hydrograph peak. The SCS technique uses an SCS curve number (CN) to relate accumulated rainfall excess or runoff to accumulated rainfall with an empirical CN value. In equation form we have

$$R = (P-I)^2/(P-I+S),\ S = 1000/CN - 10,\ \text{and}\ I = 0.2S, \qquad \text{(III-2)}$$

where

Table 3. Precipitation depths for various return periods and storm durations at Los Alamos (TA-59) and White Rock (TA-54).

Los Alamos - TA-59: Elevation = 7379 ft above MSL.

	Precipitation Depth (inches)					
Tr (yrs)	1 hr	3 hr	6 hr	12 hr	24 hr	Annual
2	1.03	1.24	1.34	1.47	1.45	18.10
5	1.38	1.60	1.71	1.84	1.90	22.90
10	1.59	1.83	1.94	2.07	2.18	25.80
25	1.86	2.10	2.21	2.35	2.54	29.00
50	2.06	2.32	2.42	2.55	2.80	31.70
100	2.25	2.52	2.61	2.74	3.06	34.00
500	2.70	3.01	3.08	3.19	3.66	39.87

White Rock - TA-54: Elevation = 6690 ft above MSL.

	Precipitation Depth (inches)					
Tr (yrs)	1 hr	3 hr	6 hr	12 hr	24 hr	Annual
2	0.69	0.81	0.89	1.06	1.18	13.10
5	0.96	1.08	1.17	1.36	1.55	16.40
10	1.15	1.27	1.36	1.55	1.78	18.40
25	1.38	1.50	1.59	1.78	2.08	21.00
50	1.56	1.68	1.77	1.95	2.31	22.90
100	1.75	1.86	1.94	2.11	2.52	24.40
500	2.18	2.28	2.39	2.49	3.03	28.41

R = runoff (in.),
P = rainfall (in.),
I = infiltration abstraction (in.),
S = potential maximum retention after rainfall begins (in.), and
CN = SCS curve number (% of runoff).

The CN is a function of land use, vegetation cover, soil classification, hydrologic conditions, and antecedent moisture and runoff conditions. Variations in infiltration rates of different soil types are incorporated in the CN through the classification of soils into four hydrologic soil groups possessing high (Group A), moderate (Group B), low (Group C), and very low (Group D) infiltration capacities. Group A soils have a water transmission rate >0.30 in./h; Group B soils have a transmission rate of 0.15–0.30 in./h; Group C soils have a rate of 0.05–0.15 in./h; and Group D soils have a rate <0.05 in./h. These soil types have been previously mapped in Los Alamos County (Nyhan et al. 1978) and were used here. In addition, CN values have been tabulated in Hoggan (1989, pp. 33–36). Antecedent moisture conditions (AMC) that are typically used for design applications are called AMC-II (average AMC). Techniques for converting CN values under AMC-II to CN values under AMC-I (very dry soil, but above the average plant-wilting point) and AMC-III (nearly saturated soil—heavy rainfall or light ranifall with low temperatures has occurred within the previous five

where

Table 4. Tabulated 2-year and 100-year, 6-hour precipitation totals for individual watershed sub-basins.

Watershed Name	Sub-Basin Centroid Elevation (ft MSL)	Precipitation (in)	
		2-year	100-year
Guaje			
1. Above BM-7172[1]	8100	1.69	3.29
2. Above BM-6253	6700	0.96	2.09
3. Randija at BM-6253	7105	1.17	2.44
4. Above BM-5897 at Barrancas	6400	0.80	1.83
5. Above LA Canyon Confluence	5920	0.55	1.44
Barrancas			
1. Townsite Tributary at El 6000	6580	0.89	1.99
2. Southern Tributary at El 6000	6200	0.69	1.66
3. Northern 2 Tributaries El 5940	6600	0.90	2.00
4. Above BM-5897 at Guaje	6140	0.66	1.61
Bayo			
1. Townsite Tributary at El 6615	7220	1.23	2.53
2. Main Channel at El 6080	6500	0.85	1.92
3. Southern Tributary at Totavi	6100	0.64	1.57
Pueblo			
1. Trib Confluence at El 7220	8400	1.84	3.54
2. Above County Line at El 6526	7300	1.27	2.60
3. HW-4 Y & LA Confluence	6480	0.84	1.90
Los Alamos			
1. Above Reservoir at El 7657	9200	2.26	4.23
2. Above Bridge at El 7126	7700	1.48	2.94
3. HW-4 Y & Pueblo Canyon	7050	1.14	2.39
4. Above Totavi at Bayo Confluence	6000	0.59	1.49
5. Above Guaje Confluence	5740	0.45	1.29
6. Above Rio Grande Confluence	5600	0.38	1.18
Sandia			
1. Above HW-4 at El 6460	6900	1.06	2.26
2. Main Channel at El 6090	6400	0.80	1.83
3. Tsankawi Drainage at El 6090	6300	0.75	1.75
4. Above Rio Grande Confluence	5800	0.48	1.32
Mortandad			
1. Ten-Site Conflu at El 7060	7200	1.31	2.67
2. Above 1st Sed Trap at El 6783	7045	1.14	2.38
3. At East DOE Boundary Line	6730	0.97	2.11
4. Above HW-4 at El 6455 & Cedro	6640	0.92	2.04
5. Cedro Canyon at Mortandad	6650	0.93	2.05
6. Canada del Buey Confluence	6340	0.77	1.78
Canada del Buey			
1. Above HW-4 at White Rock[1]	6865	1.04	2.23
2. Above Rio Grande Confluence	6500	0.85	1.92
Pajarito			
1. Above HW-503 at W. DOE Line	8720	2.01	3.92
2. Above 2-mi Canyon Confluence	7500	1.37	2.77
3. 2-mi Canyon at Pajarito	7500	1.37	2.77
4. Above 3-mi Canyon Confluence	6850	1.03	2.22
5. 3-mi Canyon at Pajarito	7030	1.13	2.37
6. Above HW-4 & White Rock	6610	0.91	2.01
7. Above Rio Grande Confluence	6330	0.76	1.77
Potrillo			
1. Above Fence Confluence	6750	0.98	2.13
2. Fence Canyon at Potrillo	6700	0.96	2.09
3. Above Water Canyon Confluence	6400	0.80	1.83
Water			
1. Above HW-503 at West DOE Line	8400	1.84	3.54
2. Above Valle Canyon Confluence	7400	1.32	2.69
3. Above HW-4 at El 6410	6600	0.90	2.00
4. Above Potrillo C. Confluence	6500	0.85	1.92
5. Above Rio Grande Confluence	5700	0.43	1.23
Valle			
1. Above HW-503 at W. DOE Line	8680	1.99	3.78
2. Above TA-16 Area P Landfill	7510	1.38	2.78
3. Above Water Canyon Confluence	7300	1.27	2.60
Ancho			
1. West Fork and HW-4 at El 6246	6900	1.06	2.26
2. East Fork and HW-4 at El 6246	6800	1.01	2.17
3. Lower East Fork at El 5558	6400	0.80	1.83
4. Main Channel at El 5558	6300	0.75	1.75
5. Above Rio Grande Confluence	5750	0.46	1.28
Chaquehui			
1. Above Rio Grande Confluence	6450	0.82	1.87
Frijoles			
1. Main Channel at El 7200	8900	2.10	3.97
2. Below Burn Mesa at El 6670	7300	1.27	2.60
3. Above USGS Gage Station	7060	1.11	2.35

[1] Location of sub-basin outflow point in main stream channel; see watershed boundary and USGS 7.5 minute topographic maps.

Table 5. Tabulated 5, 10, 25, and 50-year, 6-hour precipitation totals for individual watershed sub-basins.

Watershed Name	6-hr Precipitation Totals (in)			
	5-yr	10-yr	25-yr	50-yr
Guaje				
1. Above BM-7172[1]	2.16	2.44	2.77	3.03
2. Above BM-6253	1.27	1.47	1.72	1.91
3. Rendija at BM-6253	1.53	1.75	2.02	2.23
4. Above BM-5897 at Barrancas	1.07	1.26	1.49	1.67
5. Above LA Canyon Confluence	0.77	0.92	1.13	1.29
Barrancas				
1. Townsite Tributary at El 6000	1.19	1.38	1.63	1.81
2. Southern Tributary at El 6000	0.95	1.12	1.34	1.51
3. Northern 2 Tributaries El 5940	1.20	1.40	1.64	1.83
4. Above BM-5897 at Guaje	0.91	1.08	1.29	1.46
Bayo				
1. Townsite Tributary at El 6615	1.60	1.83	2.11	2.32
2. Main Channel at El 6080	1.14	1.33	1.57	1.75
3. Southern Tributary at Totavi	0.88	1.05	1.26	1.43
Pueblo				
1. Trib Confluence at El 7220	2.35	2.65	3.00	3.27
2. Above County Line at El 6526	1.65	1.88	2.17	2.39
3. HW-4 Y & LA Confluence	1.13	1.31	1.55	1.73
Los Alamos				
1. Above Reservoir at El 7657	2.86	3.21	3.60	3.90
2. Above Bridge at El 7126	1.90	2.16	2.47	2.71
3. HW-4 Y & Pueblo Canyon	1.49	1.71	1.98	2.19
4. Above Totavi at Bayo Confluence	0.82	0.98	1.19	1.35
5. Above Guaje Confluence	0.65	0.80	0.99	1.14
6. Above Rio Grande Confluence	0.56	0.70	0.89	1.03
Sandia				
1. Above HW-4 at El 6460	1.39	1.61	1.87	2.07
2. Main Channel at El 6090	1.07	1.26	1.49	1.67
3. Tsankawi Drainage at El 6090	1.01	1.19	1.42	1.59
4. Above Rio Grande Confluence	0.69	0.84	1.04	1.19
Mortandad				
1. Ten-Site Conflu at El 7060	1.70	1.94	2.23	2.45
2. Above 1st Sed Trap at El 6783	1.49	1.71	1.98	2.18
3. At East DOE Boundary Line	1.30	1.49	1.74	1.93
4. Above HW-4 at El 6455 & Cedro	1.23	1.43	1.67	1.86
5. Cedro Canyon at Mortandad	1.23	1.43	1.68	1.87
6. Canada del Buey Confluence	1.04	1.22	1.45	1.62
Canada del Buey				
1. Above HW-4 at White Rock[1]	1.37	1.58	1.84	2.04
2. Above Rio Grande Confluence	1.14	1.33	1.57	1.75
Pajarito				
1. Above HW-503 at W. DOE Line	2.56	2.87	3.24	3.52
2. Above 2-mi Canyon Confluence	1.78	2.02	2.32	2.55
3. 2-mi Canyon at Pajarito	1.78	2.02	2.32	2.55
4. Above 3-mi Canyon Confluence	1.36	1.57	1.83	2.03
5. 3-mi Canyon at Pajarito	1.48	1.70	1.97	2.17
6. Above HW-4 & White Rock	1.21	1.40	1.65	1.84
7. Above Rio Grande Confluence	1.03	1.21	1.44	1.61
Potrillo				
1. Above Fence Confluence	1.30	1.50	1.76	1.95
2. Fence Canyon at Potrillo	1.27	1.47	1.72	1.91
3. Above Water Canyon Confluence	1.07	1.26	1.49	1.67
Water				
1. Above HW-503 at West DOE Line	2.35	2.65	3.00	3.27
2. Above Valle Canyon Confluence	1.71	1.95	2.25	2.47
3. Above HW-4 at El 6410	1.20	1.40	1.64	1.83
4. Above Potrillo C. Confluence	1.14	1.33	1.57	1.75
5. Above Rio Grande Confluence	0.63	0.77	0.96	1.11
Valle				
1. Above HW-503 at W. DOE Line	2.53	2.85	3.21	3.49
2. Above TA-16 Area P Landfill	1.78	2.03	2.33	2.55
3. Above Water Canyon Confluence	1.65	1.88	2.17	2.39
Ancho				
1. West Fork and HW-4 at El 6246	1.39	1.61	1.87	2.07
2. East Fork and HW-4 at El 6246	1.33	1.54	1.79	1.99
3. Lower East Fork at El 5558	1.07	1.26	1.49	1.67
4. Main Channel at El 5558	1.01	1.19	1.42	1.59
5. Above Rio Grande Confluence	0.66	0.81	1.00	1.15
Chaquehui				
1. Above Rio Grande Confluence	1.11	1.29	1.53	1.71
Frijoles				
1. Main Channel at El 7200	2.67	3.00	3.38	3.66
2. Below Burn Mesa at El 6670	1.65	1.88	2.17	2.39
3. Above USGS Gage Station	1.46	1.68	1.94	2.15

[1] Location of sub-basin outflow point in main stream channel; see watershed boundary and USGS 7.5 minute topographic maps.

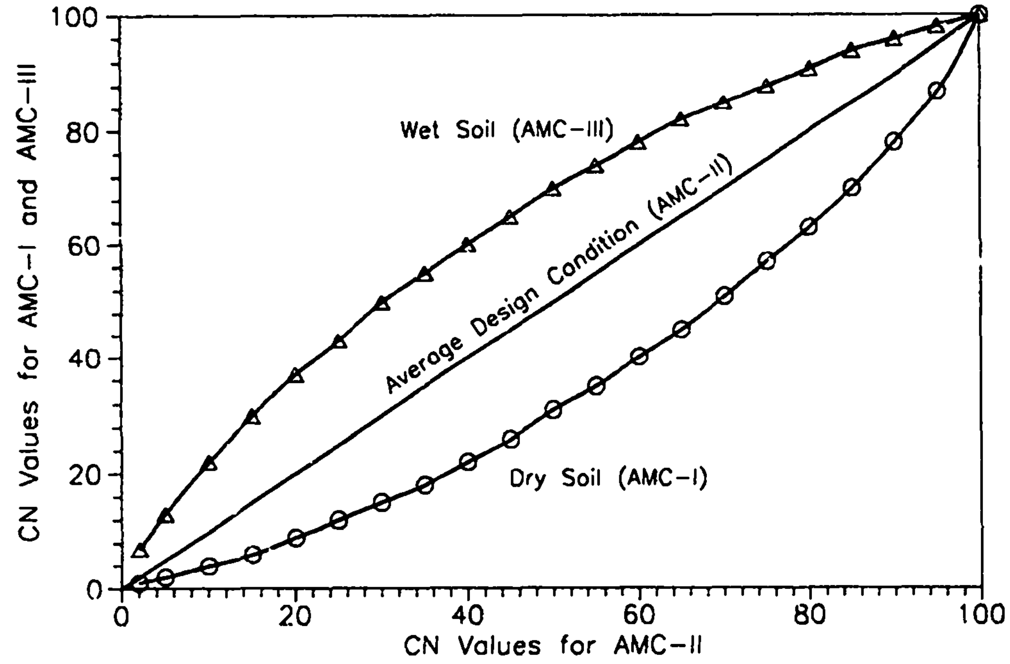

Fig. 5. Variations of SCS curve numbers for different moisture conditions.

were made in this study. Figure 5 shows the relationship of CN values under AMC-I and AMC-III conditions as a function of CN values under AMC-II conditions. Once rainfall excess has been determined, a unit hydrograph can be computed for each subbasin.

The SCS synthetic unit hydrograph procedure is based on a dimensionless unit hydrograph developed from an analysis of numerous unit hydrographs from small geographically diverse, rural watersheds. This dimensionless unit hydrograph represents the ratio of discharge to peak discharge versus the ratio of time to lag time. This lag time is a fundamental watershed characteristic and directly depends upon overland flow path length and mean flow velocity. As such, lag time is influenced by drainage basin area, main channel slope and geometry, land cover, and temporal and spatial storm patterns. In concept, the lag time incorporates the effect of basin size and much of the effect of basin shape. The advantage of the SCS approach is that it only requires the determination of time-to-peak (t_p) and peak discharge (Q_p), which are given by (Viessman et al. 1977, pp. 138–139)

$$t_p = D/2 + t_l \text{ and } Q_p = 454\ A/t_p, \qquad \text{(III-3)}$$

where

t_p = time from rainfall beginning to peak discharge (h),
D = rainfall duration (h),
t_l = basin lag time from centroid of rainfall excess to peak discharge (h),
Q_p = peak discharge (cfs),
A = watershed drainage area (sq mi).

The basin lag time (t_l) in Equation (III-3) can be expressed as

$$t_l = [l^{0.8}\ (S + 1)^{0.7}]/[1900\ Y^{0.5}], \qquad \text{(III-4)}$$

where l is the water course length (ft) going upstream to the watershed divide, Y is the average watershed slope (%) along the flow path, and all other terms are as previously defined.

Figure 6 uses Equation (III-4) and the tabulated data contained in Appendix B to depict basin lag time as a function of subbasin drainage area for Los Alamos. According to Graf (1988, p. 90), these lag times are comparable to those from northeastern US watersheds. However, he does not indicate how his values were determined. In Fig. 7 Los Alamos watershed data are used to show SCS basin lag times from Equation (III-4) as a function of Snyder basin lag times. Data used to compute these Snyder lag times are summarized in Table 6. The upper curve in Fig. 7 was obtained from a relationship derived by the US Army COE for mountainous watersheds near Los Angeles, California (Linsley et al. 1982, pp. 223–225). This relationship is given by

$$t_{sl} = C_t[(L\cdot Lc)/(s^{0.5})]^n, \qquad \text{(III-5)}$$

where

t_{sl} = Snyder lag time (h) for mountainous watersheds,
C_t = coefficient accounting for slope and storage effects,
L = channel length (mi) from basin outlet to divide,
Lc = channel length (mi) from basin outlet to centroid,
s = weighted channel slope (ft/ft), and
n = an empirical coefficient.

For mountainous watersheds near Los Angeles, California, Linsley reports values for C_t and n of 1.2 and 0.38, respectively. The lower curve in Fig. 7 represents Snyder lag times based on the US Army COE's studies from the Rio Puerco, in New Mexico, and from El Paso, Texas. For this second curve, the standard Snyder lag time equation was used. This expression is given by

$$t_{sl} = C_t(L\cdot Lc)^{0.30}, \qquad \text{(III-6)}$$

where all terms are as previously defined. Values for C_t were obtained from a logarithmic plot of C_t verses s (M. Magnuson, personal communication 1989). Figure 7 clearly shows that the SCS basin lag times used in this study are bracketed by extremes produced with the Snyder technique.

As mentioned above, the SCS runoff CN relates accumulated rainfall excess or runoff to accumulated rainfall. In addition to ease of use, Equation (III-4) has the advantage that the impacts of development within a watershed can be evaluated because changes in CN over time are easily estimated. As previously mentioned, tables exist that list CN values for a variety of conditions, ranging from urban to semiarid (Hoggan 1989, pp. 33–36). These same impacts cannot be estimated with the Snyder or Clark methods. In fact, if one originally employed either the Snyder or the Clark unit hydrograph method and land use patterns changed over time, there would be no systematic methodology for evaluating corresponding changes in the hydrograph peak, unless the SCS technique was subsequently used.

The US Army COE in Albuquerque has developed Snyder's synthetic unit hydrograph method for applications in north central New Mexico (M. Magnuson, personal communication, 1989). Regardless, it was felt that the Snyder's coefficients representing basin slopes and storage were generally not applicable to Pajarito Plateau. It can be inferred from Fig. 7 that either smaller or larger hydrograph peaks can be obtained from HEC-1 simulations if the Snyder unit hydrograph approach is used instead of the SCS technique. The potential for generating larger hydrograph peaks is obviously of interest. However, as discussed in Subsection E, use of this alternative approach in Los Alamos County cannot be justified.

D. Model Input Parameters

Because all watersheds within the DOE-LANL complex are similar, individual HEC-1 input data files have a similar structure (see Disk No. 1). This generic file structure is illustrated in Table 7. Individual watershed boundary location maps were constructed from 7.5-min USGS topographic

Table 6 Parameters used to compute Snyder basin lag times using equations (III-5 and 6). See Figure 6 and text for definitions.

Watershed Sub-Basin	Area (sq mi)	L (mi)	Lc (mi)	E-85 (ft)	E-10 (ft)	Slope (%)	Ct
Guaje[1]							
1	11.30	6.44	2.41	8840	7300	6.04[2]	0.54
2	3.25	4.55	3.69	7020	6340	3.76	0.62
3	9.59	8.71	4.83	7860	6400	4.23	0.60
4	2.13	2.41	1.61	6168	5900	2.60	0.68
5	1.45	1.70	0.99	5845	5675	2.52	0.66
Barrancas							
1	1.79	4.83	2.37	6880	6120	3.97	0.61
2	0.33	1.37	0.52	6385	6020	6.71	0.52
3	2.52	4.36	2.41	6840	6020	4.75	0.58
4	0.21	0.62	0.47	5960	5880	3.28	0.69
Bayo							
1	1.57	3.17	1.66	7150	6670	3.82	0.48
2	1.15	2.89	1.28	6560	6150	3.58	0.49
3	1.19	2.41	1.23	6220	5820	4.18	0.50
Pueblo							
1	2.24	2.84	1.56	7820	7260	4.98	0.57
2	4.61	4.55	3.17	7130	6652	2.66	0.72
3	1.55	2.65	1.56	6420	6295	1.19	0.94
Los Alamos							
1	6.33	3.79	2.18	8900	7740	7.73	0.50
2	0.74	1.89	0.95	7520	7160	4.80	0.58
3	3.31	6.63	3.50	6980	6350	2.40	0.74
4	1.96	2.23	0.99	6170	5775	4.48	0.59
5	0.77	0.95	0.52	5740	5670	1.87	0.77
6	0.67	1.47	0.99	5630	5500	2.24	0.73
Sandia							
1	2.65	6.96	3.22	7250	6530	2.61	0.72
2	0.85	2.23	1.18	6420	6240	2.04	0.76
3	1.32	1.89	1.18	6360	6160	2.67	0.72
4	0.75	1.70	1.04	5780	5510	4.00	0.61
Mortandad							
1	0.55	1.70	0.76	7360	7115	3.63	0.63
2	0.81	1.99	1.04	7020	6800	2.79	0.68
3	0.36	1.14	0.57	6765	6670	2.11	0.73
4	1.61	2.32	1.89	6630	6470	1.74	0.79
5	0.86	3.03	1.85	6760	6480	2.33	0.74
6	1.72	2.56	1.33	6425	5720	6.96	0.52
Canada del Buey[1]							
1	2.10	5.59	2.94	6980	6480	2.26[2]	0.74
2	2.42	2.79	2.79	6360	5510	7.68	0.50
Pajarito							
1	1.99	3.27	1.61	9915	7950	15.19	0.42
2	2.57	3.46	2.60	7570	6980	4.31	0.60
3	3.28	5.35	2.56	8440	6990	6.84	0.52
4	0.67	2.08	1.04	6910	6745	2.00	0.76
5	1.70	3.69	1.70	7280	6752	3.61	0.68
6	1.15	2.84	1.42	6700	6530	1.51	0.83
7	2.24	2.94	1.47	6460	5540	7.91	0.50
Potrillo							
1	2.78	5.40	2.79	7020	6460	2.62	0.70
2	1.03	3.41	2.04	6860	6490	2.74	0.69
3	0.96	1.85	0.90	6410	5880	7.25	0.51
Water							
1	4.07	3.41	1.75	9100	7605	11.07	0.46
2	2.63	3.36	1.75	7400	6880	3.91	0.61
3	1.42	3.60	1.85	6750	6450	2.11	0.73
4	1.97	2.60	1.28	6340	5880	4.46	0.59
5	0.32	0.95	0.57	5770	5400	9.87	0.47
Valle							
1	2.33	4.26	2.46	9480	7840	9.72	0.47
2	0.78	1.42	0.90	7600	7320	4.98	0.57
3	1.17	2.37	1.61	7225	6880	3.68	0.63
Ancho							
1	2.19	4.88	2.60	7060	6275	4.06	0.50
2	2.48	4.17	2.08	6860	6290	3.45	0.52
3	1.11	2.46	1.33	6450	5810	6.56	0.44
4	1.04	1.89	0.95	6210	5670	7.20	0.51
5	0.19	0.47	0.47	5530	5410	6.40	0.54
Chaquehui							
1	1.50	3.13	1.56	6540	5650	7.19	0.51
Frijoles							
1	4.97	3.83	1.89	9500	7860	10.83	0.46
2	4.92	4.62	2.46	7560	6780	4.26	0.60
3	8.13	4.55	4.17	6520	6090	2.39	0.72

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[1] See Table 4 for locations of sub-basin outflow points.
[2] Weighted sub-basin slope = (E85 - E10)*100/(0.75*L).

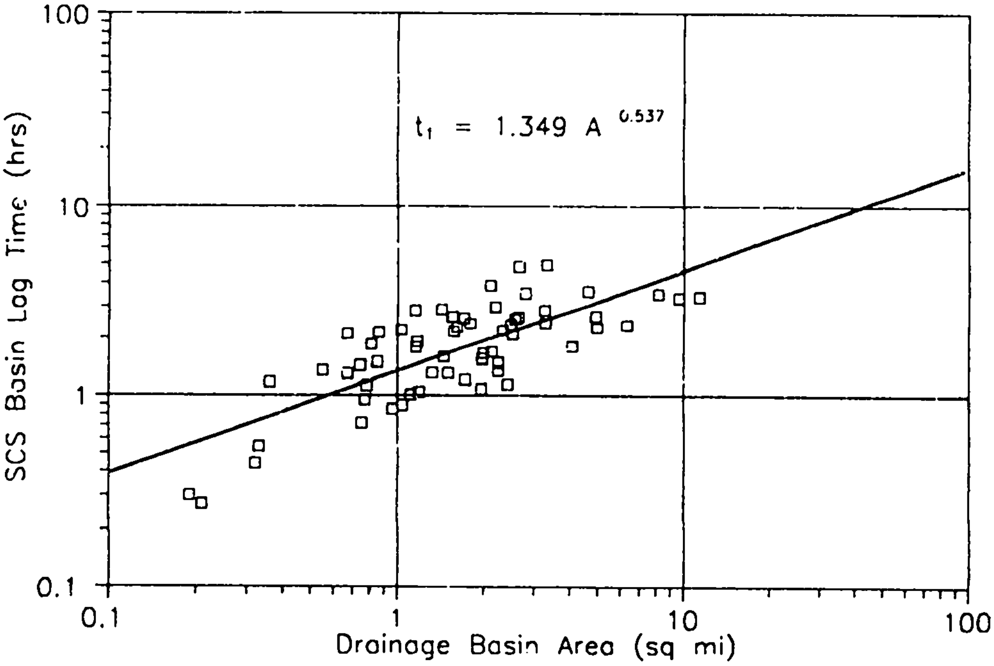

Fig. 6. Drainage basin area vs SCS basin lag time at Los Alamos.

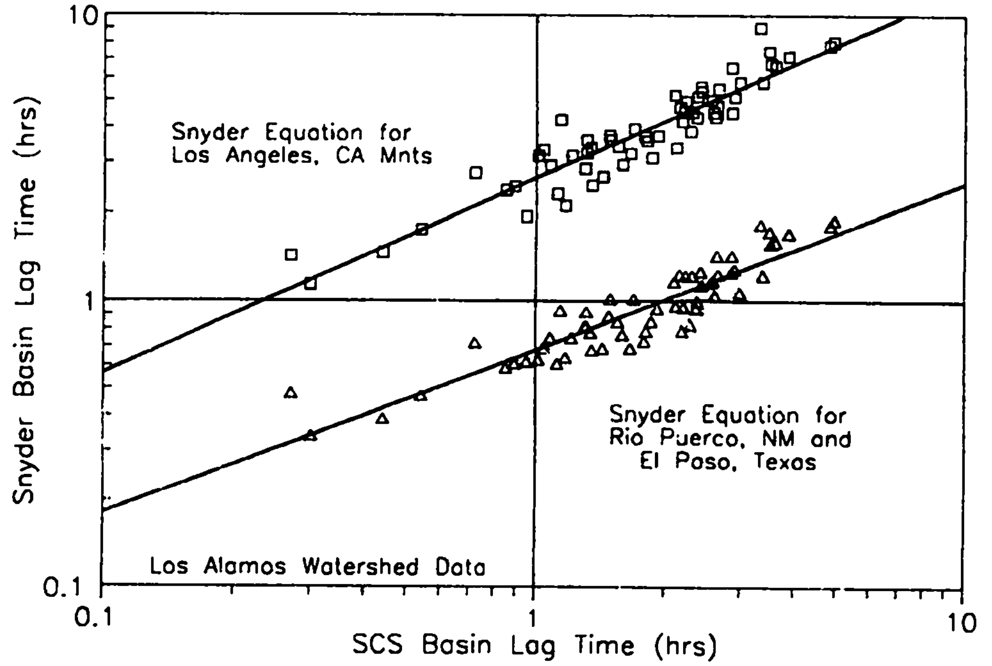

Fig. 7. SCS basin lag time vs Snyder lag times at Los Alamos.

Table 7. Typical HEC-1 input file identification scheme. See HEC-1 user manual for complete listing of other options.

Data Category	Record Identification	Data Description
Job Initialization	ID	Job Identification
	IT	Job Time Control
	IO	General Output Control
	IN	Input Data Time Control
Precipitation Data	PC[1]	Cumulative Prec Time Series
	PG[2]	Storm Gage Total Precipitation
	PR	Recording Gage to be Weighted
	PW	Precipitation Gage Weight Factor
	PT	Total Storm Gages to be Weighted
Job Step Control	KK	Stream Station Identifier
	KM	Alphanumeric Comment Message
	KO	Output Control for this Station
Basin Data	BA[3]	Basin Area
Loss Rate Data	LS[3]	SCS Curve Number Loss Technique
Unitgraph Data	UD[3]	SCS Dimensionless Unitgraph
Routing Data	RL	Channel Loss Rates
	RM[3]	Muskingum Routing Parameters
Hydrograph Transformations	HC	Combine Hydrographs
End of Job	ZZ	Required to End Job

[1] See Table 2 for design storm distribution.

[2] See Tables 4 and 5 for individual sub-basin values.

[3] See individual watershed sub-basin values in Appendix A.

maps; they are located with the floodplain boundary maps in the Facilities Engineering Planning Group Office (Comer and McLin 1991). Equations to compute individual input file parameters were listed in the previous section. Results of these calculations are listed in Appendix B. Tabulated watershed characteristics include subbasin area, subbasin main channel length to water divide or upstream subbasin boundary, elevation change over channel length, average subbasin CN value, and computed SCS basin lag time from Equation (III-4). All watersheds were outlined on the USGS topographic maps, and individual subbasin areas were measured with a planimeter. Measurements obtained from four repeated area calculations for each subbasin yielded variances that deviated <1% from average values. Selected watershed areas are listed in Table 8, and all subbasin area mean values are given in Appendix B and Disk No. 1. Channel lengths and elevation changes were also taken directly from topographic maps with similar measurement repeatability. It should also be mentioned that predicted HEC-1 hydrographs are relatively insensitive to minor measurement

Table 8a. Hydrograph peaks (cfs) corresponding to individual 6-hour Los Alamos design storm events at east DOE-LANL boundary. See Table 9 for description of exact locations. See Table 2 for cumulative storm distribution patterns.

Watershed Name	Basin Area	Recurrence Interval Hydrograph Peaks (cfs)					
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Guaje[1]	26.27[2]	20	137	265	472	666	888
Barrancas	2.12	1	12	25	47	67	90
Bayo	3.92	2	21	43	79	111	147
Pueblo	8.40	8	65	121	211	292	383
Los Alamos	10.38	19	115	204	332	447	589
Los Alamos	20.74	24	166	300	502	686	902
Sandia	2.65	1	10	21	38	54	71
Mortandad	1.72	1	6	11	19	27	35
Canada del Buey	2.10	1	11	21	38	54	72
Pajarito	11.36	5	71	143	263	372	498
2-Mile	3.28	1	19	40	77	111	149
3-Mile	1.70	1	12	24	43	60	80
Fence	1.03	1	8	16	29	41	55
Potrillo	2.78	1	14	28	53	75	99
Potrillo	4.77	2	15	30	56	81	108
Canon de Valle	4.28	2	21	41	75	104	141
Water	12.40	4	68	139	255	361	485
Ancho	4.67	2	27	57	105	150	198
Chaquehui	1.50	1	13	27	53	78	103
Frijoles[1]	18.02	33	160	284	479	654	853

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[1] Watershed boundary is outside DOE-LANL complex.
[2] Drainage basin area in square miles.

Table 8b. Total 24-hr runoff volumes (ac-ft) corresponding to individual 6-hour Los Alamos design storm events at east DOE-LANL boundary. See Table 9 for description of exact locations. See Table 2 for cumulative storm distribution patterns.

Watershed Name	Basin Area	Recurrence Interval 24-hr Runoff (ac-ft) 2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Guaje[1]	26.27[2]	8	67	133	236	333	442
Barrancas	2.12	<1	4	8	18	24	32
Bayo	3.92	<1	8	16	30	44	58
Pueblo	8.40	4	26	48	85	119	155
Los Alamos	10.38	8	48	83	137	184	240
Los Alamos	20.74	12	75	141	236	325	424
Sandia	2.65	<1	6	12	22	32	42
Mortandad	1.72	<1	1	2	4	6	9
Canada del Buey	2.10	<1	6	10	18	24	30
Pajarito	11.36	2	26	54	99	141	186
2-Mile	3.28	<1	6	14	26	38	50
3-Mile	1.70	<1	4	8	16	22	28
Fence	1.03	<1	2	4	10	12	16
Potrillo	2.78	<1	6	12	24	34	44
Potrillo	4.77	<1	8	18	32	46	60
Canon de Valle	4.28	<1	6	10	18	26	38
Water	12.40	2	24	48	87	125	169
Ancho	4.67	<1	10	20	38	54	71
Chaquehui	1.50	<1	2	6	12	16	22
Frijoles[1]	18.02	12	65	119	200	276	359

[1] Watershed boundary is outside DOE-LANL complex.
[2] Drainage basin area in square miles.

errors in subbasin area, main channel length, and elevation differences as im[illegible] by Equation (III-4). In addition, Manning's equation was used to compute Muskingum r[illegible]arameters from average channel flow velocities (Appendix B). Finally, it should be point[illegible]hat all watershed parameters are listed in the HEC-1 input data files on Disk No. 1 and a[illegible]cussed in detail here.

Note that Guaje and Frijoles Canyons have been included in Tables 4 and 5, Appendix B, and on Disk No. 1 even though these watershed stream channels do not cross the DOE-LANL complex. Guaje Canyon was included because the Guaje municipal well field is located there; Frijoles Canyon was included because a USGS gaging station is located at the Bandelier National Park Headquarters. Also note that the tabulated watershed characteristics are listed according to subbasins within a given watershed. Each subbasin boundary division was selected according to several factors. These included (1) tributary inflow, (2) significant change in CN value, (3) an important geographic feature or manmade boundary marker, or (4) another unspecified feature for which a hydrograph peak value was required in HEC-2 simulations. Finally, it should be noted that these subbasins extend from the topographic peaks that define watershed boundaries located to the west of the DOE-LANL complex to the Rio Grande drainage confluence located to the east. Hence, hydrograph peak values were obtained for numerous points along individual watercourses within the DOE-LANL complex, for individual stream channels as they exit the DOE-LANL complex, and for confluent channels merging with the Rio Grande. Only 100-yr floodplains within the DOE-LANL complex were computed, however, because the AUTOGIS-MOSS topographic data do not extend beyond this boundary.

E. Peak Hydrographs for Major Watersheds

Once all subbasin characteristic parameters (Appendix B) and HEC-1 input data files (Disk No. 1) had been prepared, individual watershed hydrographs could be generated. Before this was done, however, a parameter sensitivity analysis was made. With the approach that was used here, all model parameters, except for composite subbasin CNs, are constrained to a very narrow range of observed values. These CN values could be estimated from county soil maps (Nyhan et al. 1978) and standard tables (Hoggan 1989). In actual practice, an individual, composite, subbasin CN value was computed as an area-weighted average according to mapped soil and vegetation types and variable CN values. However, it is reasonable to expect that composite CN values can vary by as much as 10% above or below their originally estimated values. Hence, in order to reduce the uncertainty in these estimated CN values, hydrograph peaks produced by the 2-yr, 6-h design storm event for LANL were examined for all subbasin watersheds. The logic for this design procedure is straightforward: from physical observation, one can quickly develop a general appreciation for flood magnitudes associated with individual 2-yr storm events within Los Alamos County. These qualitative observations suggest that 2-yr flood peaks in Los Alamos County vary between zero and a few hundred gallons per minute. This same appreciation cannot be easily developed for 100-yr magnitude events. Following this logic, all HEC-1 simulations should accurately reflect 2-yr events if one is to have confidence in larger recurrence-interval floods. Note that once all subbasin characteristic parameters have been determined for a given HEC-1 watershed, changing the subbasin rainfall totals (i.e., the PG data card shown in Table 7 for each HEC-1 input data file) and the design storm distribution patterns (i.e., the PC cards shown in Table 7) generates different recurrence interval hydrographs. Results obtained from this design methodology are outlined below.

Each HEC-1 watershed simulation was made for the 2-yr, 6-h LANL design storm event, as described above. If a given subbasin yielded a hydrograph peak that was unreasonably high or low, then the composite CN value was adjusted either downward or upward, respectively, and a new simulation was made. Note that a change in CN value implies a corresponding change in basin lag time, as suggested by Equation (III-4). This iterative process was repeated several times for each watershed. Individual composite CN values were typically adjusted <3% until the 2-yr hydrograph peak was greater than zero but less than about 2 cfs for an average-sized subbasin. Approximately half of all subbasins required a composite CN value adjustment; these adjustments were nearly equally divided between increases and decreases in CN values. Once these CN values were fixed, the 2-, 5-, 10-, 25-, 50-, and 100-yr hydrographs were computed using the 6-h rainfall totals listed in Tables 4 and 5 and the design storm distribution patterns listed in Table 2. Resulting hydrograph peaks and 24-h runoff volumes for all watersheds crossing the eastern DOE-LANL boundary are given in Tables 8 and 9. Table 10 lists hydrograph peaks and 24-h runoff volumes for confluent stream channels at the Rio Grande. One should use care in referring to these tables. For example, the Los Alamos Canyon watershed is listed in both tables. In Table 8, the second Los Alamos hydrograph peak includes Pueblo Canyon flows because these streams are confluent above the eastern DOE-LANL boundary. In Table 10, the Los Alamos values include flows from Guaje, Rendija, Barrancas, Bayo, Pueblo, and Los Alamos Canyons because all of these streams are confluent above the Rio Grande. Similar comments apply to other listed watersheds. It should also be mentioned that these combined hydrograph peaks cannot simply be arithmetically added together. Instead they must be hydraulically routed downstream and then combined. In other words, each stream hydrograph abscissa must be aligned to account for flood wave travel time. This procedure is automatically performed in the HEC-1 hydrograph-combining subroutine. Finally, it should be pointed out that all stream channels were assumed to have zero baseflow because all streams within the DOE-LANL boundary are normally ephemeral.

F. Comparison with USGS Flood-Flow Frequencies

The USGS has developed regression equations (Waltemeyer 1986) for estimating flood discharges for the 2-, 5-, 10-, 25-, 50-, and 100-yr recurrence intervals from ungaged watersheds in New Mexico. A comparison between hydrograph peaks produced by the HEC-1 and USGS techniques was made in order to illustrate their differences. Generally, one might expect both methods to yield 100-yr peak flows of similar magnitude for Pajarito Plateau watersheds. However, the USGS approach consistently yields higher peak flows than does the HEC-1 technique employed above. At lower recurrence intervals, these differences become more pronounced. For 2-yr floods, the USGS procedure yields hydrograph peaks that are typically one or more orders of magnitude larger than HEC-1 peaks using equivalent subbasin watershed parameters. The reason for these differences is centered on the storm pattern incorporated into each technique and the fact that the HEC-1 model theoretically simulates the rainfall-runoff process more realistically.

Los Alamos County is located within the Central Mountain-Valley Region, according to Waltemeyer (1986, pp. 3 and 47). His regression equation for hydrograph peaks is given by

$$Q_n = (aA^b)(Ec/1000)^c(I^d), \qquad \text{(III-7)}$$

where

Q_n = hydrograph peak (cfs) for yearly recurrence interval n,
A = watershed area (sq mi),
Ec = average channel elevation at points that are 10% and 85% of the stream length upstream from the hydrograph peak (ft), and
I = rainfall total (in.) for the 10-yr, 24-h storm.

In Equation (III-7), parameters a, b, c, and d are the regression coefficients. For Los Alamos, these parameters are listed below.

Table 9. Channel locations of hydrograph peaks listed in Table 8; also see USGS 7.5 minute topographic maps.

Watershed Name	Stream-channel locations of hydrograph peaks
Guaje[1]	Above Barrancas Canyon confluence.
Barrancas	Tributary confluence below east DOE-LANL boundary.
Bayo	Tributary confluence above east DOE-LANL boundary.
Pueblo	Above Los Alamos Canyon confluence at HW-4.
Los Alamos	Above Pueblo Canyon confluence at HW-4.
Los Alamos	Above Bayo Canyon confluence at Totavi.
Sandia	At DOE-LANL eastern boundary.
Mortandad	At DOE-LANL eastern boundary.
Canada del Buey	At DOE-LANL eastern boundary.
Pajarito	At DOE-LANL eastern boundary.
2-Mile	Above Pajarito Canyon confluence.
3-Mile	Above Pajarito Canyon confluence.
Fence	Above Potrillo Canyon confluence at gravel pit.
Potrillo	Above Fence Canyon confluence.
Potrillo	Above Water Canyon confluence.
Canon de Valle	Above Water Canyon confluence.
Water	Stream crossing at HW-4.
Ancho	Stream confluence below HW-4.
Chaquehui	At DOE-LANL eastern boundary.
Frijoles[1]	At USGS gaging station above Rio Grande.

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[1] Watershed boundary is outside DOE-LANL complex.

Table 10a Hydrograph peaks (cfs) corresponding to individual 6-hour Los Alamos design storm events at the Rio Grande confluence. See Table 2 for cumulative storm distribution patterns.

Watershed Name	Basin[1] Area	Recurrence Interval Hydrograph Peaks (cfs)					
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Los Alamos	58.67	39	302	573	997	1392	1845
Sandia	5.57	2	23	50	96	137	182
Canada del Buey	10.43	33	74	127	220	300	395
Pajarito	13.60	24	71	142	260	369	495
Water	19.46	5	80	165	305	434	580
Ancho	7.01	2	32	67	124	179	236
Chaquehui	1.50	1	13	27	53	78	103
Frijoles[2]	18.02	33	160	284	479	654	853

[1] Drainage basin area in square miles.

[2] At USGS gaging station above Rio Grande confluence.

Table 10b Total 24-hr runoff volumes (ac-ft) corresponding to individual 6-hour Los Alamos design storm events at the Rio Grande confluence. See Table 2 for cumulative storm distribution patterns.

Watershed Name	Basin[1] Area	Recurrence Interval 24-hr Runoff (ac-ft)					
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Los Alamos	58.67	22	161	309	543	764	1010
Sandia	5.57	<1	10	24	44	61	81
Canada del Buey	10.43	6	24	44	75	103	135
Pajarito	13.60	6	36	67	121	169	222
Water	19.46	2	36	71	135	190	258
Ancho	7.01	1	14	30	54	77	103
Chaquehui	1.50	<1	2	6	12	16	22
Frijoles[2]	18.02	12	65	119	200	276	359

[1] Drainage basin area in square miles.

[2] At USGS gaging station above Rio Grande confluence.

Q_n	a	b	c	d
2	55200	0.47	−4.05	1.79
5	170000	0.44	−4.13	1.67
10	289000	0.42	−4.14	1.59
25	497000	0.40	−4.13	1.51
50	685000	0.39	−4.11	1.45
100	896000	0.38	−4.09	1.40

All other parameters for Equation (III-7) are listed in Table 11 for watersheds draining the eastern DOE-LANL facility boundary. Note that Waltemeyer (1986, p. 6) indicates that I is the maximum precipitation intensity for the 10-yr, 24-h storm event. He indicates that these I-values can be obtained from precipitation-frequency maps for New Mexico (Miller et al. 1973). However, these maps give precipitation totals rather than intensity, which is given in inches per hour. Thus, the 10-yr, 24-h precipitation total is listed in Table 11. Comparison of 2- and 100-yr hydrograph peaks, as a function of drainage basin area are shown in Figs. 8 and 9. The USGS and HEC-1 methods were used for Los Alamos County. Obviously, for Pajarito Plateau watersheds the USGS approach consistently yields larger hydrograph peaks than does the HEC-1 model. The 2-yr floods obtained from the USGS method are especially interesting because they are so large. In fact, it is this obvious discrepancy that prompted the use of the HEC-1 approach in the first place. Any long-term county resident will readily agree that the predicted 2-yr USGS hydrograph peak flows grossly disagree with his or her personal experience. By logical extension, one must also question the 100-yr flood peaks. For this reason the USGS approach was rejected for use on Pajarito Plateau watersheds. One should not infer that other New Mexico watersheds outside Los Alamos County cannot be accurately represented with the USGS technique, however.

Figures 8–10 depict the HEC-1 hydrograph peaks at the eastern DOE-LANL boundary and at the Rio Grande. These peaks are also listed in Tables 8–10. These and other peak values were used as input data in HEC-2 simulations for final definition of all 100-yr floodplains. Figure 11 shows 100-yr peak flows along the Los Alamos Canyon watershed and includes data from Los Alamos, Guaje, Rendija, Barrancas, Bayo, and Pueblo canyons.

G. Comparison with Other Flood-Flow Frequencies

Lane et al. (1985, pp. 30–37) have generated synthetic streamflow and sediment transport data for Los Alamos Canyon above the Rio Grande confluence. Many of these data were previously unpublished but have recently been reported by Graf (1991, Appendix B4). These data are summarized in Table 12. Weibull plotting positions were used to conduct a log-Pearson Type-III analysis (WRC 1967, WRC 1981, US Army COE 1982) for these data. Figure 12 clearly shows that Lane's synthetic streamflow data are statistically identical to HEC-1 hydrograph peaks obtained in this study for Los Alamos Canyon at the Rio Grande.

IV. HEC-2 WATER-SURFACE PROFILES

A. General Model Description

The HEC-2 model is similar in concept to the HEC-1 model in that it contains a calling program and multiple subroutines. The HEC-2 calculates and plots water-surface profiles for subcritical, critical, and supercritical gradually varied steady flows in channels of any cross-sectional configuration. The principal uses of the model are for floodplain definition; for evaluation of the hydraulic effects of bridges, culverts, and weirs; and for calculating stream profiles for various frequency floods for both

Table 11. Watershed parameters for estimating hydrograph peaks at east DOE-LANL boundary using equation (III-7). See Table 9 for basin locations. See text for discussion.

Watershed Name	Basin Area	E85 (ft)	E10 (ft)	Ec (ft)	I (in)
Guaje[1]	26.27[2]	8480	6060	7270	2.12
Barrancas	2.12	6880	6120	6500	1.67
Bayo	3.92	7035	6220	6628	1.74
Pueblo	8.40	7900	6395	7148	2.05
Los Alamos	10.38	8235	6415	7325	2.15
Sandia	2.65	7250	6530	6890	1.86
Mortandad	1.72	7235	6710	6973	1.94
Canada del Buey	2.10	6980	6480	6730	1.80
Pajarito	11.36	8560	6590	7575	2.29
Potrillo	4.77	6470	6050	6260	1.53
Canon de Valle	4.28	9100	7000	8050	2.57
Water	19.46	8155	5960	7058	1.99
Ancho	7.01	6960	5685	6323	1.57
Chaquehui	1.50	6540	5640	6090	1.43
Frijoles[1]	18.02	8790	6185	7488	2.24

[1] Watershed boundary is outside DOE-LANL complex.

[2] Drainage basin area in square miles.

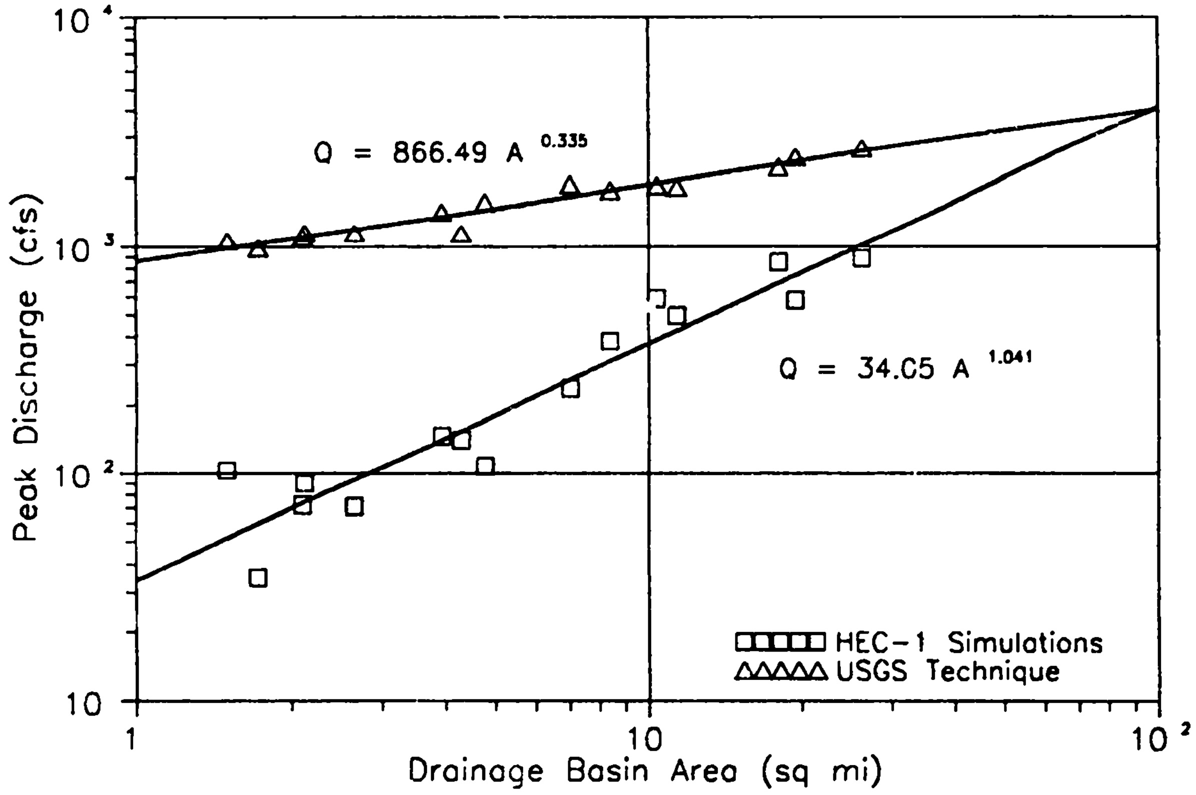


Fig. 8. Comparison of HEC-1 and USGS 100-yr peak discharges at eastern DOE-LANL boundary.

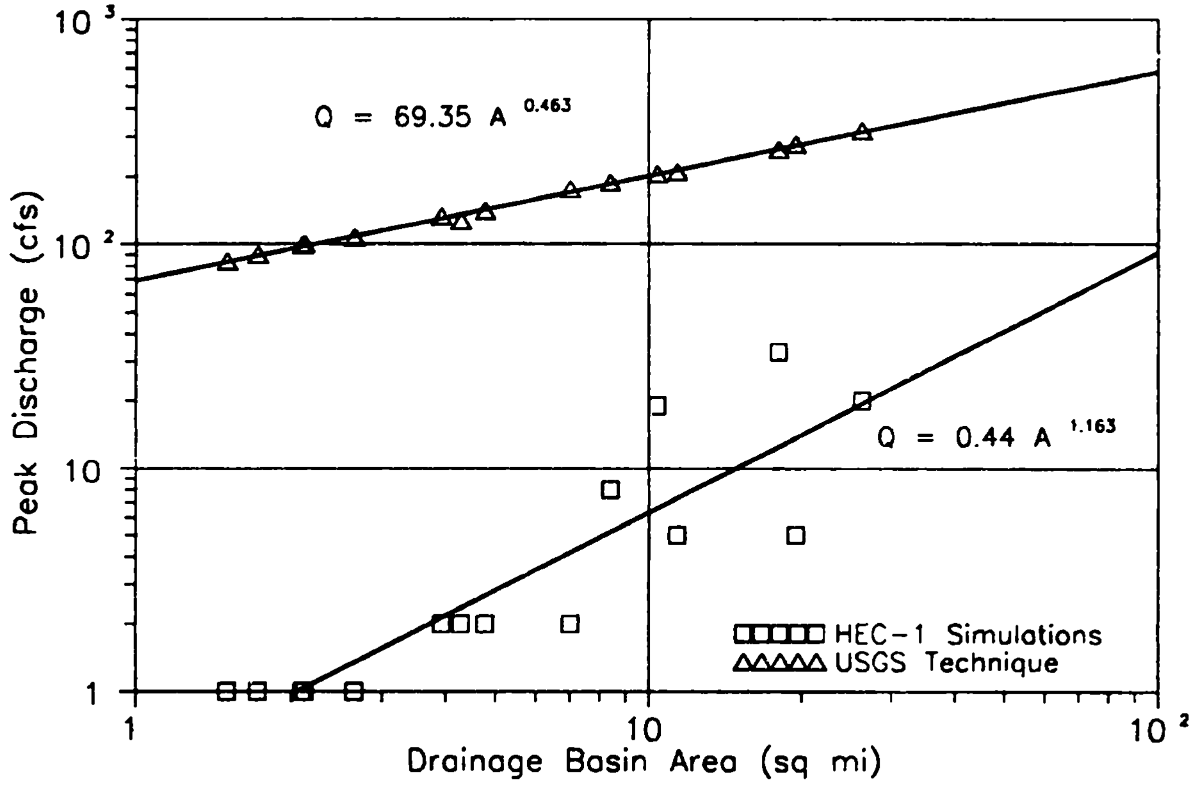


Fig. 9. Comparison of HEC-1 and USGS 2-yr peak discharges at eastern DOE-LANL boundary.

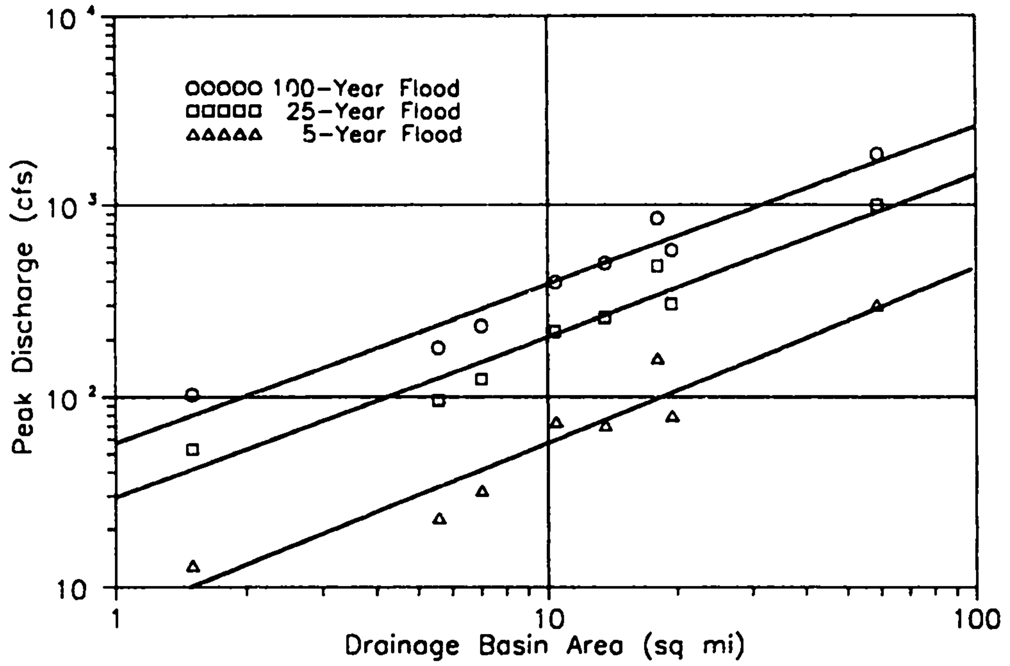


Fig. 10. Drainage basin area vs peak discharge at Rio Grande for Pajarito Plateau streams.

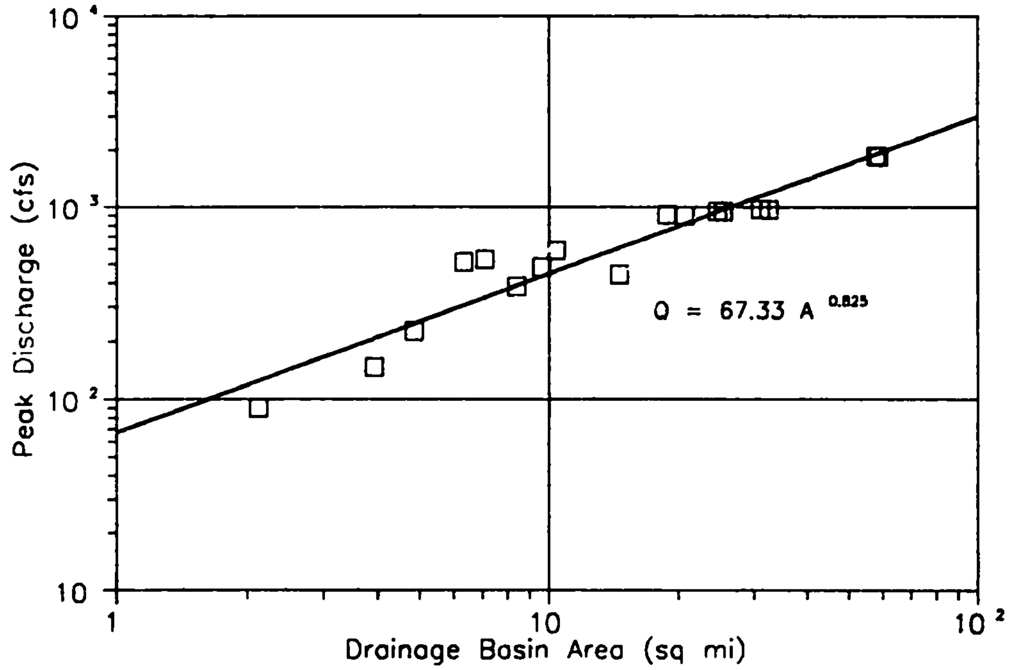


Fig. 11. Drainage basin area vs 100-yr peak discharge for Los Alamos Canyon.

Table 12. Synthetic streamflow data for Los Alamos Canyon at the Rio Grande confluence, as reported in Graf (1991, Appendix B4).

Year	Peak Flood (cfs)	Sediment Yield (tons)
1943	66	466
1944	631	8393
1945	0	61
1946	80	611
1947	2	65
1948	0	61
1949	0	61
1950	20	77
1951	687	9814
1952	386	6316
1953	4	12
1954	129	1006
1955	283	2783
1956	0	0
1957	649	16470
1958	203	2062
1959	59	532
1960	0	154
1961	53	443
1962	1	138
1963	283	2772
1964	0	0
1965	233	3163
1966	32	165
1967	361	4197
1968	924	14120
1969	149	2899
1970	0	0
1971	42	247
1972	0	0
1973	349	3955
1974	20	129
1975	6	99
1976	20	77
1977	4	8
1978	293	3198
1979	312	426
1980	0	183

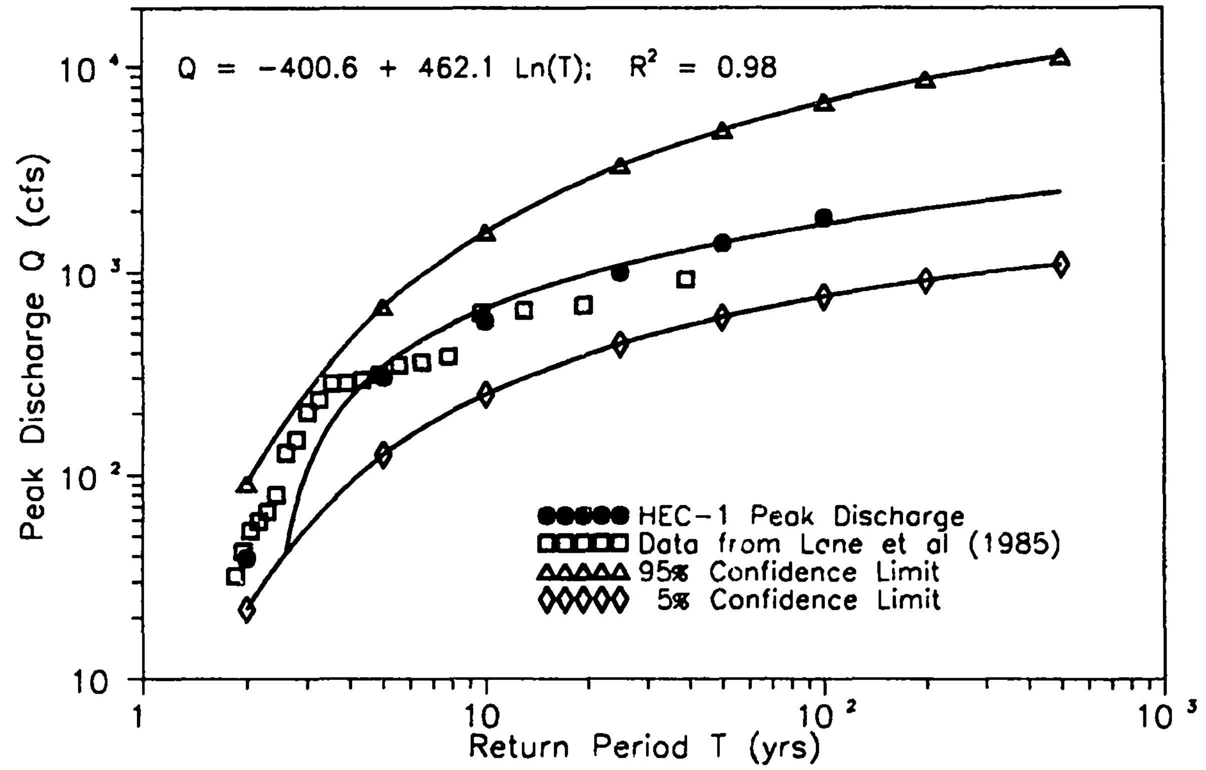


Fig. 12. Log-Pearson Type III analysis of synthetic and HEC-1 flood flows for Los Alamos Canyon at the Rio Grande.

natural and modified channel conditions. Water-surface profile analyses are commonly used to determine flood protection levee heights and flood hazard zones for insurance purposes. The HEC-1 and HEC-2 models are typically used in conjunction with one another for complex floodplain-assessment studies.

The HEC-2 program uses the standard-step numerical method that is based on energy losses to compute water-surface elevation changes between adjacent stream channel cross sections. These computed water-surface elevations correspond to hydrograph peak discharges obtained from HEC-1 simulations. Because energy, or friction, losses are intimately tied to Manning's equation for open channel flow, stream cross sections are required at locations where changes in discharge, slope, shape, and channel roughness occur. Here Manning's equation for English units is given by

$$Q = (1.49/n)AR^{2/3}S^{1/2} \text{ and } R = A/P, \qquad \text{(IV-1)}$$

where

Q = discharge (cfs),
A = area perpendicular to flow (ft^2),
R = hydraulic radius (ft),
P = wetted perimeter (ft),
S = energy slope (ft/ft), and
n = boundary surface roughness coefficient (dimensionless).

Water-surface profile calculations in HEC-2 begin at the downstream cross section for subcritical flow conditions and at the upstream cross section for supercritical flow. The same data rearranged into a different order are used to make separate model simulations for each of these flow conditions. Model calculations sequentially progress either upstream (subcritical) or downstream (supercritical) from cross section to cross section. At bridge crossings and culverts, where flow hydraulics are more complex, momentum and other equations may be used to compute water-surface elevation changes. This model also takes into account losses resulting from contraction and expansion and from eddies, bends, and tributary junctions when adjustments are made to friction loss coefficients.

The HEC-2 computational methodology is based on the following flow conditions: (1) gradually varied steady flow, (2) one-dimensional flow with horizontal-velocity distribution corrections, (3) small channel slopes not exceeding ~10%, (4) a constant average friction slope between adjacent cross sections, and (5) rigid stream channel cross-sectional boundaries. Some hydraulic flow conditions that violate one or more of the above include (1) rapid downstream flood wave propagation resulting from dam breaching; (2) significant backwater effects caused by downstream boundary conditions such as tidal flows or tributary inflow effects; and (3) wide, flat floodplains that cause hydraulic flow disparities between the main channel and overbank areas.

It is not uncommon for many channel segments to have mixed flow regimes that are characterized by subcritical and supercritical flows that occur simultaneously in different parts of a single cross section or in adjacent cross sections. In these situations, the HEC-2 model must be run for both subcritical and supercritical flow conditions to determine the complete water-surface profile. However, most natural stream channels, including most mountain stream channels, exhibit subcritical flow conditions over the major part of their watercourses. The HEC-2 model is undoubtedly the most widely used technique for defining complex water-surface profiles. Many of the HEC-2 modeling capabilities are not described in detail here. Instead, the interested reader is referred to the HEC-2 user's manual (US Army COE 1982) for a complete description. Finally, it should be noted that the September 1988 FORTRAN version of the HEC-2 model, published as PROHEC2 (March 1990 release with modification 03) by Dodson & Associates, Inc., of Houston, Texas, was used in this study.

B. Stream Channel Geometries

In the HEC-2 model, flow-regime boundary geometry is defined by cross sections and the reach distances between adjacent cross sections. These cross sections, which characterize the flow capacity in the stream channel and overbank areas, are located at user-specified intervals along the stream channel. The model's accuracy can be increased if the distance between adjacent cross sections is reduced to allow more accurate computation of energy losses. Criteria for locating stream cross sections are given by Hoggan (1989, p. 335). According to him, reach lengths should not exceed 0.5 mi for wide floodplains having slopes <2 ft/mi, 1800 ft for slopes <3 ft/mi and 1200 ft for slopes >3 ft/mi. Obviously, there is a tradeoff between stream channel surveying costs and model accuracy requirements. Throughout this study, a constant reach distance of 250 ft was used to describe the geometries of all stream channel cross sections contained within the DOE-LANL complex. This implies literally hundreds of cross sections. However, costly field surveys were kept to a minimum because the majority of this topographic detail was automatically extracted from LANL's AUTOGIS-MOSS graphic information package.

There are actually three separate reach lengths required for each stream's cross section in HEC-2: one for the channel and one for each of the overbanks HEC-2 uses a discharge-weighted, average reach length between adjacent cross sections and multiplies this distance by the average conveyance in energy loss calculations. Individual channel thalweg lengths were fixed at 250-ft intervals within MOSS. Actual stream channel locations were digitized from USGS 7.5 min base maps and read into MOSS. Cross-sections were uniquely located by MOSS using topographic profiles and geographically referenced coordinates. Because of thalweg meandering, it was assumed that both of the overbank reach lengths between all cross sections of stream channels within the DOE-LANL complex were fixed at 300 ft.

Once individual cross sections had been located within MOSS, a perpendicular topographic profile could be defined for the stream channel. Topographic data for cross sections were extracted from

Table 13. Typical HEC-2 input file identification scheme. See HEC-2 user manual for complete listing of all options.

Data Category	Record Identification	Data Description
Job Initialization	T1	Job ID Title Card (required)
	T2	Job ID Title Card (required)
	T3	Job ID Title Card (required)
	C	Comment Card for Documentation
Job Output Print Control	J1	Start Conditions and Options
	J2	Print Control and Options
	J3	Special Summary Printout Options
	J5	Special Summary Printout Options
	J6	Specify Friction Loss Equations
Job Control and Input Data Cards	QT	Peak Discharge Table from HEC-1
	NC	Manning cross-section n values
	NH	Horizontal Distance n values
	NV	Vertical Distance n values
	X1	Cross-Section ID and Data
	X3	Ineffective Flow Areas
	GR	Elevation and Station Data
	SB	Special Bridge Data Card
	BT	Bridge Geometry Data
	EJ	End of Run in Multiple Run Job
End of Job	ER	Required to End Job

MOSS and the cross sections were sequentially grouped. These groupings were then formatted within MOSS into an ASCII file, consistent with HEC-2 input data requirements, and exported to 5.25-in. magnetic disks for subsequent use. The actual input data file structure for all watersheds is very similar (see Disk No. 2). Table 13 illustrates a generic file structure for a typical subcritical flow simulation. All X1, X3, and GR data cards were generated in this fashion for each HEC-2 watershed simulation. These data files still required additional input parameters, as described below. Separate file configurations for both supercritical and subcritical conditions were generated for each stream channel, but only the latter configurations are given on Disk No. 2.

In spite of this procedure, the MOSS 2- and 10-ft topographic contour data were insufficient to hydraulically define main channel flows in HEC-2. Hence, an idealization of the main stream channel configuration was subsequently inserted into each profile as described below. These trapezoid-shaped channel inserts had a maximum top width of 4 ft, a maximum bottom width of 2 ft, and a fixed depth of 0.3 ft. Channel capacities for this idealized configuration do not exceed 1% of the specified 100-yr peak discharge for any section. Typically, this main channel insert is located near each profile midpoint and accounts for hydraulic variations in Manning's n-values between the main channel and overbank areas. In addition, this insert shape is characteristic of main channel geometries throughout Pajarito Plateau watersheds. Inclusion of these channel inserts proved satisfactory, and they were included in all subsequent HEC-2 simulations.

C. Channel Friction Losses

In HEC-2, the well-known Bernoulli equation is used to determine depths of flow between adjacent stream channel cross sections.

$$WL_2 + a_2V_2^2/2g = WL_1 + a_1V_1^2/2g + h_e$$

$$h_e = LS_f + C(a_2V_2^2/2g - a_1V_1^2/2g) \, . \qquad (IV\text{-}2)$$

where

WL_1 and WL_2 = upstream and downstream water elevations(ft),
V_1 and V_2 = upstream and downstream mean velocities (ft/s),
a_1 and a_2 = upstream and downstream velocity coefficients,
g = acceleration due to gravity (ft/sec^2),
h_e = energy head loss (ft),
L = discharge-weighted reach length (ft),
S_f = reach friction slope (dimensionless),
C = expansion or contraction loss coefficient, and
Q = peak discharge ($Q = VA$) at a section (cfs).

In general, the coefficient a in Equation (IV-2) is determined from the relationship

$$a = [(QV^2)_1 + (QV^2)_2 + \ldots + (QV^2)_k]/(QV^2)_{ave} \, . \qquad (IV\text{-}3)$$

where Q is discharge and V is velocity. The terms in the numerator represent complex velocity distribution effects in k localized subareas within a particular cross section, and the terms in the denominator represent average flow conditions in the entire cross section. Manning's Equation (IV-1) is initially used to determine how much of the cross-section's flow is in the channel and how much is in the overbank areas. Values for subarea conveyance (i.e., all terms in Manning's equation except the friction slope term) are therefore known if the friction (or energy) slope is assumed to be constant throughout a given cross section. The particular flow distribution between subareas at a given cross section is determined by multiplying the subarea conveyance and the square root of the friction slope. Localized mean velocities are determined by dividing subarea discharges by cross-section flow areas. Friction slope is approximated by the stream channel bottom slope because the water surface is assumed to parallel it in uniform flow. Hence, all of the terms in Equations (IV-2) and (IV-3) are known, except for a starting water-surface elevation at either the downstream (subcritical) or upstream (supercritical) end of the watercourse, expansion or contraction coefficients, Manning's roughness factor n, and stream discharge. All of these parameters are specified as input data. Therefore, iteration by the standard-step method is used to solve Equations (IV-2) and (IV-3) for WL at all remaining cross sections.

The iteration process mentioned above is terminated when successive, unknown water-surface elevation values at a given cross section converge to within 0.01 ft. Once this elevation has been determined, additional checks are performed to see if this value is above the critical depth for a subcritical simulation or below the critical depth for a supercritical run. If these checks indicate otherwise, then the critical depth is assumed to exist at that section, and a message is printed by the program. The simulation then continues with the next unknown water surface elevation at an adjacent cross section until the last profile is reached. It should be emphasized that the computed depths are constrained to be equal to or greater than the critical depth for subcritical simulations and equal to or less than the critical depth for supercritical runs. Hence, one must run separate simulations for subcritical and supercritical flows. On occasion, changes in velocity heads between adjacent cross sections are too great for the HEC-2 model to accurately determine the energy gradient. For these situations, the HEC-2 model will automatically insert up to three interpolated cross sections between two adjacent user-specified cross sections so that the velocity head difference does not exceed a user-specified amount, typically 0.5 ft. By comparing velocity heads at successive cross sections the program also determines whether or not the flow is contracting or expanding. The program then applies the appropriate coefficient based on this determination.

It should be noted that only the subcritical flow depths at individual cross sections were used to map 100-yr floodplains in this study. While computed water surface elevations at individual cross sections occasionally corresponded to the critical depth at that section, supercritical depths were not subsequently calculated. The reason for this is straightforward: if a critical depth were found at a given section during a subcritical run, we would know that the actual flow depth must be equal to or less than the critical depth. Thus, the actual floodplain width will be equal to or less than the computed width at that cross-section. In other words, using a computed floodplain width from a subcritical flow simulation that corresponds to the critical depth is conservative, and the mapped floodplain is depicted as being wider than it would actually be While this procedure is conservative if we are defining floodplain widths, it should not be used for any design calculations that utilize flow velocities (i.e., embankment stability or sediment transport calculations). The reason for this statement is that supercritical flow velocities are equal to or larger than the computed critical flow velocities.

Finally, it should be mentioned that friction losses can be simulated four different ways in the HEC-2 model. The actual technique employed can be user specified or automatically selected by the HEC-2 model according to certain selection criteria. These criteria are based on flow conditions (i.e., either subcritical or supercritical) and a comparison of friction slope changes between cross sections. All of these loss equations produce similar results when short reach lengths are used. Because relatively short reach lengths were used in this study, the automatic selection option was used here. In addition, a constant Manning's n-value of 0.09 was used in all stream channels, and an n-value of 0.12 was used for all overbank areas. The first value (Hoggan 1989, pp. 327-330) corresponds to a tabulated n-value for natural mountainous channels with deep pools, large boulders, and heavy timber stands. The second value corresponds to floodplains with heavy timber stands that have flood stages below branches, little undergrowth, and downed trees. All of these conditions are typical throughout the LANL complex. If localized conditions indicated a change was warranted, individual cross sections were occasionally given different n-values from those listed above. However, standard tabulated n-values were still employed. Perhaps it should also be noted that the effects of channel improvements were also simulated in Los Alamos Canyon near TA-41 and TA-2. These improvements are not discussed in detail here. Instead the interested reader is directed to the input data file for this site. Standard expansion/contraction coefficients of 0.2 and 0.4 were also used throughout this study for all watersheds.

D. Starting Water-Surface Elevations

The starting water-surface elevation must be specified for all HEC-2 simulations. This single parameter is the most difficult starting condition to determine. Typically, one of three techniques is used to establish this value. These techniques are (1) obtaining a known water-surface elevation from a channel rating curve or from direct field observations, (2) estimating a normal flow depth from slope/area computations, and (3) assuming the critical depth. In this study, a combination of the second and third techniques was used, as explained below.

Initially, the critical depth at the down stream cross section was assumed for all HEC-2 subcritical watershed simulations. These initial simulations yielded a preliminary estimate for the energy grade line passing through the first three cross sections located immediately adjacent to the starting cross-section. Hence, refined estimates for the starting water-surface elevation and the slope of the energy grade line at the downstream cross-section were obtained through linear interpolation. These values were specified on the J1 data card in the HEC-2 input data file, as seen in Table 13. A second simulation was then performed. The program computed a discharge for uniform flow conditions and compared it to the user-specified discharge. If there was a significant difference in these two discharge values, the program adjusted the starting water-surface elevation and computed a new normal discharge. This procedure was repeated until the normal discharge agreed to within 1% of the user-specified discharge. The final computed water-surface elevation was then taken as the starting elevation. It should be noted that this elevation was still constrained to be equal to or greater than the critical depth for subcritical flow simulations and equal to or less than critical depth for supercritical runs. Once this starting depth was fixed, the remaining cross section's flow depths were computed as previously described. This technique worked for most stream channels. Occasionally, however, it was not successful and the critical depth was finally assumed to be the starting water-surface elevation for that watershed.

The above procedure implies that natural channels meet uniform flow conditions, that the energy grade is approximately equal to the average channel-bed slope, and that water surface elevations can be obtained from a normal-depth calculation. These assumptions are probably conservative in most natural channels. This procedure will even accommodate situations where floodplain topography is relatively uneven. It should be pointed out, however, that floodplains at the eastern boundary of the DOE-LANL complex are relatively broad and flat. Hence the above procedure proved more than adequate.

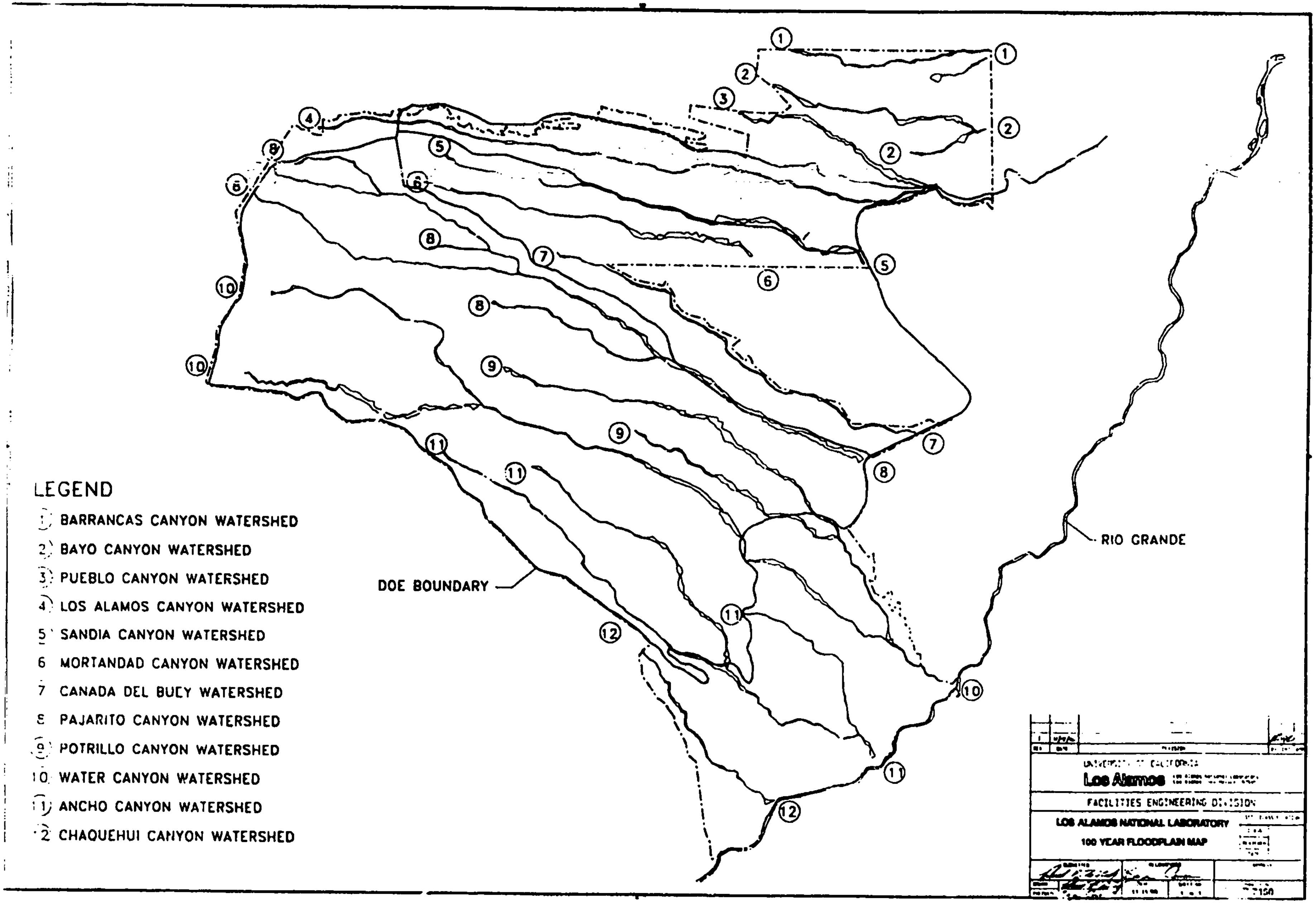
E. Computed Water-Surface Profiles

The above procedures were used to map all 100-yr floodplain boundaries within the DOE-LANL complex. The HEC-2-computed water-surface elevation at each channel section, along with the left and right channel stations where this water surface intersects the ground, were then read back into the MOSS system. This information was then transformed within MOSS to determine New Mexico state plane geographically referenced coordinates that uniquely define the 100-yr floodpool at each cross section. These paired coordinates were linked together as MOSS area features to identify each watershed floodplain. In this particular application, 11 separate elongated watersheds traverse LANL lands. with individual channels ranging up to 9 mi in length. The 100-yr floodplain was defined on each channel segment at 250 ft intervals. Figure 13 shows these preliminary floodplain boundaries. Detailed, 1:4800-scale maps with 10-ft topographic contours and floodplains were then generated by MOSS. Floodplain boundaries were defined by connecting 100-yr floodpool elevations located at channel cross sections with straight lines. These lines were then hand smoothed, using elevation contours and floodplain widths for control. This procedure was followed because occasional small stream bends that are located between cross sections periodically meander outside the original straight-line floodplain boundaries. Finally these smoothed boundaries were digitized within the MOSS system to define floodplains within the DOE-LANL facility. These floodplain boundary maps are intended to supplement this report and are maintained on file in LANL's ENG-2 group office.

Using the information provided in the appendixes of this report, the interested reader can replicate these floodplain maps. In addition, other important hydraulic data may be generated for individual watershed cross sections. This additional information is not included here because it is quite extensive. Using the HEC-1 and HEC-2 input data files listed on Disks 1 and 2, however, the reader can simply run individual watershed simulations and generate the data as required. When the HEC-2 model is used, approximately 40 different variables may be printed for each crosssection. Standard model output includes an input data file listing, detailed output for each section, summary tables, and line printer profile plots. This output can be directed to the computer screen for review, or it may be saved to an output file for later use. The user can tailor the majority of this output for specific needs. The HEC-2 input data files listed on Disk No. 2 of this report have been customized for limited output. The interested reader should be aware that these input data files may be modified to generate as much or a little information as he or she desires.

V. FINAL FLOODPLAIN DEFINITIONS

The procedure described in Appendix A initially defined floodplains in the MOSS system using the MOSS polygon feature to connect 100-yr floodpool elevations with straight lines. Ten-ft topographic contours were overlaid onto these floodplain boundaries and 25 maps were plotted at a scale


LEGEND
1 BARRANCAS CANYON WATERSHED
2 BAYO CANYON WATERSHED
3 PUEBLO CANYON WATERSHED
4 LOS ALAMOS CANYON WATERSHED
5 SANDIA CANYON WATERSHED
6 MORTANDAD CANYON WATERSHED
7 CANADA DEL BUEY WATERSHED
8 PAJARITO CANYON WATERSHED
9 POTRILLO CANYON WATERSHED
10 WATER CANYON WATERSHED
11 ANCHO CANYON WATERSHED
12 CHAQUEHUI CANYON WATERSHED
DOE BOUNDARY
RIO GRANDE
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
UNIVERSITY OF CALIFORNIA
Los Alamos
FACILITIES ENGINEERING DIVISION
LOS ALAMOS NATIONAL LABORATORY
100 YEAR FLOODPLAIN MAP
7150

of 1:4800. These maps provide coverage of the entire DOE-LANL complex. However, meandering stream channels occasionally crossed these straight line floodplain boundaries at locations midway between HEC-2-defined stream cross sections. In order to correct this apparent inconsistency, the following additional mapping procedure was employed. For control, topographic contours and HEC-2 floodplain elevations and widths were used to hand smooth all straight-line floodplain boundaries between individual stream cross sections. It should be emphasized that original HEC-2 floodplain elevations and widths were not altered during this process. These new floodplain curvilinear boundaries were finally digitized and remain in MOSS system files (ENG-2 File Number R-7160).

VI. CONCLUSIONS

The following general conclusions can be stated:

1. The HEC procedures described here are recognized by the EPA, the COE, and others as being a state-of-the-art technique for mapping 100-yr floodplain boundaries in ungaged watersheds. This report documents this mapping procedure and, along with the floodplain boundary maps (ENG-2 File Number R-7160), is intended to satisfy the RCRA/HSWA permit condition requiring complete floodplain definitions within the DOE-LANL facility boundary.

2. The 100-yr floodplain boundary maps referenced herein are only intended to satisfy the RCRA/HSWA permit condition. Other applications of these maps at specific locations within the LANL complex may warrant additional site-specific field investigations and modified HEC-1 and HEC-2 simulations. For example, individual road culverts were often omitted in HEC-2 simulations. Furthermore, only MOSS 10-ft-contour-interval data were available for a large percentage of the DOE-LANL complex. These areas tended to be located within the canyons on the eastern facility boundary but are certainly not confined to these perimeter regions. Hence, additional floodplain mapping efforts would be desirable for specific waste disposal site investigations or any safety-related site evaluations.

3. LANL's AUTOGIS-MOSS graphic information system was used in this study to define all HEC-2 stream channel profiles at 250-ft intervals. These data were automatically extracted from the MOSS system in an ASCII format compatible with HEC-2 input data requirements. Approximately 65% of the DOE-LANL facility has 2-ft-topographic contour interval data, and 35% has 10-ft contour interval data. Once the HEC-2 model had been used to define floodplain boundaries for all major watershed channels, this information was read back into the MOSS system. Floodplains were initially defined by connecting 100-yr floodpool elevations with straight lines. These boundaries were then hand smoothed using topographic contours and floodplain widths and elevations for control. All original HEC-2 floodplain widths and elevations at stream cross sections were retained during this procedure. These new floodplain line boundaries were finally digitized and remain in MOSS system files.

4. Continuous rainfall-runoff simulation models calibrated to specific gaged watersheds may represent an improvement over the HEC-1 and HEC-2 modeling procedures employed in this study. However, extensions of these research models to ungaged watersheds have not been adequately documented in the literature. Criticism of the event-simulation approach centers on the design assumption that rainfall of a given frequency results in runoff of the same frequency. However, this issue was not addressed in this work. Until the dynamic nature of the rainfall-runoff process is better understood, HEC-1 and HEC-2 represent the best available technology for the definition of floodplains in ungaged watersheds.

5. The SCS curve number method was used in this study to predict runoff. The relative merits of this empirical approach versus physically based representations have been extensively debated in the literature. However, Loague and Freeze (1985) have shown that physically based models

generally do not predict runoff any better than relatively simple approaches. Furthermore, the SCS method has the advantage that future changes in watershed land-use patterns can be easily simulated.

6. The procedure outlined here is flexible in that other return-period intervals for the floodplain could also be computed. For example, other storm durations and return-period intervals could be used to define other floodplain boundaries. In addition, the Nuclear Regulatory Commission does not use a return-period definition for their floodplain elevation studies. Instead, they typically specify that the probable maximum flood (PMF) be used to define the floodplain. With minor changes, the input data files contained in this report could also be used to define the PMF floodplain boundary.

7. Flood flow studies described here can provide information for sediment transport simulations that use the HEC-6 model (US Army COE, 1977). For example, once floodplain elevations have been specified for a given canyon, one can associate a peak hydrograph with that floodplain definition. One could extend this hydrograph peak association to include a mean channel stream velocity for each individual canyon location. These mean velocities would obviously have future implications for sediment transport potential.

VII. ACKNOWLEDGMENTS

This study could not have been completed without the assistance of several key individuals. George Fuller, MOSS systems programer with Autometric, Inc., Lakewood, Colorado, developed the software to extract topographic data from LANL's AUTOGIS-MOSS graphical information system and to insert floodplain elevations back into this system. George Tauxe, Associate Professor, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, Oklahoma, participated in invaluable discussions concerning HEC-1 and HEC-2 input file structure and parameter evaluation techniques. Brian Comer, Section Leader with ENG-2 at LANL, provided MOSS system support and plotted all floodplain maps. Finally, Molly Magnuson, hydrologist with the US Army COE in Albuquerque, New Mexico, provided valuable information on various topics including the application of Snyder's unit hydrograph theory to New Mexico streams. These individuals' contributions to this effort are greatly appreciated.

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APPENDIX A
AUTOGIS-MOSS SYSTEM

I. Extraction of MOSS Topographic Data

This section documents the procedure used to automatically extract topographic data from LANL's graphic information system for use in HEC-2 simulations. Readers who are not familiar with the procedure can skip to the next section without loss in continuity. The MOSS source codes used to extract this topographic data are given on Disk No. 1 in this report.

In order to transport MOSS topographic data to an HEC-2 input data file, a series of user-activated steps was performed on existing and derived MOSS data sets. This procedure is briefly described below. The source programs to extract this information were developed by Autometric, Inc., under contract to LANL, and are maintained on the AUTOGIS-MOSS system by ENG-2. Section III of this appendix contains a complete source listing of these programs. Note that these programs require other MOSS utility features, which are described in the MOSS users manual. The sample MOSS session listed below details all necessary interactive user responses in a typical MOSS data-extraction process. Note that MOSS computer terminal user responses are in bold letters.

MOSS data extraction requirements for HEC-2 utilization include topographic contour files and stream channel location files. The contour files already existed in the LANL's MOSS system and were originally obtained from aerial photography transformations. The stream channel location files were created for this floodplain study by digitizing major stream channel locations from USGS 7.5-min topographic maps and geographically referencing them to known bench marks. These location files, which indicate the stream center line and have the drainage basin name as their subject, were entered into MOSS in a line format. The MOSS file name containing these stream channel location files is DRAINS. The MOSS topographic data are also in a line format and have numerical subjects that equal their represented elevations. These topographic data are actually included on a series of MOSS contour maps having either 2- or 10-ft contour intervals. However, in order to obtain complete topographic coverage for a given watershed, use of both the 2- and 10-ft-contour-interval maps was required. This resulted in a total number of contour maps that exceeded the maximum allowable active IDs within MOSS. Hence, the 2- and 10-ft-contour-interval maps of the entire LANL complex were merged into a series of single maps each containing both 2- and 10-ft-contour-interval data. The resultant MOSS master project file, LANLM, contains these merged contour maps. This master project file, which represents the resultant file from the MOSS utility entiled MAPIDX, also contains the maps, DRAINS and LANLINDEX, as described below. Using the stream location file, DRAINS, and the contour map index, LANLINDEX, it is a straightforward process to identify those merged MOSS contour maps that may be required for a given watershed application.

For each watershed draining the LANL complex, a file was constructed that defined the map names containing the topographic data This file was then used with the MOSS SELECT command using the FROM option. For more information concerning the SELECT FROM command, see the MOSS user's manual or use the MOSS HELP SELECT command. A list of the SELECT FROM files used in this study includes

FORALAMOS
FORINDEX
FORPOTRIL
FORANCHO
FORMORTAN
FORPUBELO
FORBAYO
FORPAJAR0
FORSANDIA
FORCANADA
FORPAJAR1
FORWATER
FORCHAQUE
FORPAJAR2

The file, USESPLAT, was also used with the SELECT FROM command, as illustrated by the following example:

```
SELECT FROM FORALAMOS USESPLAT
```

The content of USESPLAT is the single ASCII character "*", which is the MOSS wild card character that matches any character string, and is similar to the AOS/VS "+" template.

There is also a set of files that were used in conjunction with the special FORINDEX file. This file contains all the contour map minimum-bounding rectangles from the map index for each watershed. A list of the SELECT FROM FORINDEX files includes

FALAX FANCX FBAYX FCANX FCHAX
FMORX FPAJX0 FPAJX1 FPAJX2 FPOTX
FPUEX FSANX FWATX

These files replace the USESPLAT file mentioned above, as illustrated by the following example:

SELECT FROM FORINDEX FALAX

The result of the SELECT FROM command produces from 1 to 38 active data sets from the merged contour maps, as detailed below. For a given watershed, the stream location file will be a single active ID within MOSS, while the corresponding contour data files will be several active IDs. It is possible that more than one ID will represent the stream location data and also that only one active ID will represent the topographic data. Derived data sets include extracted topographic profiles at stream cross sections and the imported maps produced from these profiles.

Once the stream location and contour data sets have been selected and placed into the active table as IDs, then the MOSS window must be set to include all of these data sets. The first stage of the data-extraction process (AHEC2) can now begin. The MOSS source code for the program AHEC2 is contained on Disk No. 1 in this report. The output from AHEC2 is imported into MOSS and visually checked. Once verified, the second stage of the data-extraction process (EXHEC2) can be initiated. The MOSS source code for the program EXHEC2 is also contained on Disk No. 1. The following abbreviated MOSS dialog provides an example of program execution. It is procedurally correct and represents either MOSS commands or programmatic dialog.

FREE ALL - Start with a clean active table

The selection of contour maps required for a given data-extraction application is best determined through the use of the utility procedure MAPIDX. This procedure will make an index map based on the minimum-bounding rectangular coverages of the contour maps. After plotting the stream location data and the index map, the user must select each contour map that contains topographic data of interest. Results of this utility execution were saved in the file named LANLINDEX. In this example, two files are used to select the contour data. The first file is called FORALAMOS and contains a list of the contour maps that could possibly contain topographic data on Los Alamos that may be of interest. The second file is called USESPLAT and contains the single wild-card character "*" to match all strings. For more information about these two files, see the MOSS users manual under SELECT FROM.

SELect DRAINAGE SUbject *ALAMOS* -- Select stream location files for this run.

SELect FROM FORALAMOS USESPLAT — Select all contour maps around the Los Alamos Canyon drainage basin.

WIndow ALL — Set window to entire geographic region

AHEC2 — Invoke the AHEC2 program

At this point, the automated topographic data-extraction and file generator program, AHEC2, will prompt the user to give definable parameters before execution. In this example, there is one active ID for the stream location data, and there are 38 IDs for the contour data. The default vertical height and horizontal distance values are displayed by MOSS in square brackets. These default values are selected by hitting NEWLINE or CARRIAGE RETURN; alternate values may also be entered by the user. Here the vertical height refers to the maximum elevation difference between the stream channel's highest and lowest elevation points within the profile. Horizontal distance refers to the distance along the profile located perpendicular to either side of the stream channel. The extracted topographic data will be constrained to these limits

Enter active IDs to use for DRAINAGES. 1

Enter active IDs to use for CONTOURS. 2 TH 39

Enter vertical HEIGHT from bottom of DRAINAGE [25] Carriage Return — 25 ft of vertical relief will be included in the stream channel profile.

Enter horizontal DISTANCE between PROFILES [250]. Carriage Return -- the total profile width will be 250 ft on either side of the stream channel, giving a total profile distance of 500 ft.

The program could spend time determining which way is downhill or uphill. However, it is much simpler for the user to point with the graphics cursor to indicate drainage direction. After entering these points, the program will pause until the user enters an additional CARRIAGE RETURN, indicating that everything is correct and ready to proceed.

Point to DOWNHILL end of DRAINAGE — use graphics cursor. Point to UPHILL end of DRAINAGE -- use graphics cursor. HIT NEWLINE TO CONTINUE.

Two MOSS IMPORT files are now generated. The first is a 2-D file containing profile lines at 250-ft intervals along the stream location file, and the second is a corresponding 3-D file containing data about stream channel cross sections. These 2-D profile lines were generated and used by AHEC2 to construct the 3-D cross sections by intersecting each 2-D profile line with all topographic contour data. The 3-D cross sections are a series of (X,Y,Z) triplets with the (x,y) portion defined by the intersection of a specific 2-D profile line with a specific contour line. The subject of the contour line determines the z portion, or elevation, of the triplet. The (x,z) data pairs in each triplet correspond to the station and elevation locations required on GR data cards in the HEC-2 input data file, as shown in Table 13. Note that this information is actually exported as (z,x) during the formatting process. It should also be noted that the first x value on a given cross section profile line is assigned a relative value of zero, and all remaining x values are referenced to this origin. This procedure is identical to that in the HEC-2 model as one looks downstream at the profile line. Hence, the first x position is located at the extreme left of the profile line as one looks downstream. The MOSS file maintains the original geographically referenced coordinate positions of all x values, but this information is not used in the HEC-2 model.

Results from the AHEC2 program are now imported to MOSS. The 2-D profile lines are not essential but allow the user to determine where contour data are missing. The 2-D profile lines are imported as a Type 2 map (line) with the input file name PROFILE.2D. The 3-D cross sections are critical to the second and final stage of the extraction process and must be imported to MOSS. The input file which is named PRCFILE.3D, is imported as a Type 12 map [(x,y,z) line map]. Once imported, the resultant Type 12 map must be selected.

The selected ID will be used in the EXHEC2 program command procedure. This portion of the extraction program will take the (x,y,z) data pairs and reformat them into (z,x) pairs as required by the HEC-2 model input structure on GR cards, as seen in Table 13. The EXHEC2 program will ask the user to give an active data set for reformatting, a resultant target file name, and information on whether the file is for a subcritical or supercritical HEC-2 input data file. The program will not overwrite an existing file name unless specified by the user. The example given below illustrates this procedure.

EXHec2 -- Invoke the HEC-2 reformatter program option.
Enter active data set ID to reformat to HEC-2 standard

```
[CR = Exit]
40
For LOSALA3D , EXHEC2 file name [EXHEC2]
SUBLOSALA     File name for Los Alamos Canyon subcritical run
Is this a SUB- or SUPER- critical run (SUB/SUPER) [SUB]
SUB
NUMBER OF DATA ITEMS TO BE REFORMATTED = 184
EXECUTING. PLEASE WAIT...
```

This example uses active ID 40 as the 3-D map of the cross section. The HEC-2 input data file will be called SUBLOSALA and is a subcritical run. The program informs the user that 184 3-D cross sections will be in the final HEC-2 input data file. SUBLOSALA is subsequently transferred to a 5.25-in. magnetic disk in ASCII format for direct use by the HEC-2 program. This data transfer procedure only creates T1, T2, X1, X3, and GR cards, as seen in Table 13. Hence, the HEC-2 user must still enter additional input parameters into this file before a successful HEC-2 simulation can be performed.

II. Insertion of Floodplain Boundaries

This section documents the procedure used to automatically reinsert HEC-2 floodplain boundaries into LANL's graphic information system for final map generation. Readers who are not familiar with the procedure can skip to the next section without loss in continuity. The MOSS source code used to reinsert HEC-2 flood plan boundaries into MOSS is listed on Disk No. 1 in this report.

Once the HEC-2 simulation has been successfully completed for a given stream channel segment, the HEC-2 floodplain boundaries must be read back into MOSS. This procedure is described below. Before this second transfer, however, the HEC-2 user must tailor model output for this floodplain boundary-insertion process. Required HEC-2 output includes the cross section's number; the left- and right-station numbers where the computed water surface intersects the ground; and the computed water-surface elevation, floodplain top width, floodplain depth, and cross-sectional flow area. The HEC-2 output file name must correspond to an original MOSS data-extraction output file, and all cross-section numbers must be identical in both files. The MOSS insertion program uses this HEC-2 file name and cross-section-numbering scheme to translate floodplain boundary data into unique, geographically referenced New Mexico state plain coordinates. The HEC-2 input data files listed on Disk No. 2 of this report are set up to provide the proper output to the MOSS insertion program. The first J3 card shown in Table 13 for each file actually provides this required output for the MOSS insertion procedure. All remaining HEC-2 output is extraneous and must be stripped from the HEC-2 output file. Hence, the HEC-2 user must edit output files with an independent file editor or word processor and remove all unnecessary information from an HEC-2 output file. This modified HEC-2 output file is now transferred back to the MOSS system in ASCII format on a 5.25-in magnetic disk. The actual insertion procedure can now begin.

To insert HEC-2 floodplain elevations into the MOSS system at known cross sections, a series of user-activated steps is performed on pre-existing MOSS data sets. These data sets correspond to the modified HEC-2 output files that were described above. The actual MOSS insertion procedure is briefly described here. The source program used to complete this task was developed by Autometric, Inc., under contract to LANL, and is maintained on the AUTOGIS-MOSS system by ENG-2; this source program is listed on Disk No. 1 of this report. The sample MOSS session listed below details all necessary interactive user responses in a typical floodplain boundary-insertion process.

FPHEC2 is the AUTOGIS-MOSS data-reformatting program, or command, and is the third and final step in the floodplain-modeling process. As mentioned above, this step makes use of data files generated from the actual HEC-2 modeling process and MOSS data files created with EXHEC2. The EXHEC2 command was described above; this command generates a 3-D floodplain MOSS import file. The FPHEC2 command format is specified as follows:

FPHec2 (active data set) (output file name).

The following dialog illustrates the use of this MOSS command in a typical floodplain data reinsertion procedure. Note that user responses are in bold letters.

```
Enter Command? FPHec2
Enter HEC-2 model results filename [CR = EXIT]
CANADA.DAT
Enter HEC-2 model Geo-Reference filename [CR = EXIT]
SUBCANA.REF
Enter resultant MOSS IMPORT floodplain name [CR = EXIT]
CANAFP.EXP
HEC RECORDS 158 REF RECORDS 156 CORDS 313
```

This example matches the HEC-2 output file named CANADA.DAT with the MOSS EXHEC2-generated Geo-Reference file named SUBCANA.REF and produces a MOSS import file named CANAFP.EXP. For each complete stream channel profile in both the MOSS Geo-Reference and the HEC-2 files, a pair of coordinate triplets (x,y,z) are generated. Once these triplets have been calculated, they are ordered by section number to form a 3-D polygon and written to the MOSS export file specified by the user. The HEC-2 output file must include each stream channel cross section number and the computed water-surface elevation. The Geo-Reference file's section numbers are checked to insure that they match. This is the only way to determine the actual New Mexico state plane ground coordinates that delineate the floodplain. The resulting MOSS import file should then be imported into MOSS as a Type 13 (3-D polygon) file. Finally, it should be noted that any HEC-2 sections that are not exactly matched with corresponding sections in the MOSS Geo-Reference file are not included in the final MOSS export file.

APPENDIX B
TABULATED HEC-1 INPUT PARAMETERS

GUAJE CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	34000	3277	55	8.18	9.64	11.30	3.38
2	24000	947	68	4.71	3.95	3.25	2.86
3	46000	3600	69	4.49	7.83	9.59	3.33
4	12750	355	75	3.33	2.78	2.13	1.69
5	9000	215	70	4.29	2.39	1.45	1.59

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
1/[2(1-x)] < CHECK < 1/(2x)
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	34000	7.3	1.29	5.14	5	1.03	1.29
2	24000	4.7	1.42	5.67	6	0.95	1.42
3	46000	6.6	1.93	7.72	8	0.97	1.93
4	12750	3.9	0.90	3.59	4	0.90	0.90
5	9000	3.7	0.68	2.73	3	0.91	0.68

BARRANCAS CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	25500	1245	72	3.89	4.88	1.79	2.42
2	7250	750	76	3.16	10.34	0.33	0.54
3	23000	1267	72	3.89	5.51	2.52	2.10
4	3250	365	76	3.16	11.23	0.21	0.27

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
$1/[2(1-x)] <$ CHECK $< 1/(2x)$
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	25500	5.2	1.36	5.42	5	1.08	1.36
2	7250	7.6	0.26	1.06	1	1.06	0.26
3	23000	5.6	1.15	4.60	5	0.92	1.15
4	3250	7.9	0.11	0.46	1	0.46	0.11

BAYO CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	16750	745	65	5.38	4.45	1.57	2.19
2	15250	535	74	3.51	3.51	1.16	1.79
3	12750	945	75	3.33	7.41	1.19	1.04

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$ x = 0.20
$Vel = 1.49R^{0.67}S^{0.5}/r$ (ft/sec) R(ft) = 2.00
K = L/(3600*Vel) (hours) n = 0.10
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT NMIN = 15.00
$1/[2(1-x)] < CHECK < 1/(2x)$ $1/[2(1-x)]$ = 0.63
CHECK = (60K)/(NMIN*NSTPS) $1/(2x)$ = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	16750	5.0	0.93	3.73	4	0.93	0.93
2	15250	4.4	0.96	3.82	4	0.96	0.96
3	12750	6.4	0.55	2.20	2	1.10	0.55

PUEBLO CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	15000	1930	56	7.86	12.87	2.24	1.48
2	24000	694	65	5.38	2.89	[illegible].61	3.62
3	14000	246	74	3.51	1.76	1.55	2.37

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
1/[2(1-x)] < CHECK < 1/(2x)
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	15000	8.5	0.49	1.96	2	0.98	0.49
2	24000	4.0	1.66	6.63	7	0.95	1.66
3	14000	3.1	1.24	4.96	5	0.99	1.24

LOS ALAMOS CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	20000	1943	52	9.23	9.72	6.33	2.37
2	10000	531	62	6.13	5.31	0.74	1.43
3	35000	846	68	4.71	2.42	3.31	4.95
4	11750	525	80	2.50	4.47	1.96	1.08
5	5000	100	75	3.33	2.00	0.77	0.95
6	7750	165	75	3.33	2.13	0.67	1.30

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
1/[2(1-x)] < CHECK < 1/(2x)
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	20000	7.4	0.75	3.01	3	1.00	0.75
2	10000	5.5	0.51	2.04	2	1.02	0.51
3	35000	3.7	2.64	10.57	11	0.96	2.64
4	11750	5.0	0.65	2.61	3	0.87	0.65
5	5000	3.3	0.42	1.66	2	0.83	0.42
6	7750	3.5	0.62	2.49	2	1.25	0.62

SANDIA CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)

L = CHANNEL LENGTH TO WATER DIVIDE (ft)

X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)

CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)

S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)

Y = 100X/L = GROSS WATERSHED SLOPE (%)

A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	36750	1000	68	4.71	2.72	2.65	4.85
2	11750	370	75	3.33	3.15	0.85	1.49
3	10000	300	76	3.16	3.00	1.32	1.31
4	9000	635	79	2.66	7.06	0.75	0.72

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$ x = 0.20

$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec) R(ft) = 2.00

K = L/(3600*Vel) (hours) n = 0.10

Nstps = 60K/NMIN (dimensionless)

NSTPS = INTEGER VALUE FOR Nstps

NMIN = MINUTES FROM CARD IT NMIN = 15.00

1/[2(1-x)] < CHECK < 1/(2x) 1/[2(1-x)] = 0.63

CHECK = (60K)/(NMIN*NSTPS) 1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	36750	3.9	2.62	10.46	10	1.05	2.62
2	11750	4.2	0.78	3.11	3	1.04	0.78
3	10000	4.1	0.68	2.71	3	0.90	0.68
4	9000	6.3	0.40	1.59	2	0.80	0.40

MORTANDAD CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	9000	390	65	5.38	4.33	0.55	1.35
2	10500	277	67	4.93	2.64	0.81	1.86
3	6000	125	72	3.89	2.08	0.36	1.17
4	12250	203	72	3.89	1.66	1.61	2.31
5	16000	465	72	3.89	2.91	0.86	2.16
6	13500	855	74	3.51	6.33	1.72	1.21

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
$K = L/(3600*Vel)$ (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
$1/[2(1-x)] <$ CHECK $< 1/(2x)$
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
$1/[2(1-x)]$ = 0.63
$1/(2x)$ = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	9000	4.9	0.51	2.03	2	1.02	0.51
2	10500	3.8	0.76	3.04	3	1.01	0.76
3	6000	3.4	0.49	1.95	2	0.98	0.49
4	12250	3.0	1.12	4.47	4	1.12	1.12
5	16000	4.0	1.10	4.41	4	1.10	1.10
6	13500	6.0	0.63	2.52	3	0.84	0.63

CANADA DEL BUEY

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
$S = 1000/CN - 10$ = POTENTIAL RAINFALL RETENTION (in)
$Y = 100X/L$ = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	29500	836	69	4.49	2.83	2.10	3.88
2	14750	1345	72	3.89	9.12	2.42	1.14

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$ — $x = 0.20$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec) — R(ft) = 2.00
$K = L/(3600*Vel)$ (hours) — n = 0.10
$Nstps = 60K/NMIN$ (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT — NMIN = 15.00
$1/[2(1-x)] < CHECK < 1/(2x)$ — $1/[2(1-x)]$ = 0.63
$CHECK = (60K)/(NMIN*NSTPS)$ — $1/(2x)$ = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	29500	4.0	2.06	8.23	8	1.03	2.06
2	14750	7.1	0.57	2.29	2	1.15	0.57

PAJARITO CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	17250	2711	52	9.23	15.72	1.99	1.66
2	18250	795	62	6.13	4.36	2.57	2.56
3	28250	2890	61	6.39	10.23	3.28	2.43
4	11000	205	70	4.29	1.86	0.67	2.12
5	19500	710	67	4.93	3.64	1.70	2.59
6	15000	225	72	3.89	1.50	1.15	2.86
7	15500	1050	73	3.70	6.77	2.24	1.34

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
1/[2(1-x)] < CHECK < 1/(2x)
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	17250	9.4	0.51	2.04	2	1.02	0.51
2	18250	4.9	1.03	4.11	4	1.03	1.03
3	28250	7.6	1.04	4.15	4	1.04	1.04
4	11000	3.2	0.95	3.78	4	0.95	0.95
5	19500	4.5	1.20	4.80	5	0.96	1.20
6	15000	2.9	1.44	5.75	6	0.96	1.44
7	15500	6.2	0.70	2.80	3	0.93	0.70

POTRILLO CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	28500	875	70	4.29	3.07	2.78	3.53
2	18000	630	71	4.08	3.50	1.03	2.23
3	9750	620	75	3.33	6.36	0.96	0.90

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
$1/[2(1-x)]$ < CHECK < $1/(2x)$
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	28500	4.1	1.91	7.64	8	0.95	1.91
2	18000	4.4	1.13	4.52	5	0.90	1.13
3	9750	6.0	0.45	1.82	2	0.91	0.45

WATER CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	18000	2305	54	8.52	12.81	4.07	1.81
2	17750	705	62	6.13	3.97	2.63	2.62
3	19000	405	72	3.89	2.13	1.42	2.90
4	13750	615	72	3.89	4.47	1.97	1.55
5	5000	405	77	2.99	8.10	0.32	0.44

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
$1/[2(1-x)] <$ CHECK $< 1/(2x)$
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	18000	8.5	0.59	2.36	2	1.18	0.59
2	17750	4.7	1.05	4.18	4	1.05	1.05
3	19000	3.5	1.53	6.11	6	1.02	1.53
4	13750	5.0	0.76	3.05	3	1.02	0.76
5	5000	6.7	0.21	0.83	1	0.83	0.21

CANON DE VALLE

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	22500	2756	53	8.87	12.25	2.33	2.26
2	7500	393	63	5.87	5.24	0.78	1.12
3	12500	477	64	5.63	3.82	1.17	1.92

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
1/[2(1-x)] < CHECK < 1/(2x)
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	22500	8.3	0.75	3.02	3	1.01	0.75
2	7500	5.4	0.38	1.54	2	0.77	0.38
3	12500	4.6	0.75	3.01	3	1.00	0.75

ANCHO CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	25750	1044	68	4.71	4.05	2.19	2.99
2	22000	1035	69	4.49	4.70	2.48	2.38
3	13000	1102	74	3.51	8.48	1.11	1.01
4	10000	688	75	3.33	6.88	1.04	0.89
5	2500	168	75	3.33	6.72	0.19	0.30

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$ — $x = 0.20$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec) — $R(ft) = 2.00$
K = L/(3600*Vel) (hours) — $n = 0.10$
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT — NMIN = 15.00
1/[2(1-x)] < CHECK < 1/(2x) — 1/[2(1-x)] = 0.63
CHECK = (60K)/(NMIN*NSTPS) — 1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	25750	4.8	1.50	6.01	6	1.00	1.50
2	22000	5.1	1.19	4.76	5	0.95	1.19
3	13000	6.9	0.52	2.10	2	1.05	0.52
4	10000	6.2	0.45	1.79	2	0.90	0.45
5	2500	6.1	0.11	0.45	1	0.45	0.11

CHAQUEHUI CANYON

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	16500	1292	73	3.70	7.83	1.50	1.31

HEC-1 INPUT DATA FILE PARAMETER CALCULATION
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec)
K = L/(3600*Vel) (hours)
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT
1/[2(1-x)] < CHECK < 1/(2x)
CHECK = (60K)/(NMIN*NSTPS)

x = 0.20
R(ft) = 2.00
n = 0.10
NMIN = 15.00
1/[2(1-x)] = 0.63
1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	16500	6.6	0.69	2.77	3	0.92	0.69

CANON DE LOS FRIJOLES

HEC-1 INPUT DATA FILE PARAMETER CALCULATION

SEE UD DATA CARD FOR SCS UNIT HYDROGRAPH LAG TIME DEFINITIONS

$T = (L^{0.8})(S+1)^{0.7}/(1900Y^{0.5})$ = SCS BASIN LAG TIME (hrs)
L = CHANNEL LENGTH TO WATER DIVIDE (ft)
X = BASIN ELEVATION CHANGE OVER LENGTH L (ft)
CN= SCS CURVE NUMBER FOR AMC-II MOISTURE CONDITIONS (dim)
S = 1000/CN - 10 = POTENTIAL RAINFALL RETENTION (in)
Y = 100X/L = GROSS WATERSHED SLOPE (%)
A = SUB-BASIN DRAINAGE AREA (sq. miles)

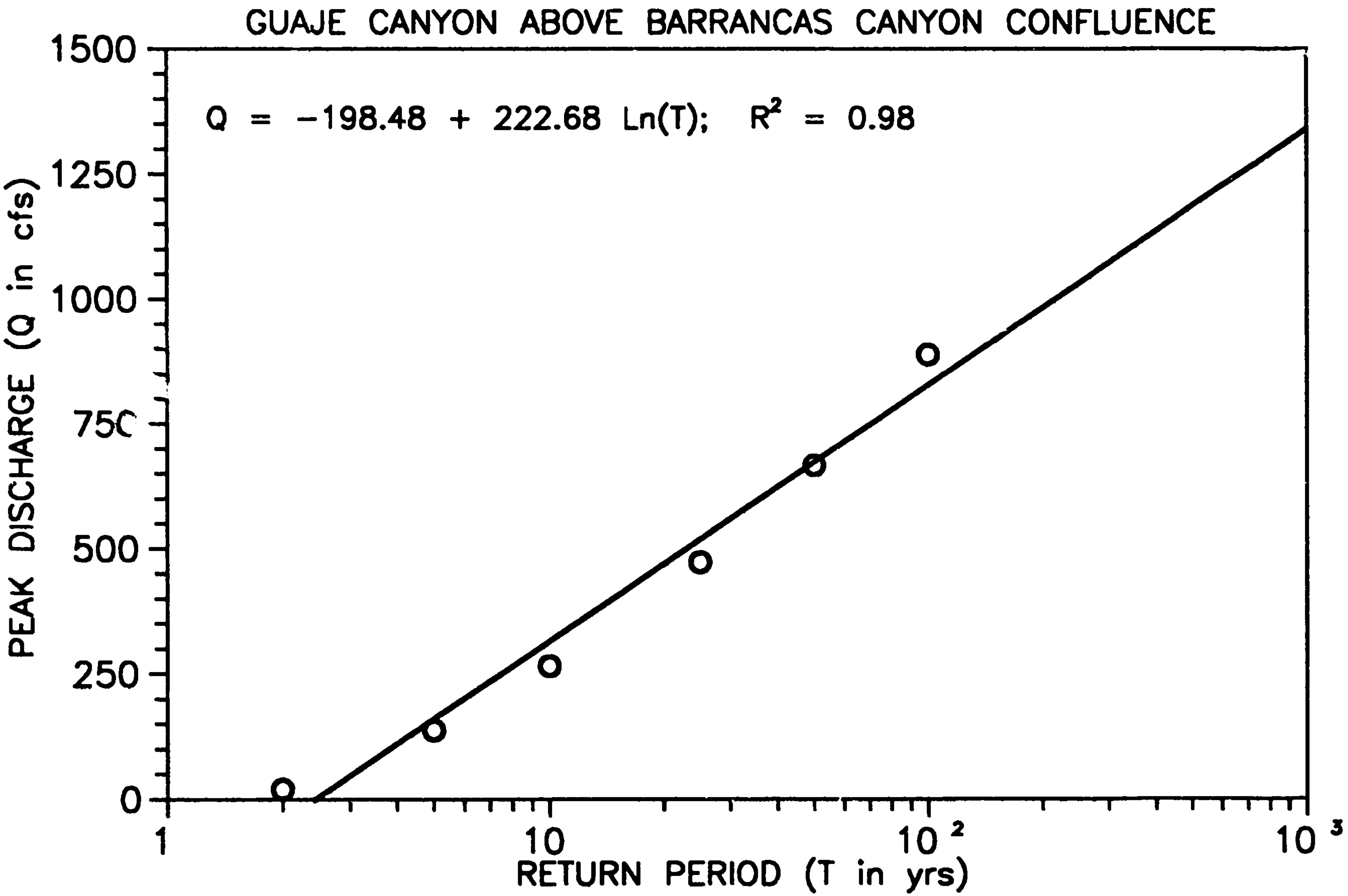
BASIN NO.	L (ft)	X (ft)	CN	S	Y (%)	A (sm)	T (hrs)
1	20200	2499	50	10.00	12.37	4.97	2.23
2	24400	1030	70	4.29	4.22	4.92	2.66
3	24000	633	68	4.71	2.64	8.13	3.50

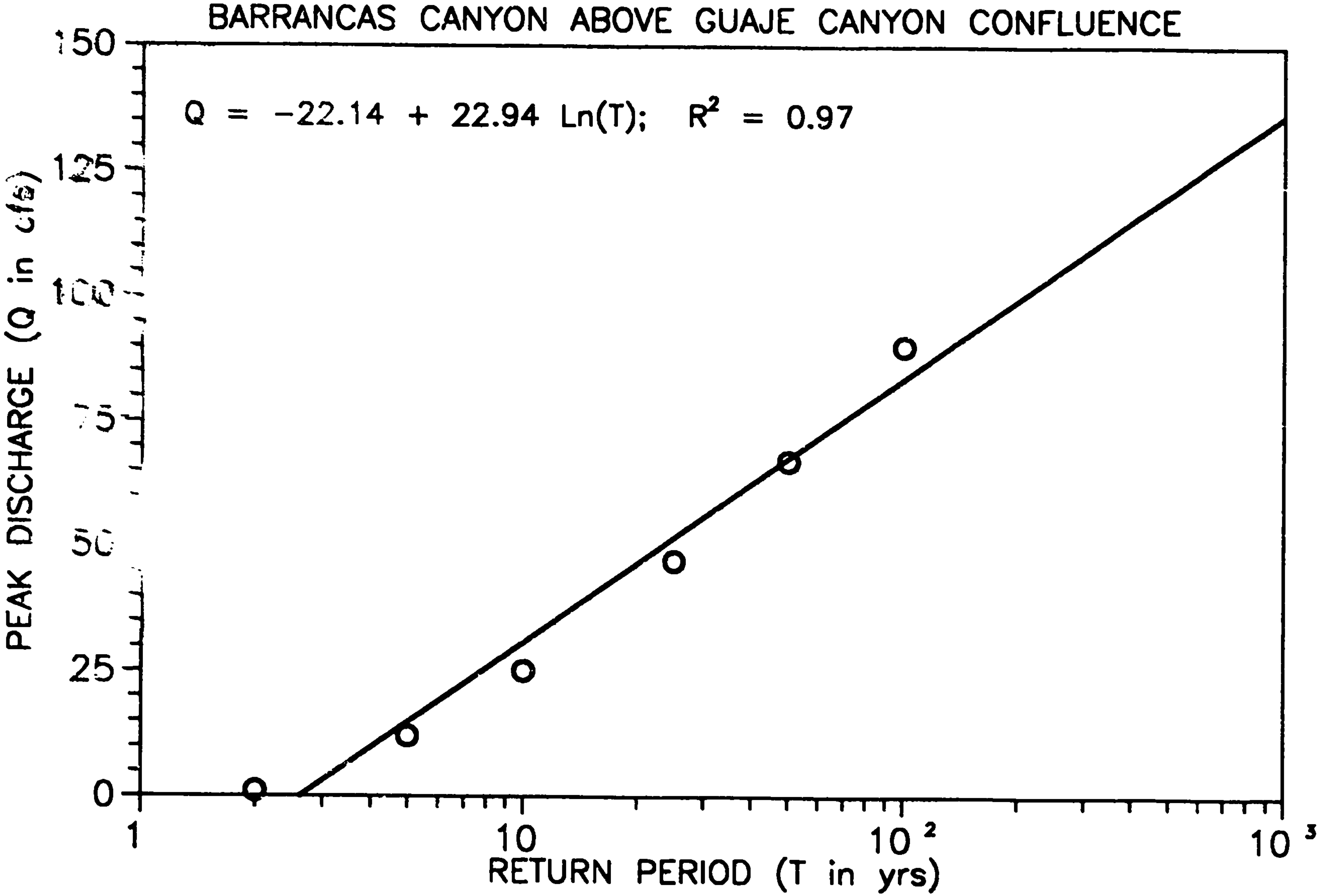
HEC-1 INPUT DATA FILE PARAMETER CALCULATION

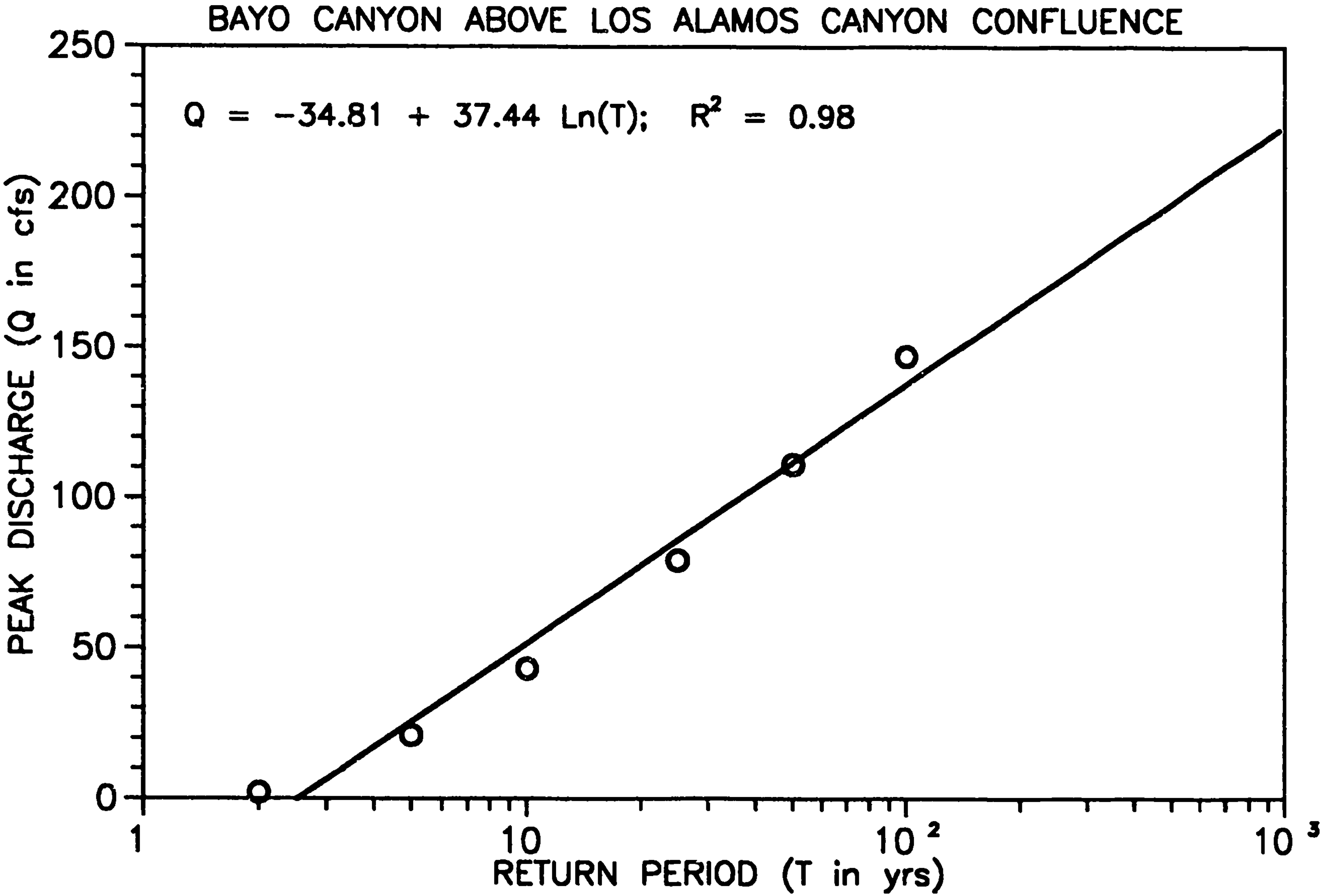
SEE RM DATA CARD FOR MUSKINGUM ROUTING PARAMETER DEFINITIONS

$0.1 < x < 0.3$ — x = 0.20
$Vel = 1.49R^{0.67}S^{0.5}/n$ (ft/sec) — R(ft) = 2.00
K = L/(3600*Vel) (hours) — n = 0.10
Nstps = 60K/NMIN (dimensionless)
NSTPS = INTEGER VALUE FOR Nstps
NMIN = MINUTES FROM CARD IT — NMIN = 15.00
$1/[2(1-x)] < \text{CHECK} < 1/(2x)$ — 1/[2(1-x)] = 0.63
CHECK = (60K)/(NMIN*NSTPS) — 1/(2x) = 2.50

BASIN NO.	L (ft)	Vel	K	Nstps	NSTPS	CHECK	AMSKK
1	20200	8.3	0.67	2.70	3	0.90	0.67
2	24400	4.9	1.39	5.58	6	0.93	1.39
3	24000	3.8	1.74	6.94	7	0.99	1.74

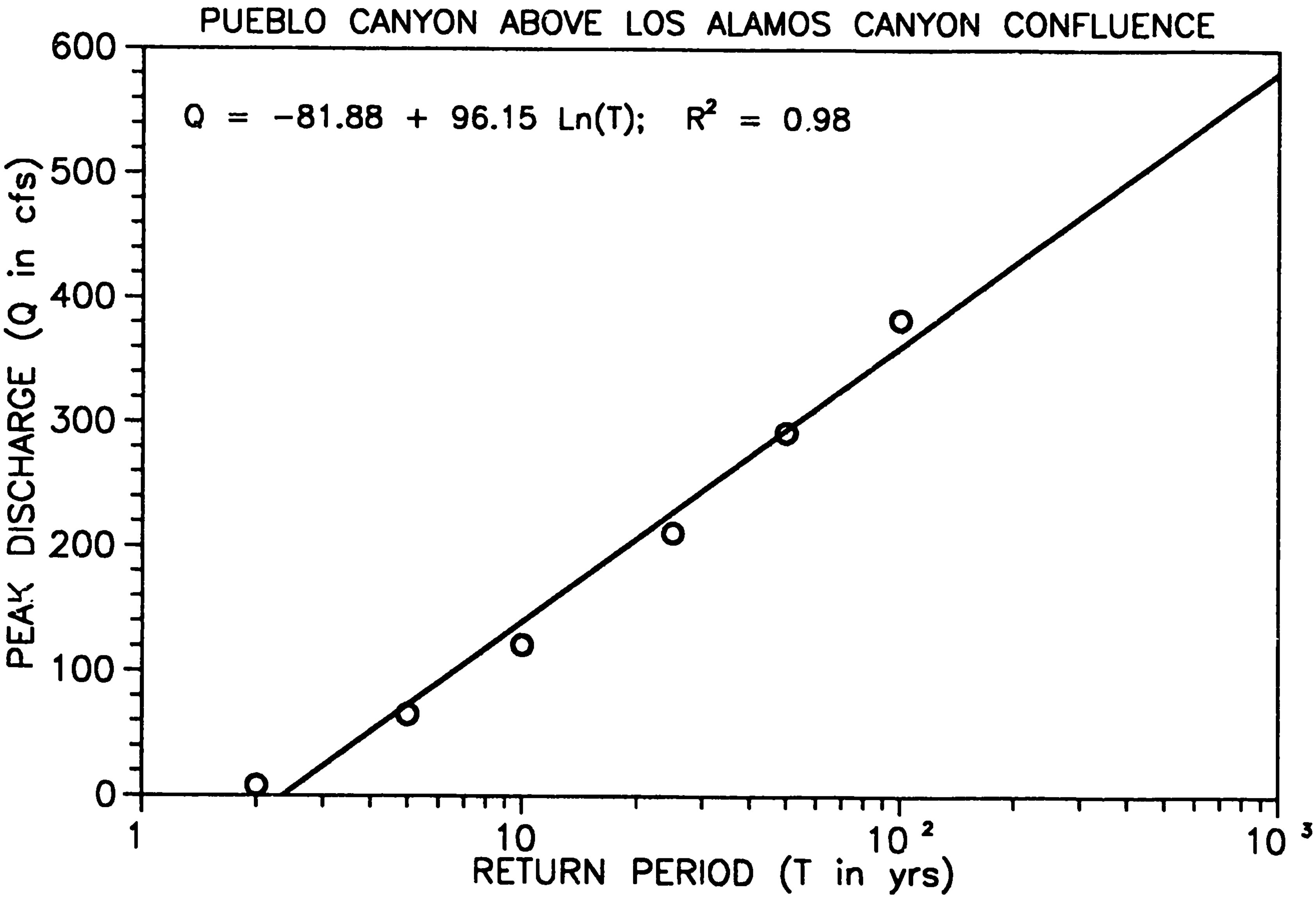

GUAJE CANYON ABOVE BARRANCAS CANYON CONFLUENCE
Q = −198.48 + 222.68 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
1500
1250
1000
750
500
250
0
RETURN PERIOD (T in yrs)
1
10
10 ²
10 ³

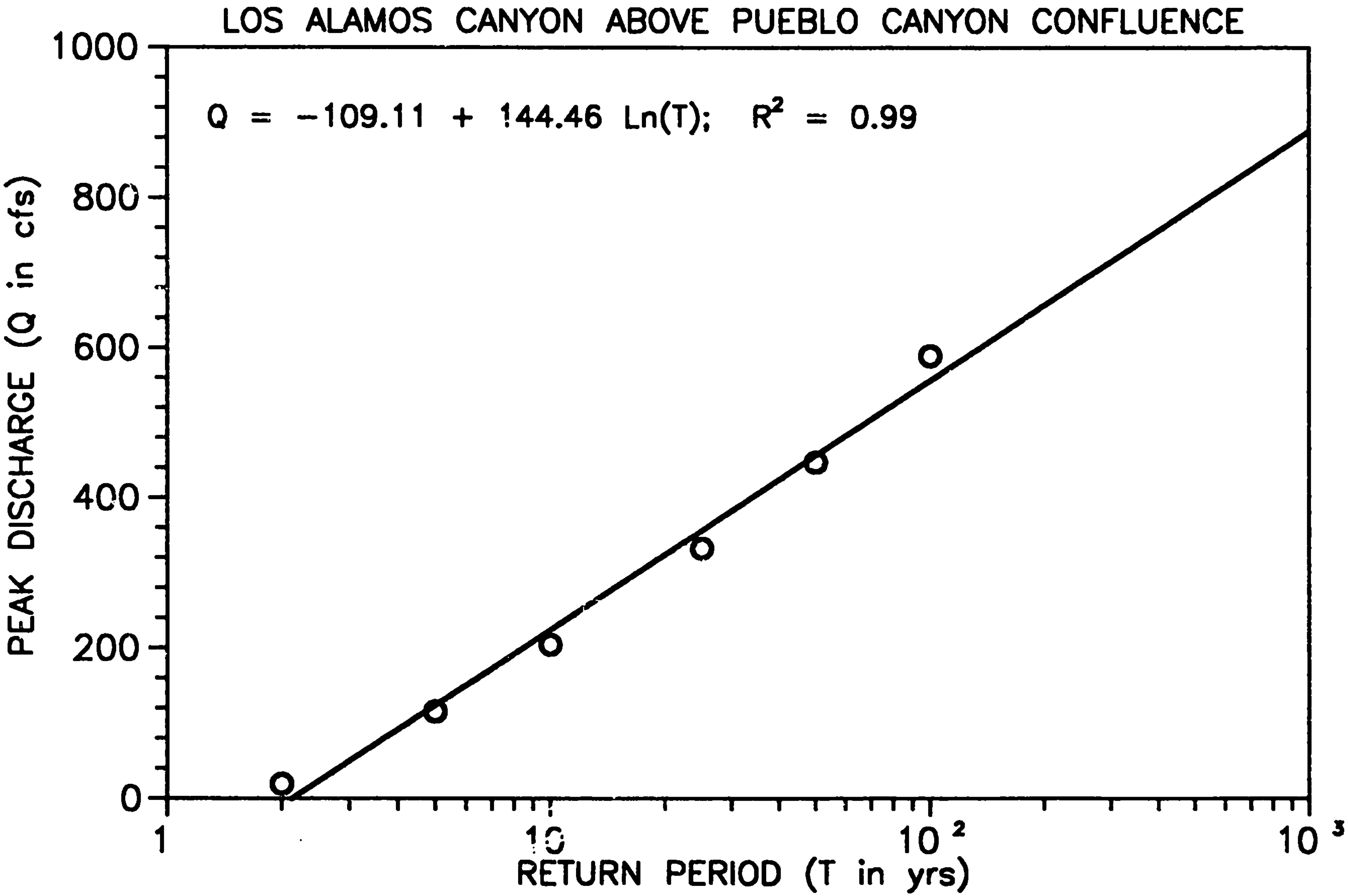

BARRANCAS CANYON ABOVE GUAJE CANYON CONFLUENCE
$Q = -22.14 + 22.94\ \mathrm{Ln}(T);\quad R^2 = 0.97$
PEAK DISCHARGE (Q in cfs)
150
125
100
75
50
25
0
RETURN PERIOD (T in yrs)
1
10
10^2
10^3

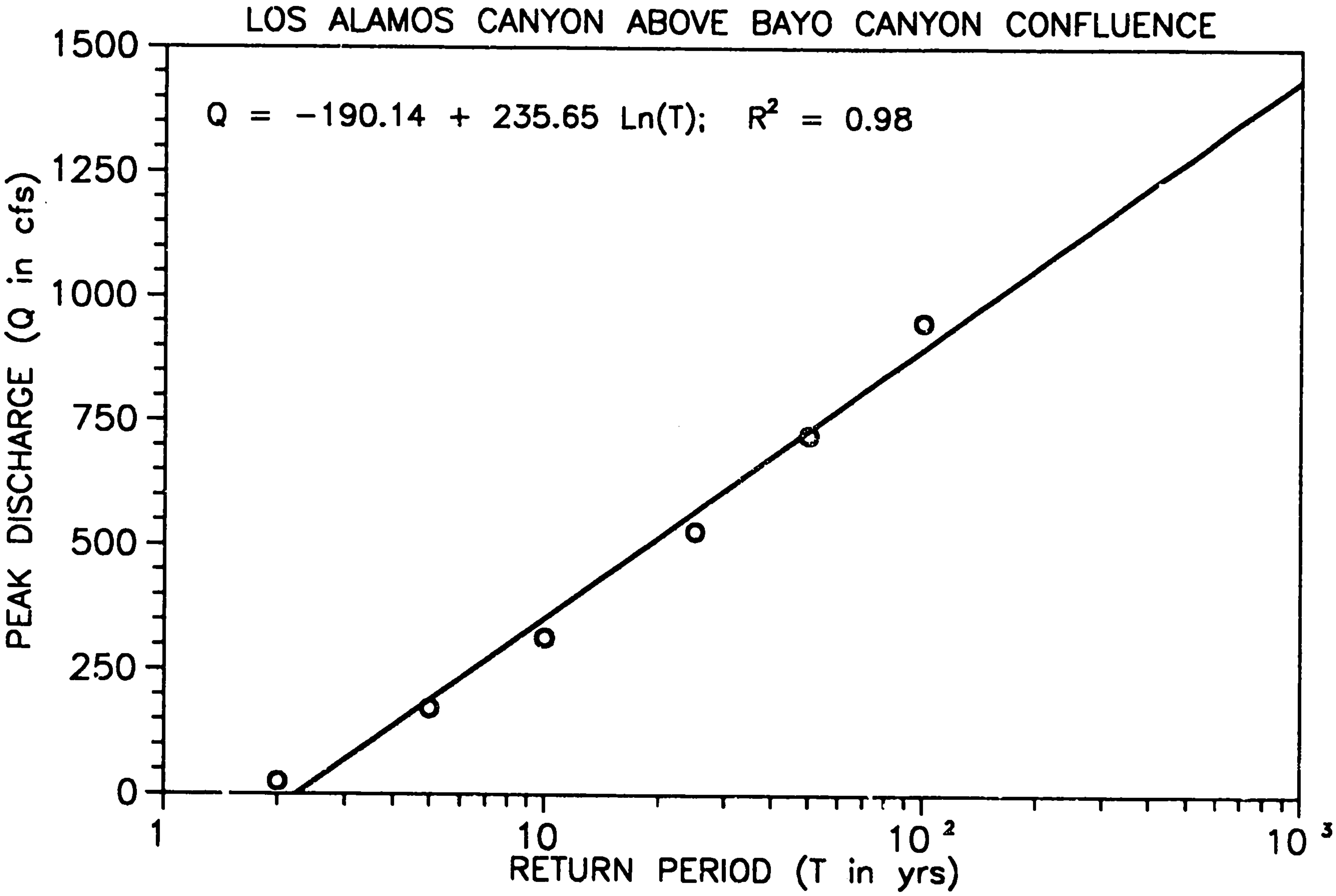


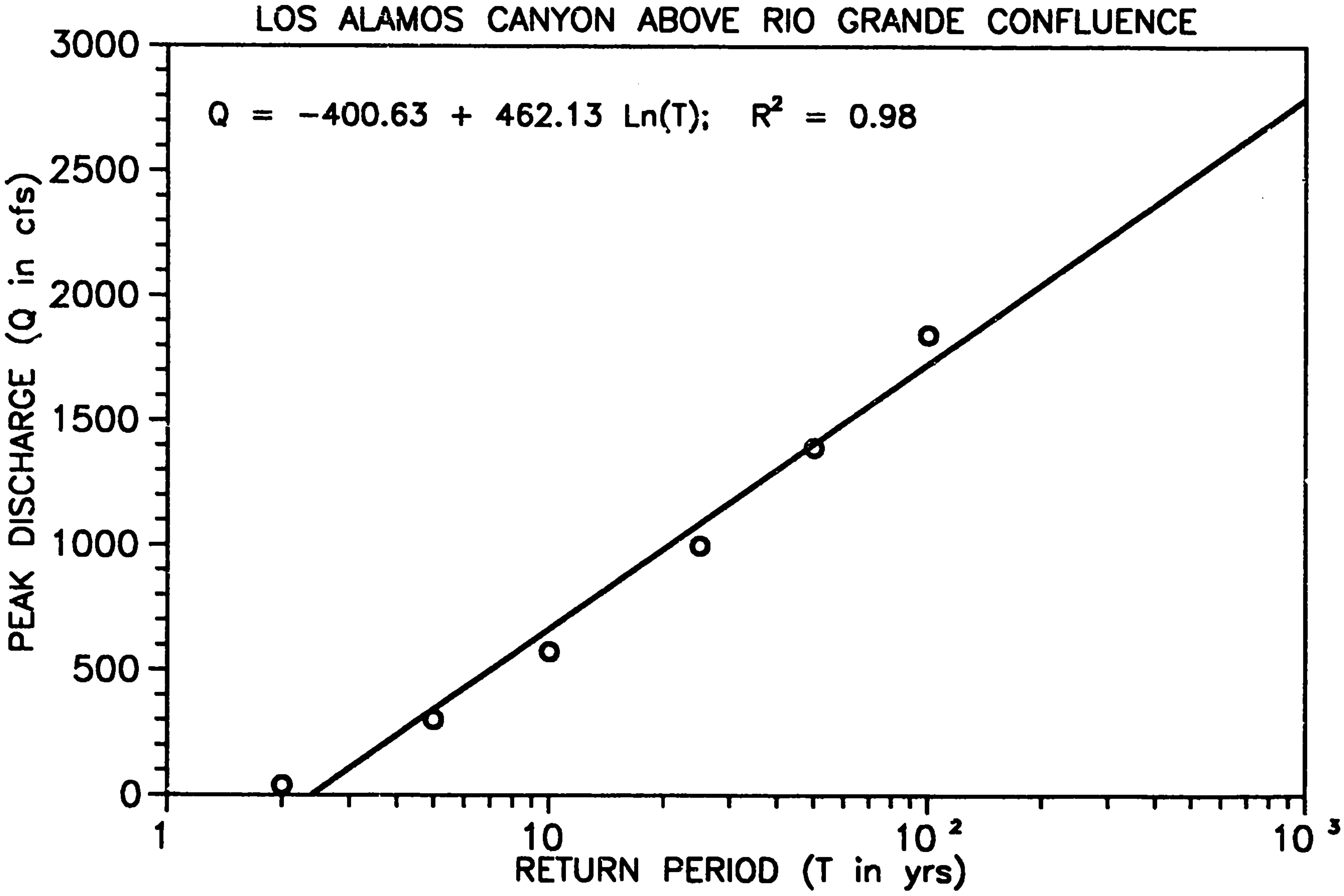
BAYO CANYON ABOVE LOS ALAMOS CANYON CONFLUENCE

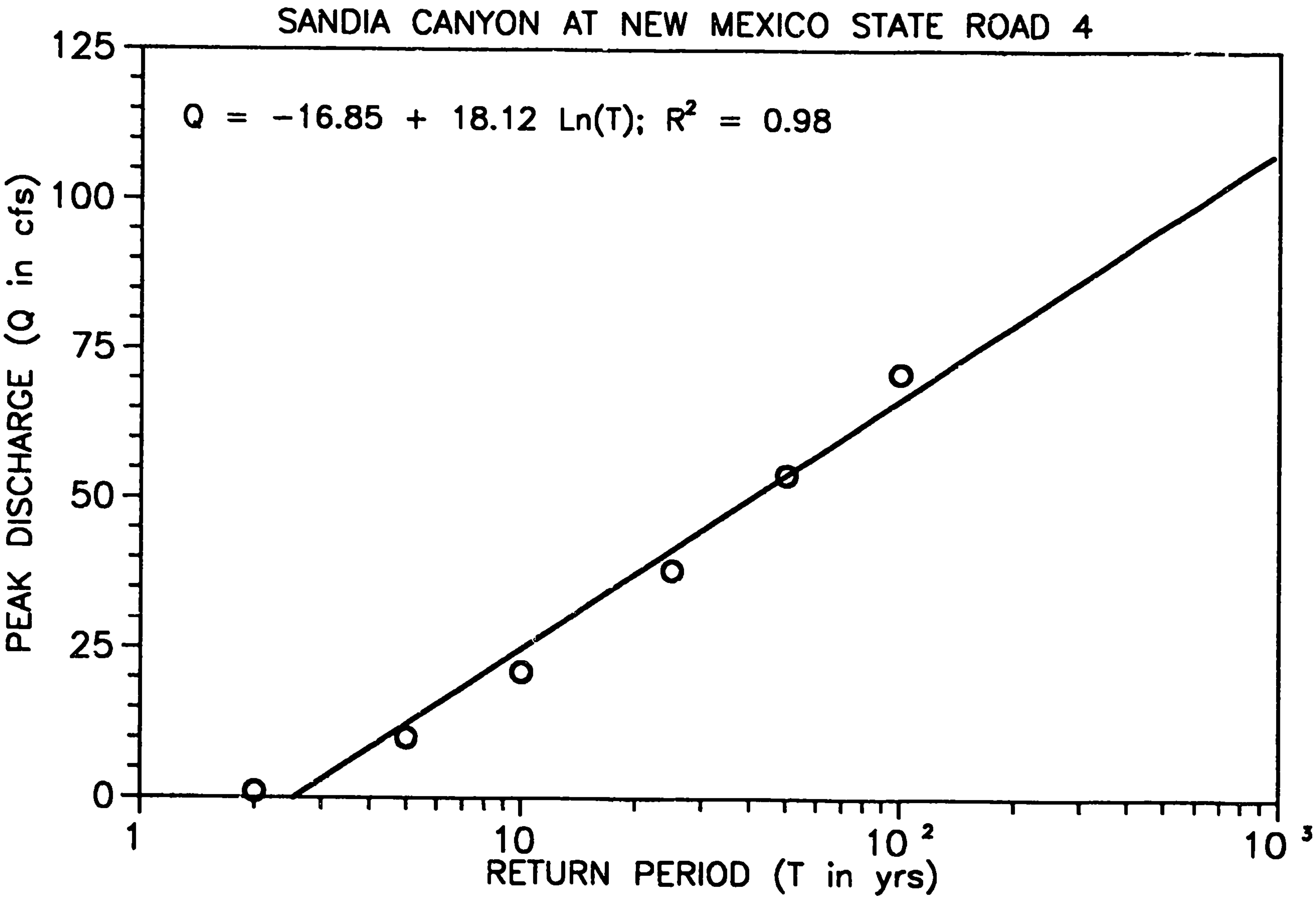
$Q = -34.81 + 37.44\ \mathrm{Ln}(T); \quad R^2 = 0.98$

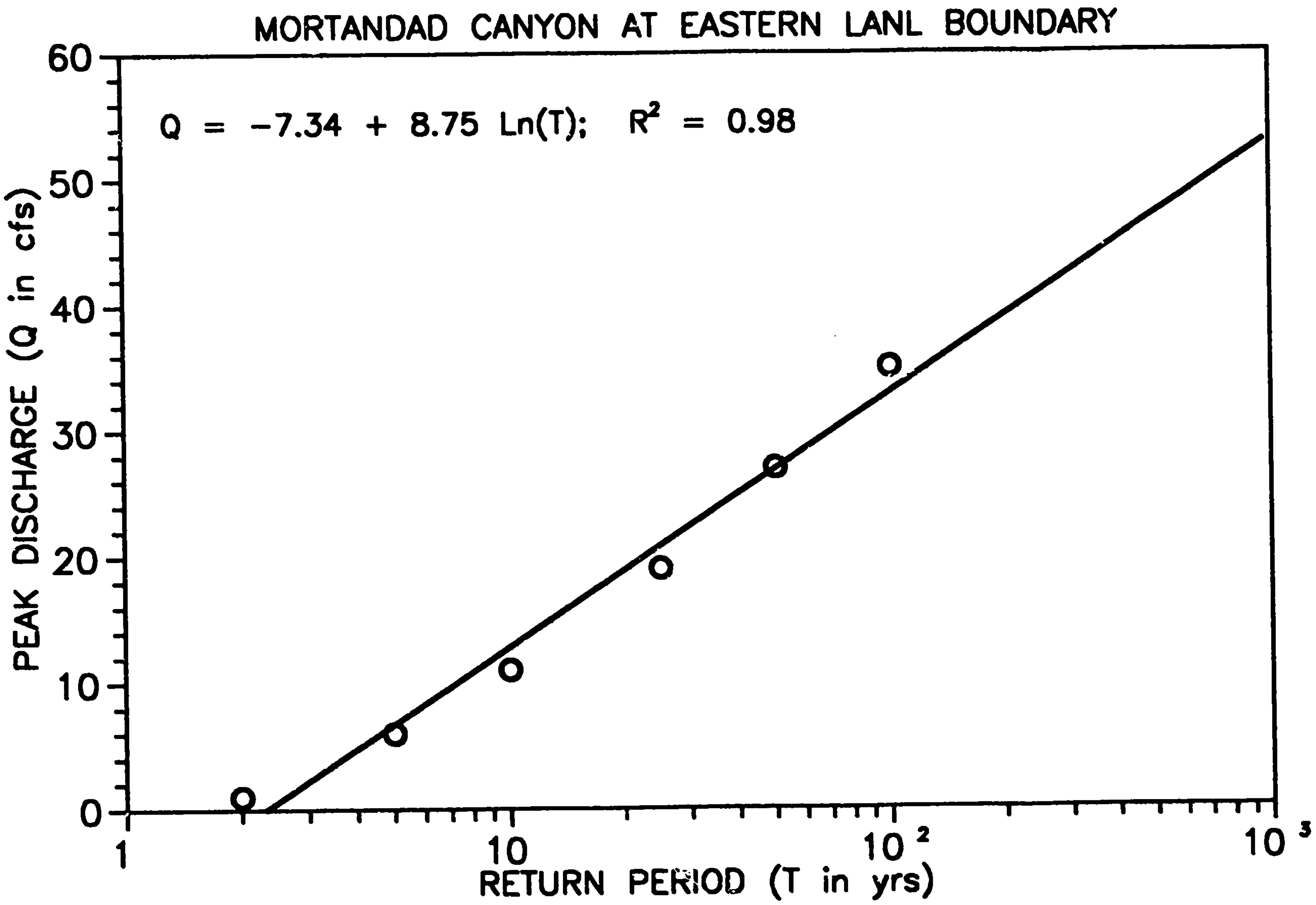

PUEBLO CANYON ABOVE LOS ALAMOS CANYON CONFLUENCE
$Q = -81.88 + 96.15 \, Ln(T); \quad R^2 = 0.98$
PEAK DISCHARGE (Q in cfs)
600
500
400
300
200
100
0
1
10
10^2
10^3
RETURN PERIOD (T in yrs)

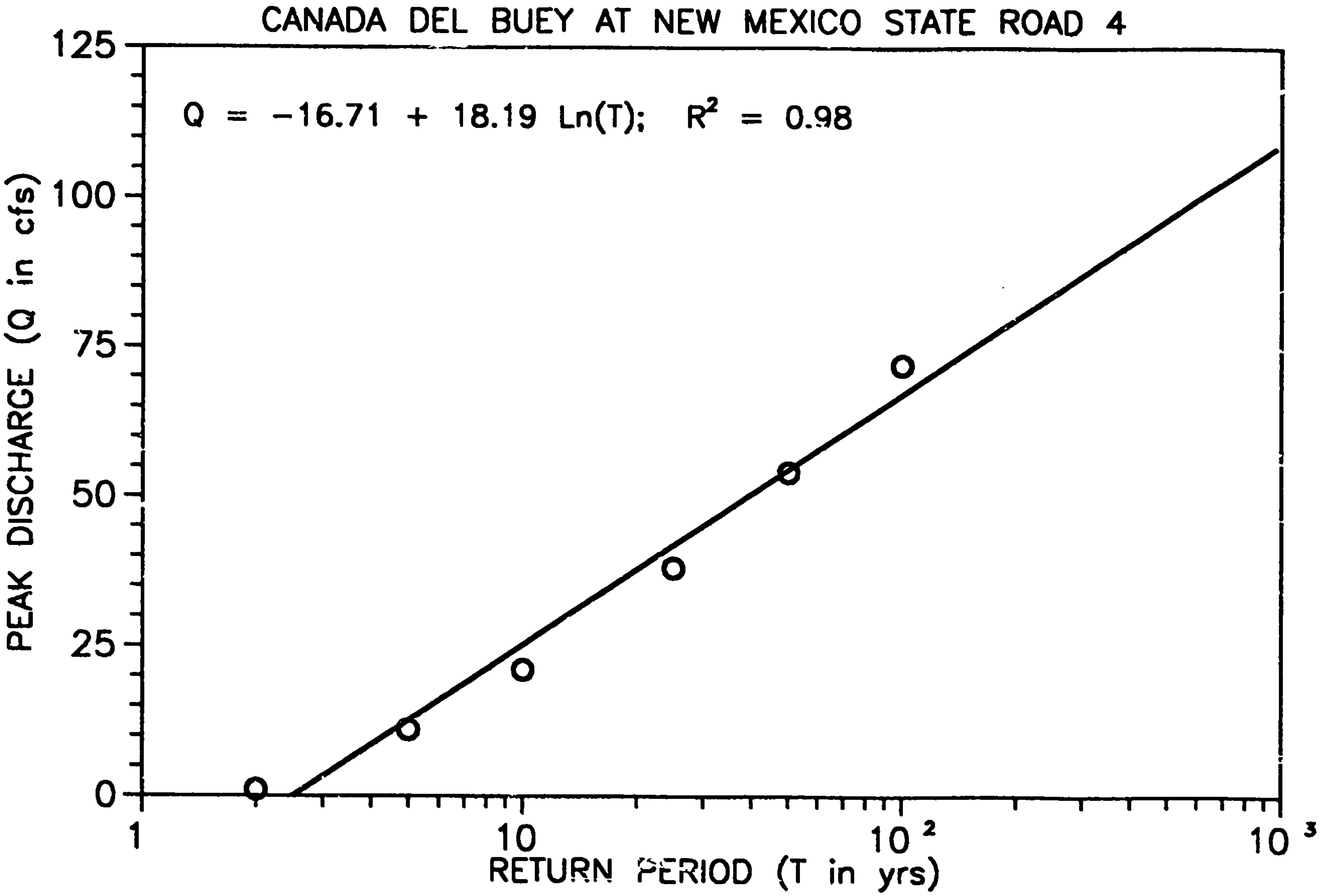

LOS ALAMOS CANYON ABOVE PUEBLO CANYON CONFLUENCE
Q = −109.11 + 144.46 Ln(T); R² = 0.99
PEAK DISCHARGE (Q in cfs)
1000
800
600
400
200
0
1
10
10 ²
10 ³
RETURN PERIOD (T in yrs)

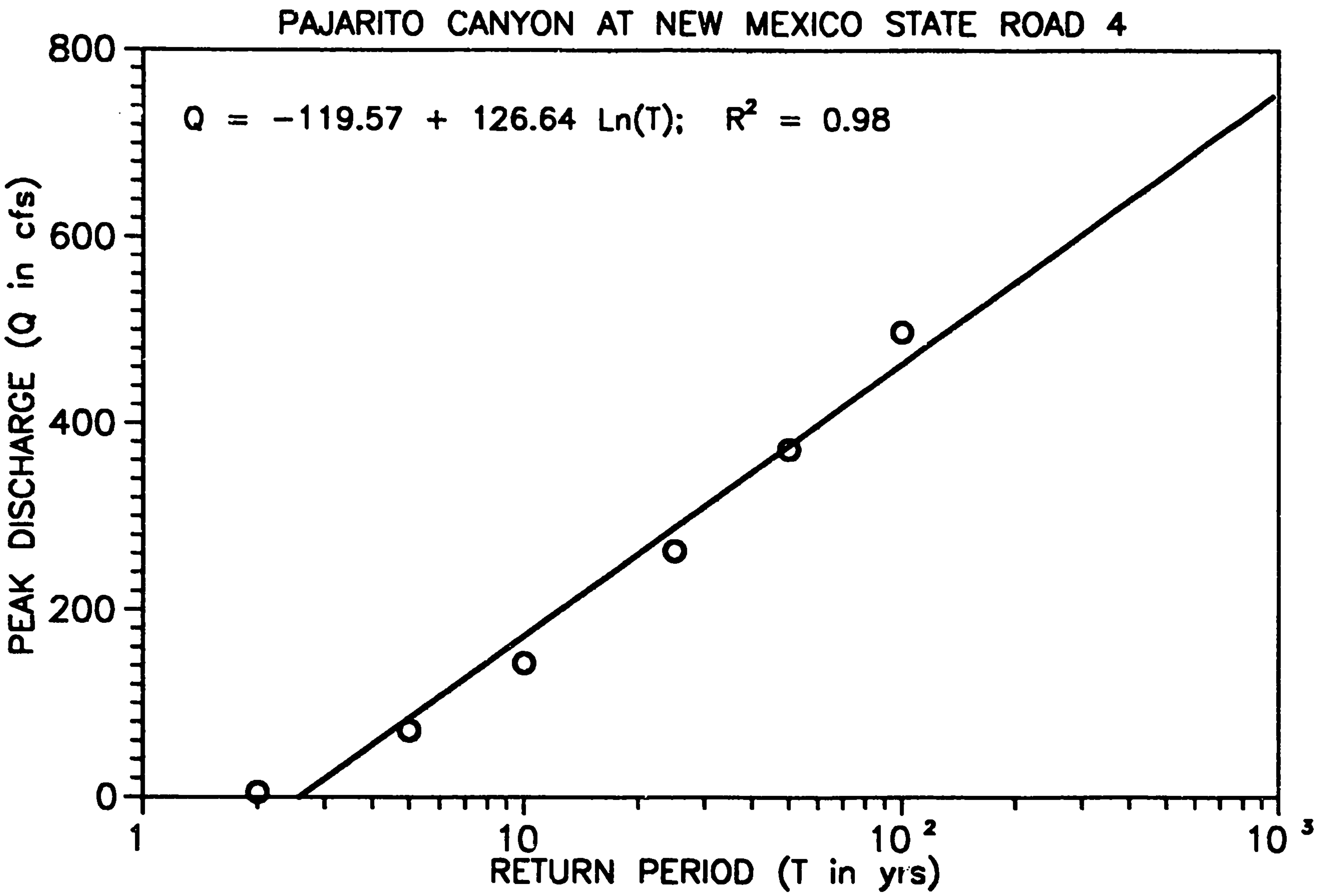

LOS ALAMOS CANYON ABOVE BAYO CANYON CONFLUENCE
Q = −190.14 + 235.65 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
1500
1250
1000
750
500
250
0
1
10
10 ²
10 ³
RETURN PERIOD (T in yrs)


LOS ALAMOS CANYON ABOVE RIO GRANDE CONFLUENCE
Q = −400.63 + 462.13 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
3000
2500
2000
1500
1000
500
0
1
10
10²
10³
RETURN PERIOD (T in yrs)

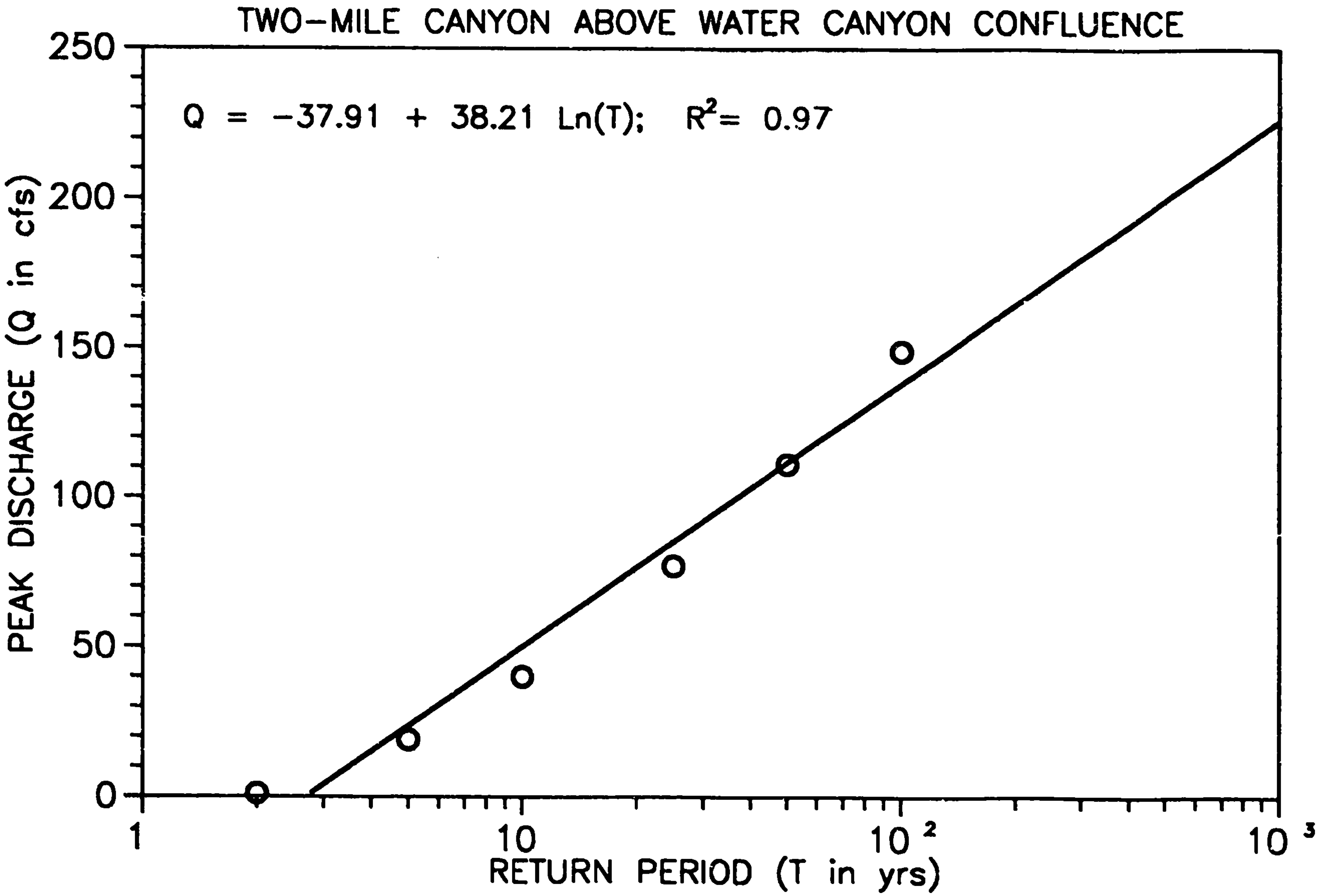

SANDIA CANYON AT NEW MEXICO STATE ROAD 4
Q = −16.85 + 18.12 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
125
100
75
50
25
0
1
10
10²
10³
RETURN PERIOD (T in yrs)

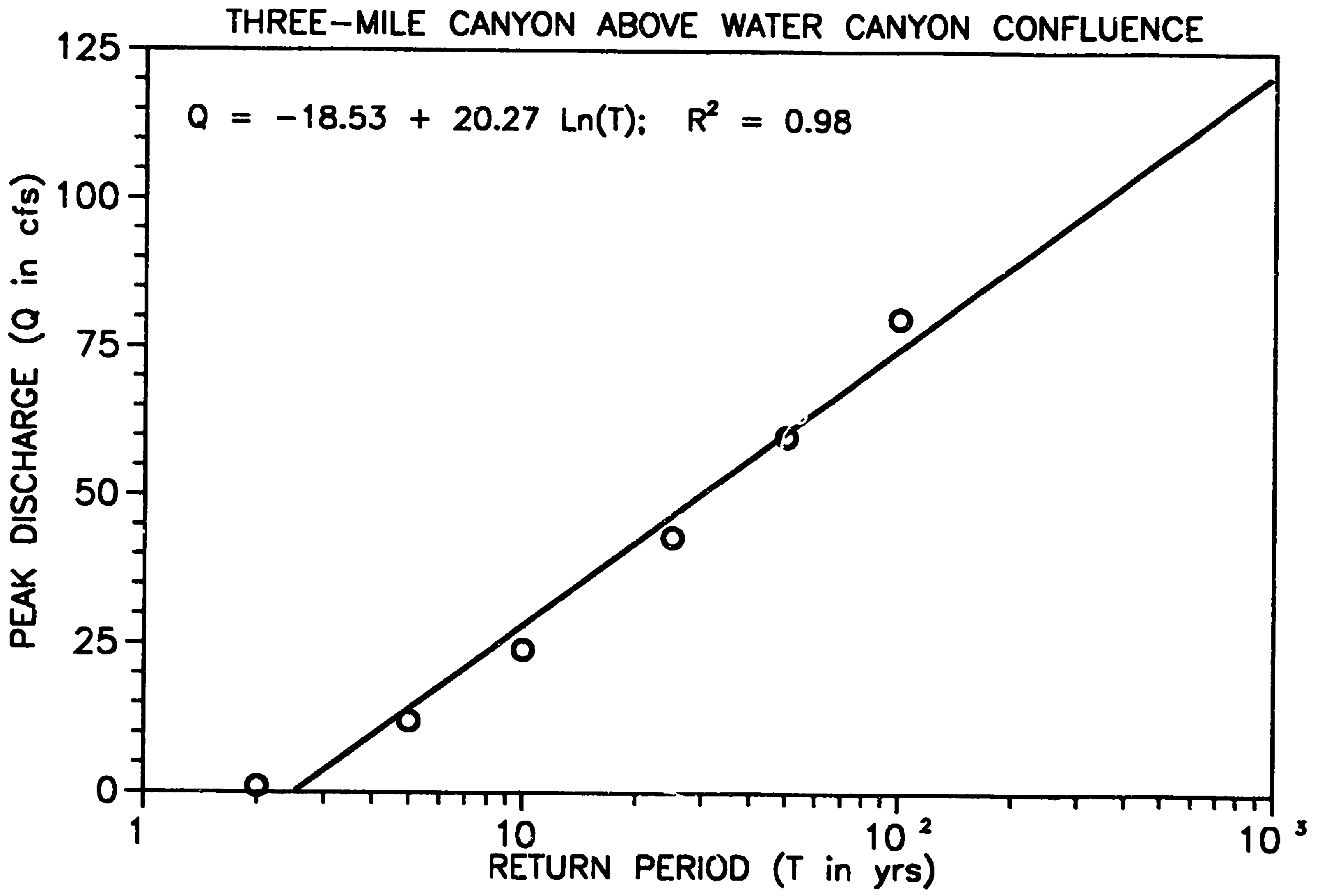

MORTANDAD CANYON AT EASTERN LANL BOUNDARY

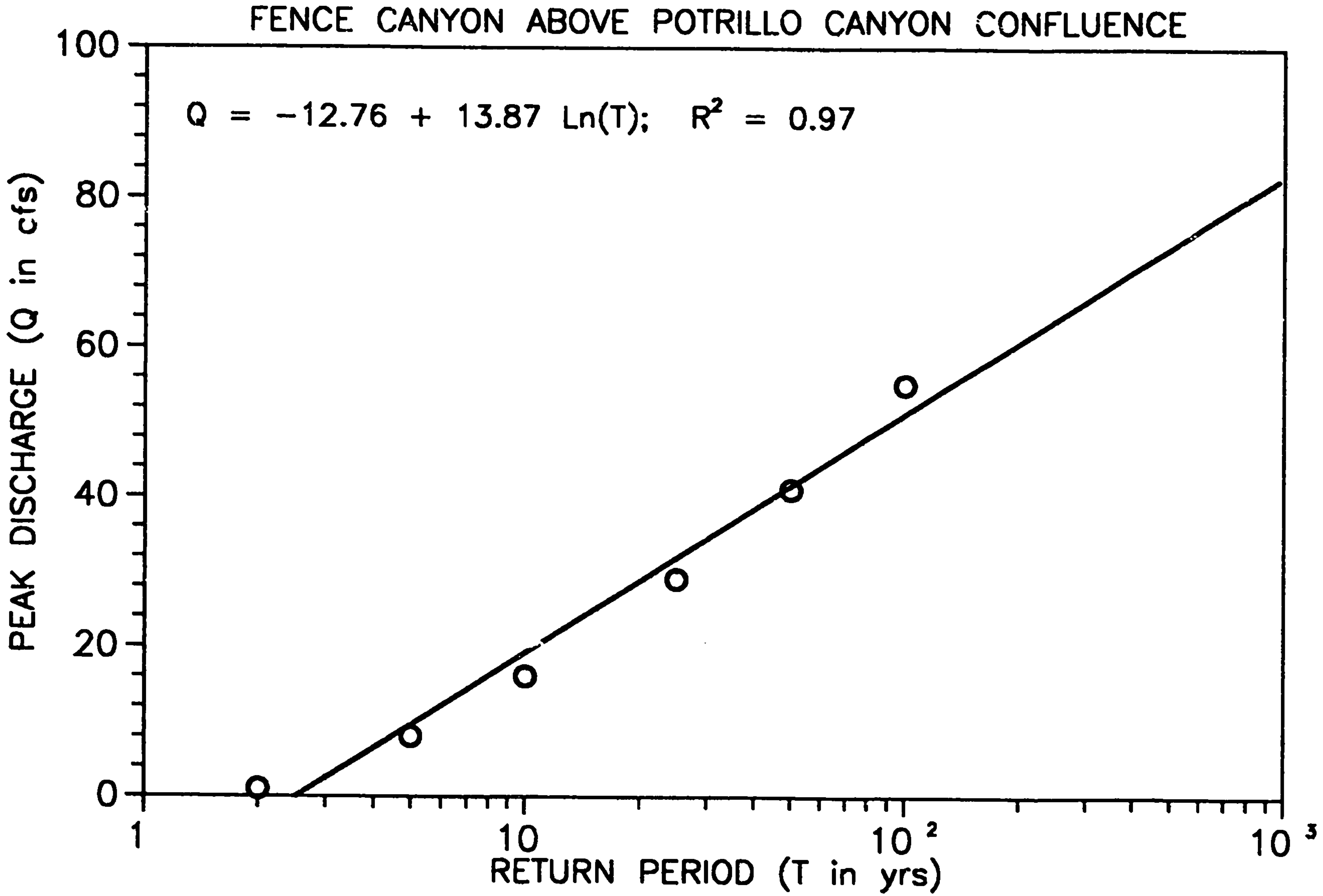

CANADA DEL BUEY AT NEW MEXICO STATE ROAD 4
Q = −16.71 + 18.19 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
125
100
75
50
25
0
1
10
10²
10³
RETURN PERIOD (T in yrs)

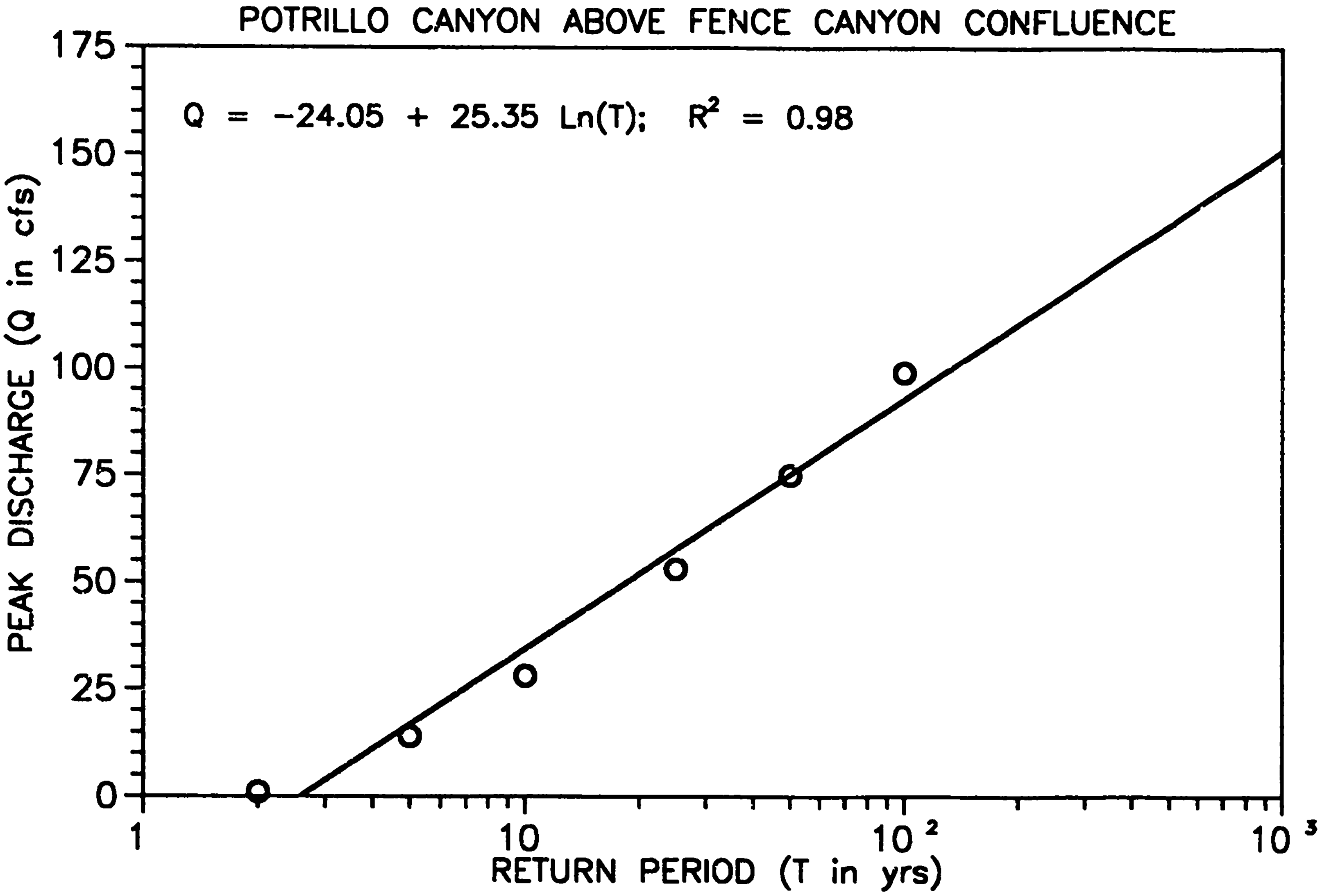


PAJARITO CANYON AT NEW MEXICO STATE ROAD 4

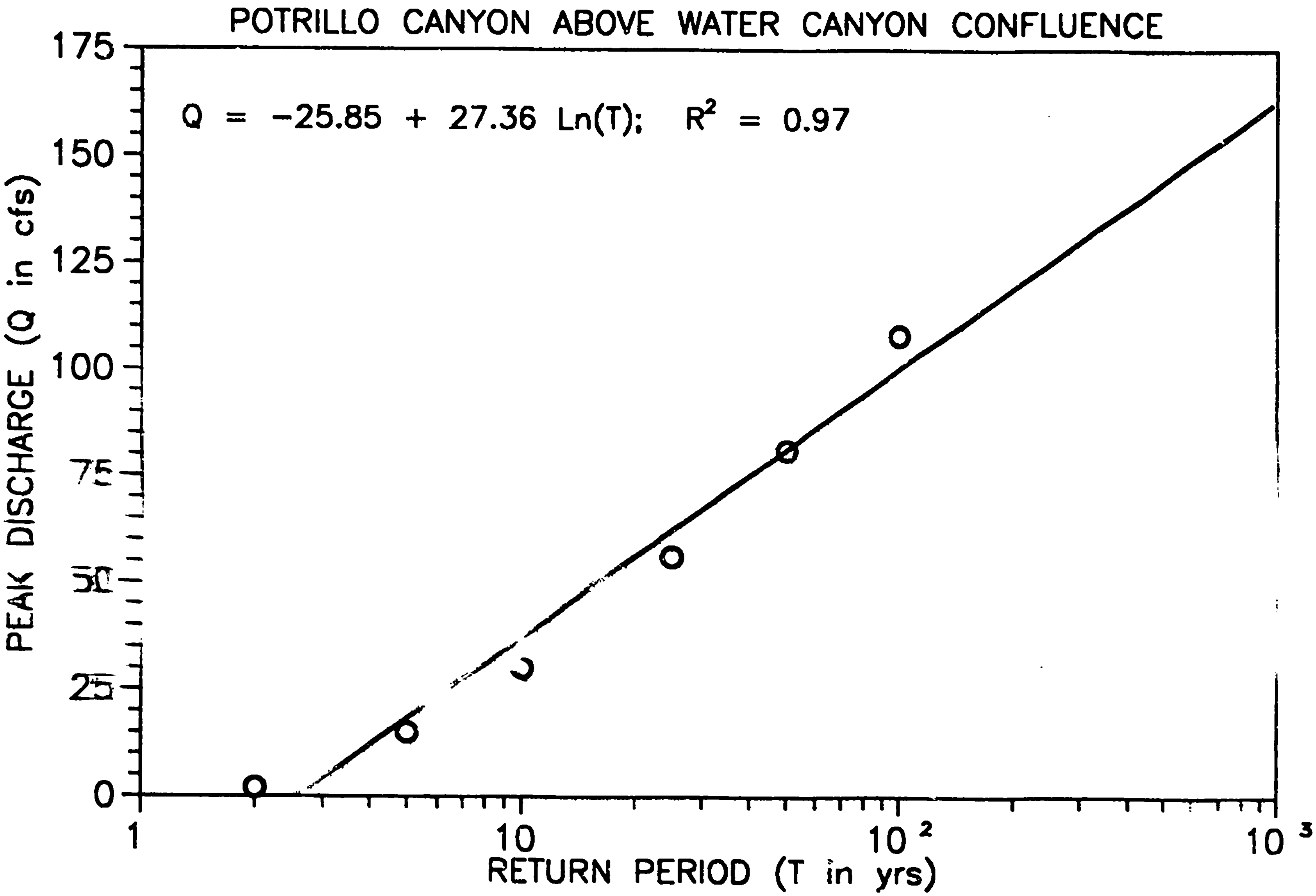

TWO-MILE CANYON ABOVE WATER CANYON CONFLUENCE
Q = −37.91 + 38.21 Ln(T); R²= 0.97
PEAK DISCHARGE (Q in cfs)
250
200
150
100
50
0
1
10
10 ²
10 ³
RETURN PERIOD (T in yrs)

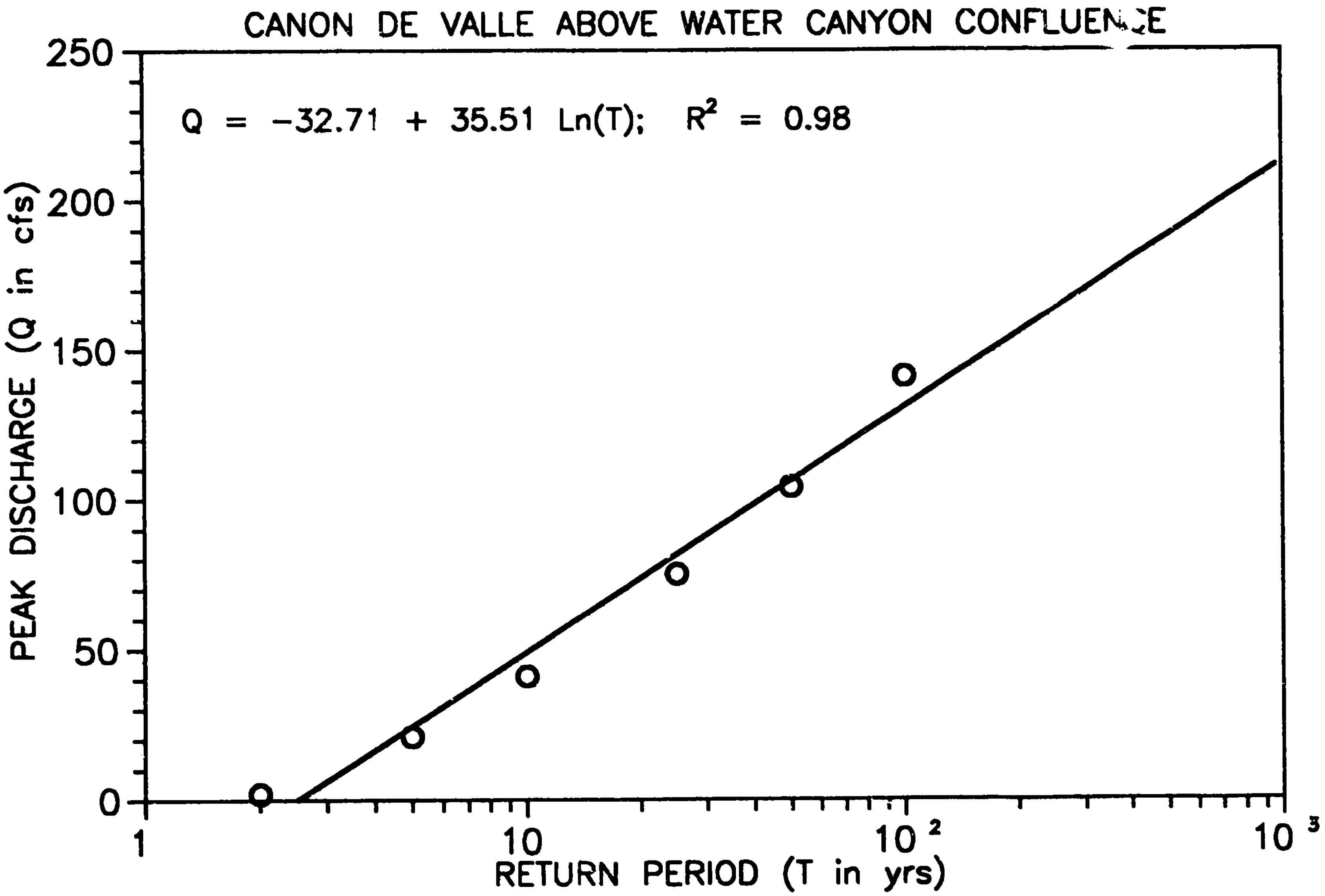

THREE-MILE CANYON ABOVE WATER CANYON CONFLUENCE
Q = -18.53 + 20.27 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
0
25
50
75
100
125
RETURN PERIOD (T in yrs)
1
10
10 ²
10 ³

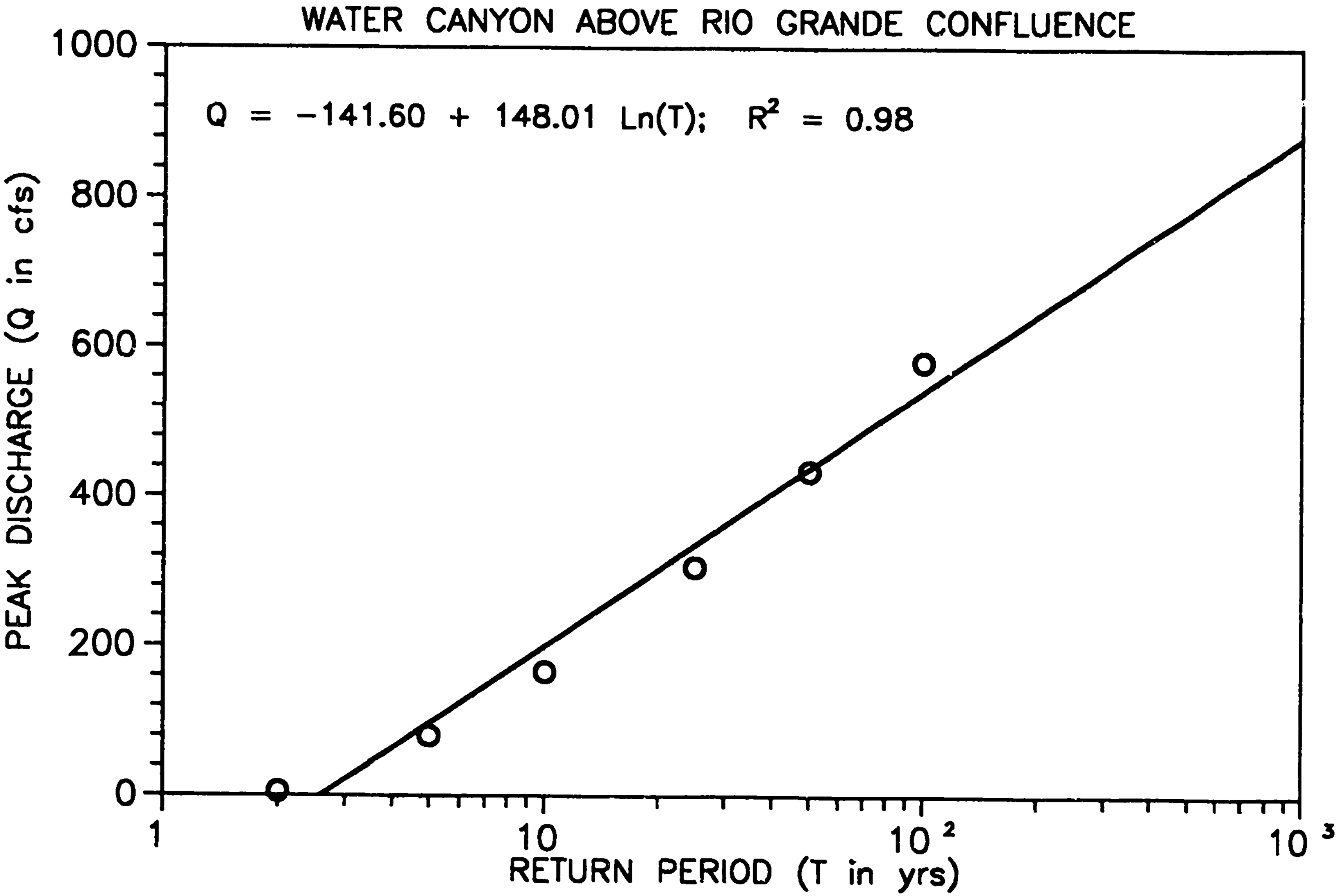

FENCE CANYON ABOVE POTRILLO CANYON CONFLUENCE
Q = −12.76 + 13.87 Ln(T); R² = 0.97
PEAK DISCHARGE (Q in cfs)
100
80
60
40
20
0
1
10
10 ²
10 ³
RETURN PERIOD (T in yrs)

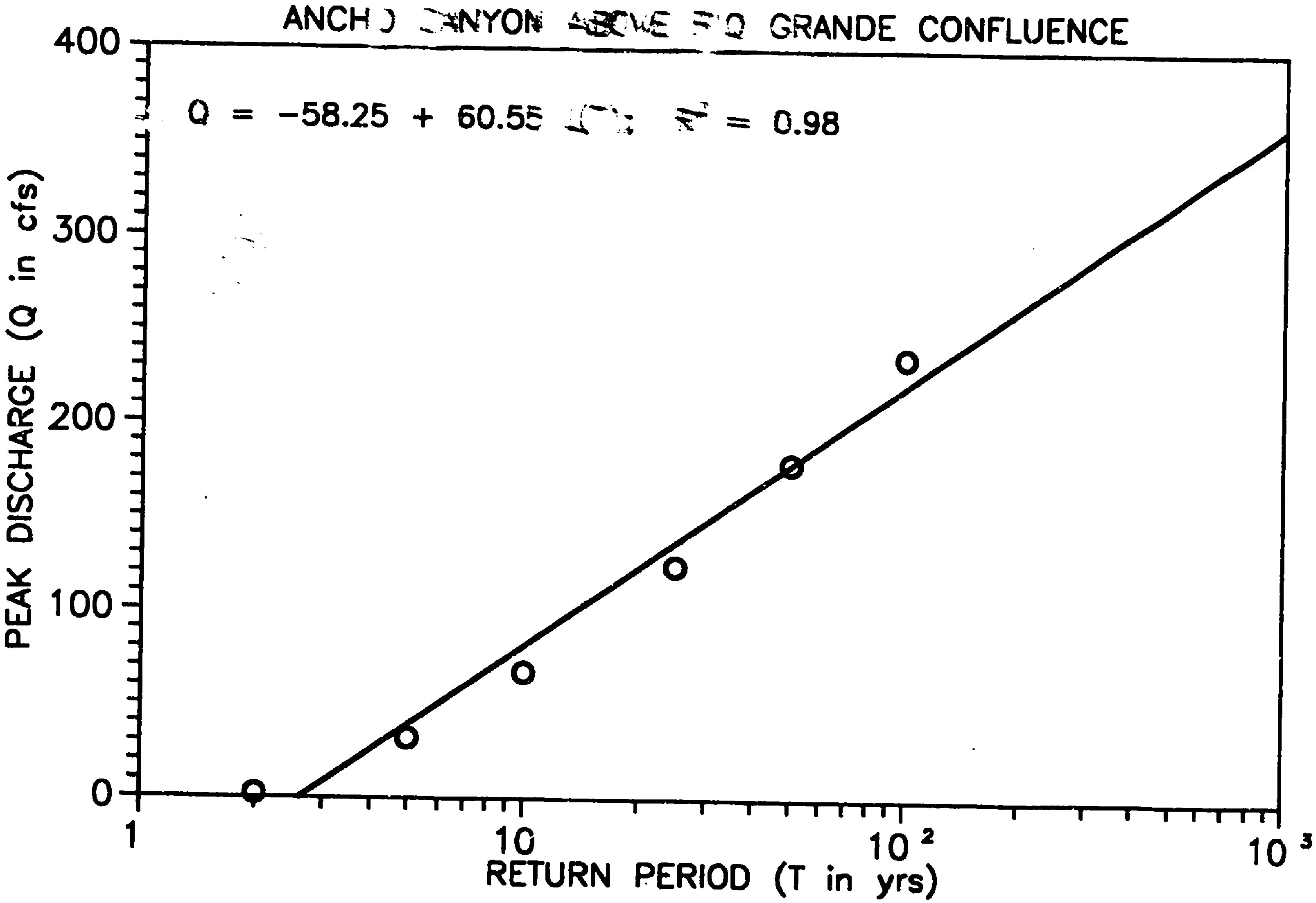


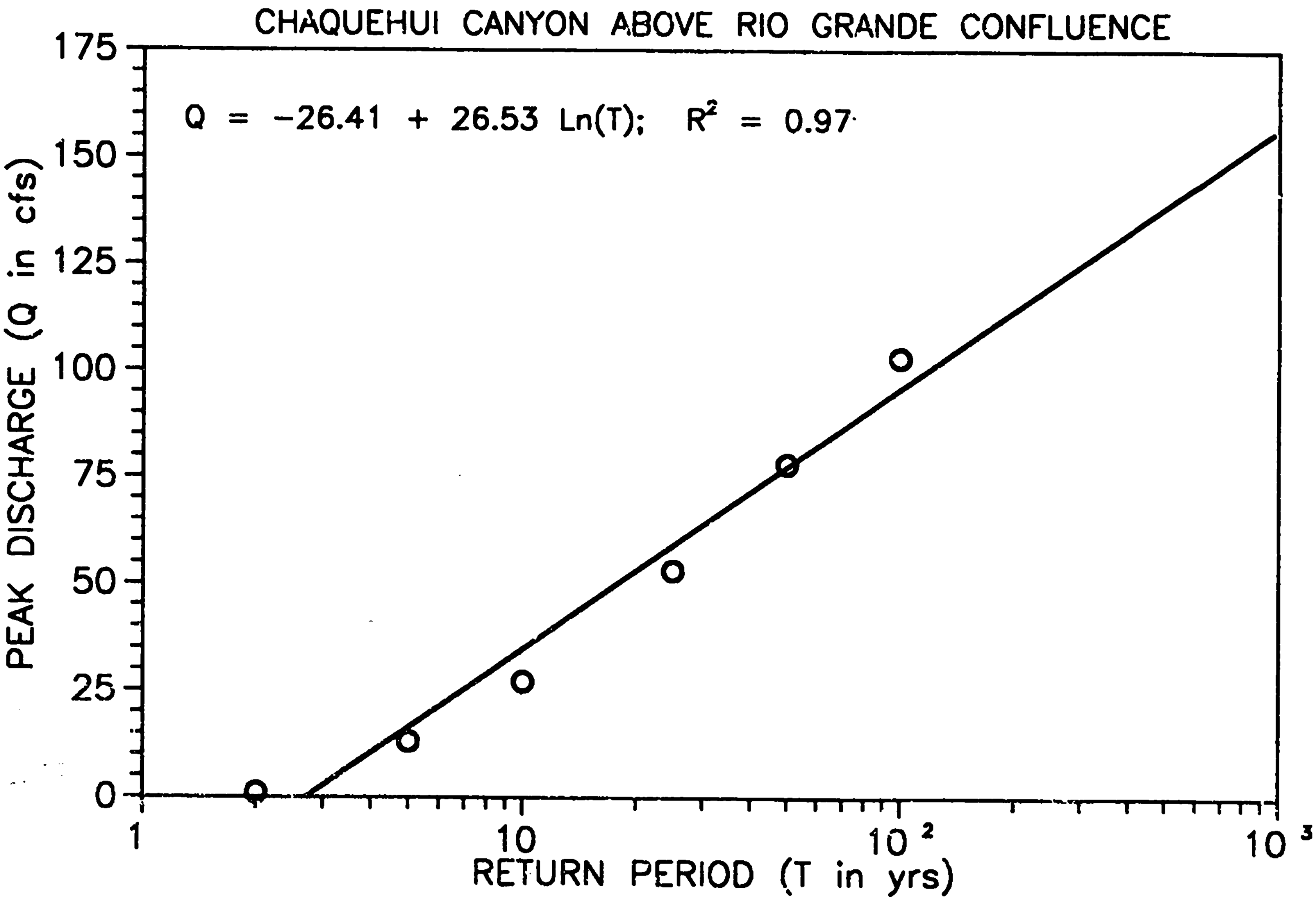
POTRILLO CANYON ABOVE FENCE CANYON CONFLUENCE

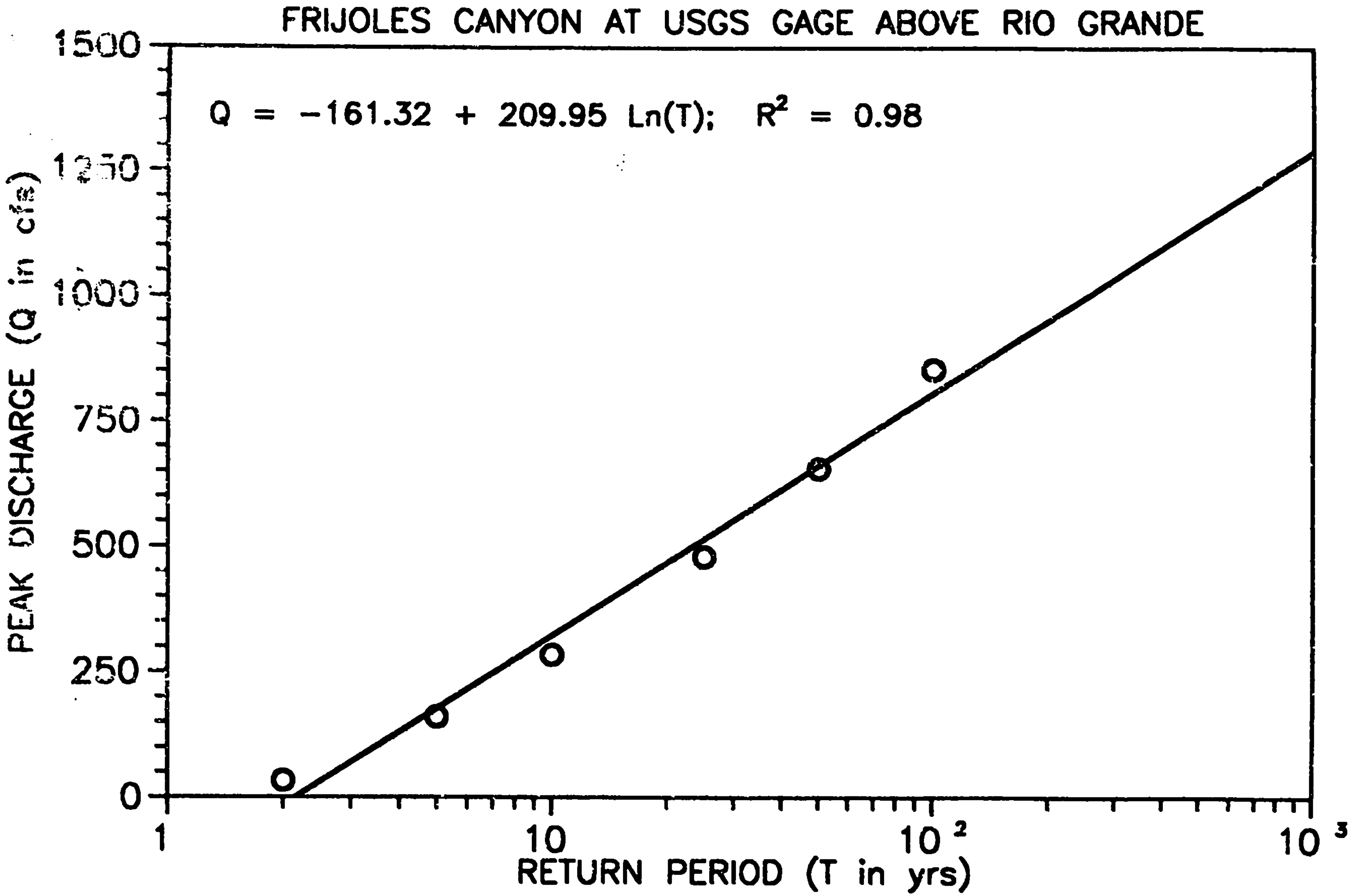

POTRILLO CANYON ABOVE WATER CANYON CONFLUENCE
Q = −25.85 + 27.36 Ln(T); R² = 0.97
PEAK DISCHARGE (Q in cfs)
175
150
125
100
75
50
25
0
1
10
10²
10³
RETURN PERIOD (T in yrs)


CANON DE VALLE ABOVE WATER CANYON CONFLUENCE
Q = -32.71 + 35.51 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
250
200
150
100
50
0
1
10
10 ²
10 ³
RETURN PERIOD (T in yrs)


WATER CANYON ABOVE RIO GRANDE CONFLUENCE
Q = −141.60 + 148.01 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
1000
800
600
400
200
0
1
10
10²
10³
RETURN PERIOD (T in yrs)


ANCHO CANYON ABOVE RIO GRANDE CONFLUENCE
Q = −58.25 + 60.55 LN(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
400
300
200
100
0
RETURN PERIOD (T in yrs)
1
10
10 ²
10 ³


CHAQUEHUI CANYON ABOVE RIO GRANDE CONFLUENCE
Q = −26.41 + 26.53 Ln(T); R² = 0.97
PEAK DISCHARGE (Q in cfs)
175
150
125
100
75
50
25
0
1
10
10 ²
10 ³
RETURN PERIOD (T in yrs)


FRIJOLES CANYON AT USGS GAGE ABOVE RIO GRANDE
Q = −161.32 + 209.95 Ln(T); R² = 0.98
PEAK DISCHARGE (Q in cfs)
1500
1250
1000
750
500
250
0
RETURN PERIOD (T in yrs)
1
10
10²
10³