Los Alamos Environmental Restoration Records Processing Facility

ER Record I.D.# 50127

LOS ALAMOS

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION
Records Processing Facility
ER Record Index Form
RPF USE ONLY

PAGE COUNT: 7

DATE RECEIVED: 11/03/95 PROCESSOR: Dic

RECORD CATEGORY (P/R): P

INITIALS: Dic

RECORD PACKAGE NO.: ——

FILE FOLDER: ——

CORRECTION (Y/N): —— CORRECTED NO.: —— CORRECTED BY: ——

AR (Y/N): yes

INITIALS: Dic

AR DESCRIPTION (D/G): ——

PRIVILEGED Y/N: ——

ELECTRONIC INDEX

INITIALS:

MISCELLANEOUS: OU 1049 Field Unit 4

14008

(7)

CONF-9310102

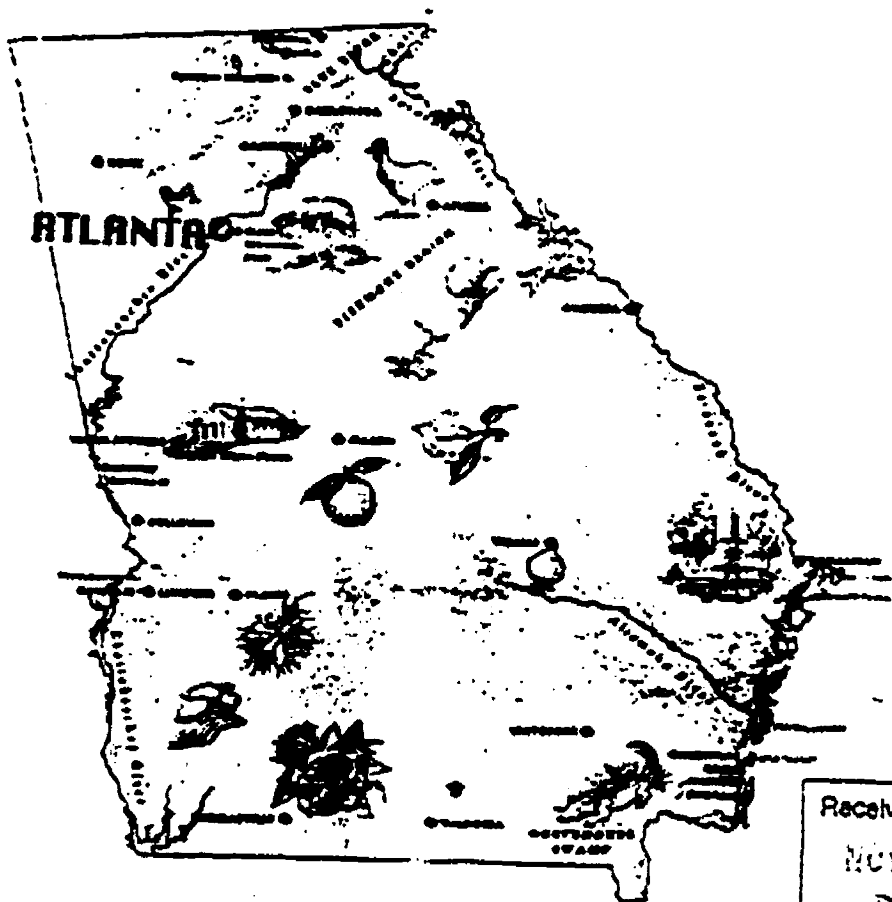
DOE Natural Phenomena Hazards Mitigation Conference

VOLUME II

PROCEEDINGS

October 19-22, 1993

Atlanta Marriott Northwest, Atlanta, Georgia



Sponsored by
U.S. Department of Energy Headquarters

Organized by
Lawrence Livermore
National Laboratory

ANALYSIS OF ROCKFALL HAZARDS AT LOS ALAMOS NATIONAL LABORATORY

Stephan G. McLin
Los Alamos National Laboratory
P.O. Box 1663 MS-K490
Los Alamos, NM 87545

ABSTRACT

In the early years at Los Alamos National Laboratory, rockfall hazards were intuitively recognized and avoided. Hence mesa tops were selected over canyon floors for construction sites, although some canyon bottoms were still used. The Omega West reactor site was located in a narrow portion of Los Alamos Canyon adjacent to 400 foot high vertical cliffs. In 1944, a quarter-mile long rock catcher was installed above the reactor to protect the facility from occasional rockfalls. In addition, an annual rock catcher inspection was initiated. Between 1944 and 1993, 24 separate rockfall events were documented; individual rocks trapped in the catcher ranged in size from 300 to 21,000 pounds.

These rockfall inspection data were arranged into an annual exceedance series, and a frequency analysis was performed. This type of analysis is routinely employed in flood studies when stream gaging records are available. Prior to this study, however, such techniques had never been used with rockfall data. This analysis indicates that the annual rockfall series is approximately log-normally distributed, and that the 500-year rockfall event will probably exceed 157 tons. In addition, a Markov generation scheme, which preserves the statistics of observed logarithms from the historical data, was used to generate a synthetic rockfall series. These synthetic data suggest that the cliff face will retreat at an average rate approximating 2 to 3 centimeters per 1000 years. This rate is comparable to independently computed rates that range from 4 to 14 centimeters per 1000 years. These cliff-face erosion processes are important because they affect mesa-top trench burial operations of low-level radioactive wastes.

INTRODUCTION

Sequential environmental observations, or time series, are often best understood and explained in a probabilistic, statistical, or stochastic context. For example, streamflow data are often characterized by dramatic changes that occur over time, including diurnal, seasonal, annual, and multi-year patterns. Specific recurrence-interval flood events may appear as uncertainties of nature, and may be viewed as having a random or stochastic component. Well-established statistical techniques allow these physical observations to be summarized in order to comprehend underlying patterns contained within these data, and to predict future system behavior for engineering design evaluations. Common statistical data summaries that describe these phenomena include mean, variance, maximum and minimum (i.e., range), skewness, coefficient of variation, and lag-one and larger serial correlation coefficients. Standard term definitions for unbiased computations may be found in any statistical textbook [1].

Many well-behaved statistical distributions have been used to describe natural hydrological processes [2]. Typically these theoretical distributions are tested when observational data are plotted on various types of probability paper. Despite these efforts, however, there is usually no single best distribution for a given observational data set. Still, certain distributions have found wide-spread application in routine streamflow analysis. The log-Pearson Type III distribution has been formally adopted for flood flow analysis in the United States by federal agencies, whereas the Gumbel Type I distribution is recommended in the United Kingdom. This report describes an application of some of these flood flow statistical methods to rockfall data in order to predict long-term recurrence interval rockfall hazards, and to estimate cliff-face retreat rates in Los Alamos County using synthetically generated time series.

Rockfalls have been observed at the rock catchers at Technical Areas 2 and 41 (TA-2 and TA-41) since these structures were installed in 1944 and 1978, respectively. A summary of these annual rockfall inspection reports is listed in McLin [3]. These reports were used to construct an annual rockfall exceedance series, as defined by Chow [4], for subsequent analysis. According to these inspection reports, at least 24 separate rockfall events have been documented at these two rock catchers between 1944 and 1993. Individual rock weights varied between approximately 300 and 21,000 pounds. For those years where no rockfalls were recorded, it was assumed that a one pound rockfall occurred. This assumption was made to preserve the continuous nature of the annual exceedance series as explained below. This series was then analyzed using a routinely accepted technique [5]. This computer program was originally designed for statistical analysis of stream flood-flows using the log-Person Type III distribution in the computation of frequency curves [6]. However, it is also applicable to the rockfall problem in Los Alamos Canyon, as explained below.

ANALYSIS OF OBSERVED ROCKFALL DATA

For the purposes of this report, recorded rockfall weights at the TA-2 and TA-41 rock catchers are treated exactly like peak flood flows commonly observed by the U.S. Geological Survey (USGS) at numerous stream gaging stations throughout the nation. Typically the peak annual flood flow is obtained from a continuously observed flow record for a particular water year (i.e., October-September) by the USGS at a given stream gaging station. A sequential time series of these peak flows is collectively referred to as an annual maximum series and typically contains 20-30 or more annual peaks (or years of record). Often times, however, a partial duration series is also selected for analysis. Here a partial duration series is defined as a series of data that is selected so that individual flow magnitudes are greater than some predefined base value. In flood flow studies, this base value is usually selected so that the final number of observations in the series is equal to the number of years of record. The resulting partial duration series is then referred to as an annual exceedance series. Hence for streamflow data, either the partial duration or annual exceedance series may contain several individual peaks recorded in the same water year, and may also have some water years with no peak flows that exceed the base value. For practical purposes, an annual exceedance series and the corresponding annual maximum series do not differ greatly except in the values at low magnitude.

The observed rockfall series obtained from the TA-2 and TA-41 inspection reports should be viewed as an annual exceedance series because individual inspections were sometimes conducted at intervals exceeding one year. From 1950 to 1970, there were no documented annual inspections at the TA-2 rock catcher. However, a USGS inspection in 1970 recorded approximately 15 individual rockfalls that were retained on the rock catcher during this time interval (recall that the rock catcher at TA-41 was constructed in 1978). Because we do not know exactly which rocks fell in any given year between 1950 and 1970, we elected to treat the resulting series as a partial duration series with a base value of one pound, and obtained the annual exceedance series. The subsequent analysis of this series is assumed to be statistically similar to an annual maximum rockfall series if that series were available for analysis. The assumption that an annual exceedance series and its corresponding annual maximum series yield nearly identical recurrence-interval results is fully supported by numerous flood-flow analyses conducted throughout the world. However, no other rockfall series are available in the literature or at Los Alamos to confirm this assumption.

The frequency analysis procedure for either an annual exceedance or annual maximum series is identical. First individual observations are arranged in decreasing order of magnitude, and each observation is then assigned an order number m that corresponds to the ranked values. The probability of exceedance (P) of any ranked event is then obtained from a "plotting position" formula. One obvious formula is simply $P = m/n$, where n is the total number of observations. A number of minor refinements in these formulas has evolved over the years [2]. In this study, the Gringorten formula was selected because it accounts for variations in sample size. A plot of rock weight (RW) versus P completes the frequency analysis procedure. Recall that the recurrence interval (T) is just the inverse of P; furthermore, T has units of years because our series is an annual one. If these data plot as a straight line on normal probability paper, then the underlying statistical distribution is normal. However, many environmental data sets exhibit a pronounced right skewness, and the data transformation y = log(RW) often reveals a lognormal distribution. In other words, a graph of ordered y versus P or T produces a straight line on normal probability paper. Actually this lognormal distribution is a special case of the more general log-Pearson Type III distribution because the skewness is reduced to zero by the logarithmic transformation. The emphasis on obtaining a straight line is stressed in engineering applications because extrapolation to large recurrence intervals is made easier simply by extending the straight line. A more complete theoretical discussion may be found in previously cited references. Results of this analysis suggest that the rockfall time series for Los Alamos Canyon is approximately lognormally distributed. Furthermore, they indicate that the 500-year rockfall event will be approximately 407 tons if our straight-line extrapolation is valid. We can improve upon this estimate, however, as seen below.

GENERATION OF SYNTHETIC ROCKFALL DATA

Synthetic streamflow generation methods have become a well-established tool in engineering practice. They enable water resources planners and engineers to more thoroughly evaluate designs for highway culverts, flood-control levees, bridges, and other important structures. It should be noted, however, that synthetic data generating schemes do not improve poor observational records. Instead these techniques improve the quality of design estimates that are made with whatever records are available. Many of these techniques are summarized by Fiering and Jackson [7]. Extension of these techniques to observed rockfall data is straight-forward, and requires no additional assumptions.

Perhaps the simplest synthetic rockfall generating technique takes the form of a scheme that produces individual time series values with separate deterministic and random components. The non-zero deterministic components should be designed to reflect any persistence in the observed data set, while the random component is usually assumed to be independently distributed with zero mean and constant variance. In addition, one generally makes the important assumption that the correlation between sequential rockfall values depends only on the time interval between these values, and that this expected persistence remains constant and is independent of rockfall magnitude. The resulting lag-one, or Markovian, synthetic rockfall generating scheme may be written as:

$$RW_i = xbar + r(RW_{i-1} - xbar) + \epsilon_i \qquad (1)$$

where RW_i is the rock weight of i-th member of time series, xbar is the observed mean rockfall weight, r is the observed lag-one serial correlation coefficient, and ϵ_i is a random component with zero mean and constant variance.

If RW in equation (1) is normally distributed, then ϵ must also be normal. If we select a normally distributed, serially independent random variable, t_i, with zero mean and unit variance, then we may write,

$$\epsilon_i = t_i s[(1-r)^2]^{0.5} \qquad (2)$$

where s represents the standard deviation from our observed rockfall time series. Equations (1) and (2) give a Markovian generating scheme that will yield a normally distributed synthetic rockfall series that preserves the observed mean, variance, and lag-one serial correlation coefficient of the original rockfall series. These relationships say that any given rockfall weight in our synthetic series depends only on the preceding rockfall weight and some random component. This serial dependence may be difficult to physically justify in general, but it is often characteristic of observed environmental time series. It is interesting to note that there is no apparent lag-one serial correlation in the rockfall data until we make the logarithmic transformation, y = log [RW].

A synthetic generation scheme for the lognormal distribution still uses equations (1) and (2), with y replacing RW. Xbar, r, and s now represent the mean, lag-one serial correlation coefficient, and standard deviation, respectively, of the logarithms. After using equation (2) with log-transformed data, we must back-transform, using RW = exp [y]. Now our synthetic generation scheme will preserve the observed mean, variance, skewness, and lag-one serial correlation coefficient of the logarithms of the original rockfall series. Because of the large positive skewness in the original rockfall series, the log-transformation was used in the synthetic data generation scheme for Los Alamos Canyon. Our analysis clearly shows that the lag-one serial correlation and skewness of the original series are not preserved in the synthetic data. It should be noted that such preservation is sometimes important, and techniques [8] exist for ensuring that statistical moments from the original series will be maintained in the synthetic series. These procedures were not employed in this study, however.

The only question that remains for the synthetic generation of rockfall data is the initiation procedure for equation (1). Fiering and Jackson [7] suggest that any convenient initial value for RW or y may be selected, and the observed mean is a logical choice. They also recommend that the first 50 synthetic rockfall values be discarded because these may potentially be influenced by the selection of an initial value for RW. This procedure was followed here. Figure 1a shows a log-log plot of T versus RW for the synthetic rockfall time series obtained from equations (1) and (2), and using the logarithmically transformed data. Synthetically generated output data for this plot were obtained from the same computer program [5] previously employed for our observed series. Results of this analysis indicate that the synthetic rockfall time series is also lognormally distributed, and that the 500-year rockfall event will be approximately 187 tons. It is important to note that a significant reduction in the magnitude of the 500-year rockfall event was obtained, along with a corresponding improvement in the confidence intervals. Note that the observed data are still contained within the synthetic confidence intervals shown in Figure 1a. We conclude that the synthetic data generation procedure represents an obvious improvement upon more traditional straight-line extrapolation techniques.

According to equations (1) and (2), our synthetically generated rockfall data set only depends on the mean, standard deviation, and the lag-one serial correlation coefficient from the observed series. Empirical studies have shown that the mean and standard deviation are much more significant than other statistical parameters in producing good synthetically generated series. Fortunately these dominating parameters are fixed by our observed series; furthermore, the mean and standard deviation are not influenced by the order of the observed data. However, the lag-one serial correlation coefficient is. Recall that our observed rockfall data comprise an annual exceedance series where the actual order of annual rockfalls has not been fully preserved. Hence a parameter sensitivity question arises. Exactly what influence does the lag-one serial correlation coefficient have on the resulting synthetic series? Figure 1b summarizes this influence on predicted rockfall weights. One may conclude that if sequential rockfalls in Los Alamos Canyon are not serially correlated (i.e., $r = 0$), then the predicted 500-year rockfall event will be approximately 225 tons. However, logarithms of the observed annual exceedance events are somewhat related since $r = 0.36$. Thus the predicted 500-year rockfall event should decrease for increasing values of r. Note that r may vary between 0.0 (i.e., no lag-one serial correlation) and 1.0 (i.e., perfect lag-one serial correlation). One concludes that small errors in observed r will not severely affect the predicted 500-year rockfall event in our synthetic generation scheme.

One final question remains. Is it physically possible for a 100 to 200 ton rock to fall from the cliffs above TA-2 and TA-41? The answer to this question depends upon the geometric spacing and orientation of existing fractures in the Bandelier Tuff units above these technical areas. Intersection of these fractures will directly influence the shape and size of any potential rockfalls. Ultimately, rock density and three-dimensional block geometry determine rockfall size. Efforts that will fully quantify this question are currently underway. Preliminary evaluations, however, suggest that large rockfalls exceeding 200 tons are indeed possible.

DISCUSSION AND CONCLUSIONS

This paper has attempted to demonstrate our contention that synthetically generated rockfall series can improve our estimation of long-term recurrence interval events. In other words, it provides us with a systematic methodology of controlling overly conservative design estimates for natural phenomena hazards like rockfalls and floods. These approaches are well established in many engineering fields, and the extension made here seems natural.

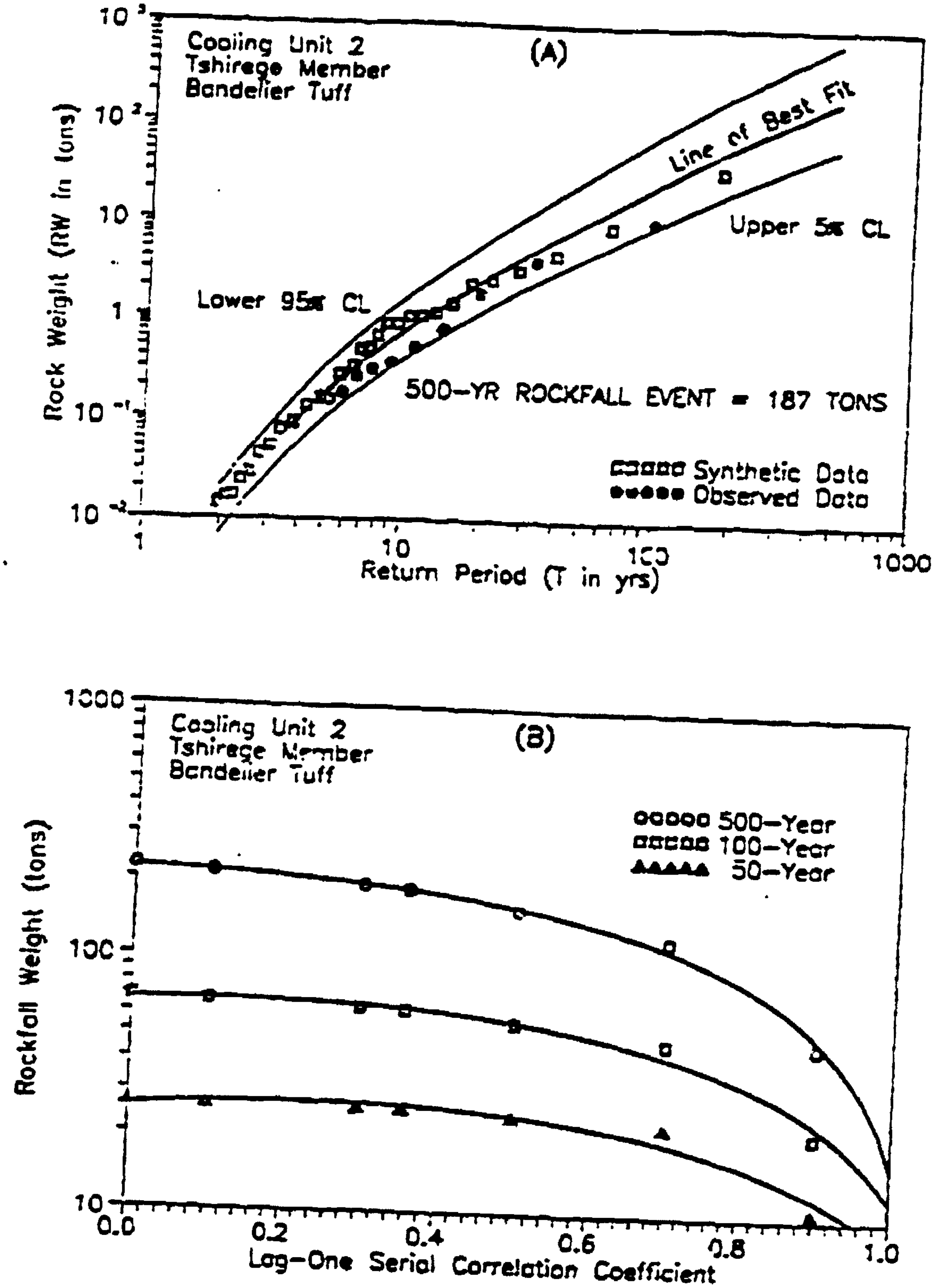


Figure 1. Frequency analysis for observed and synthetic (A) annual rockfall weights in Los Alamos Canyon; effects of serial correlation (B) on synthetic rockfalls.

In addition to the above, we may use our synthetic rockfall series to estimate rates of cliff-face retreat. This computation is straightforward: we know the rock catcher length, cliff height, rock density, and total rock weight that will fall during some simulated time interval. Hence we simply compute the average cliff-face dimension that would yield our simulated rock volume. For the Omega West Site, this procedure suggests that the cliff-face is retreating at approximately 2-3 cm/1000 years. This somewhat simplistic approach probably underestimates the actual rate of cliff-face retreat because our synthetic series is an annual exceedance one that does not account for all rockfalls. It still compares favorably, however, to previous estimates of 13-14 cm/1000 years [9], and 4-5 cm/1000 years [10]. Determination of these rates is important because the mesa tops are used for trench disposal of low-level radioactive wastes. Hence it is important to accurately estimate how long one may reasonably expect these trenches to remain intact before natural erosion eventually breaches them.

REFERENCES

[1] J.R. Benjamin and C.A. Cornell, Probability, Statistics, and Decision for Civil Engineers, McGraw-Hill, New York, 684 p., 1970.

[2] W. Viessman, J.W. Knapp, G.L. Lewis, and T.E. Harbaugh, Introduction to Hydrology, Harper and Roe Publishers, New York, 1977.

[3] S.G. McLin, "Synthesis of Rockfall Data in Los Alamos and Pajarito Canyons," Los Alamos National Laboratory, LAMS report in press, 1993.

[4] V.T. Chow (editor), Handbook of Applied Hydrology, McGraw-Hill, New York, 1964.

[5] Hydrologic Engineering Center, "Flood Flow Frequency Analysis," users guide to computer program 723-X6-L7550, Water Resources Center, U.S. Army Corps of Engineers, Davis, California, 1982.

[6] Water Resources Council, "Guidelines for Determining Flood Flow Frequencies," Bulletin 17 and Bulletin 17B, Washington, D.C., 1981.

[7] M.B. Fiering and B.B. Jackson, Synthetic Streamflows, American Geophysical Union, Water Resources Monograph No. 1, Washington, D.C., 98 p., 1971.

[8] N.C. Matalas, "Mathematical Assessment of Synthetic Hydrology," Water Resources Research, Vol. 3, no. 4, pp. 937-945, 1967.

[9] W.D. Purtyman and W.R. Kennedy, "Geology and Hydrology of Mesita del Buey," Los Alamos National Laboratory, Report No. LA-4600, 1971.

[10] D.P. Dethier, C.D. Harrington, and M.J. Aldrich, "Late Cenozoic Rates of Erosion in the Western Española Basin, New Mexico: Evidence from Geologic Dating of Erosion Surfaces," Geological Society of America Bulletin, Vol. 100, pp. 928-937, 1988.