ANALYSIS OF LANDSLIDE OCCURRENCES IN IDAHO

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Wayne C. Adams

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ABSTRACT

The purpose of this thesis is to evaluate the relation between landslides in Idaho and several related site conditions. In this landslide study I gathered information from landslide sites in order to attain two goals. The first goal was to evaluate the number of failures associated with earth-materials. The second goal was to determine the site characteristics that are most likely to promote failure in these materials. I propose that a simple inventory of site conditions from known landslides coupled with a careful data analysis can direct an investigator to a particular earth-material that has significant landsliding potential.

The scope of the study involved an analysis of the site conditions from over 1500 landslides. The methods used in this analysis of landslides were based on the following set of nine interactive site conditions; elevation, slope angle, slope aspect, rock type or material origin, presence of formational contact, presence of mapped fault, square mile area, precipitation and snow load. The initial data gathering was completed for the Landslide Inventory of Idaho, a project funded by the Idaho Geological Survey and the U.S. Geological Survey. The landslides were categorized by the "naturally occurring" materials at the failure site. The data describing each landslide site were gleaned from several sources and map scales. The precipitation and snow load values were assigned after the initial inventory using a weighted averaging technique based on the spatial dependence of the values.

The selection of the landslide site characteristics was dependant on the scale of the inventory and chosen for various reasons relating slope stability to the site geometry, material strength and water conditions. The landslide material group was the major division for classification and site variables for these groups are distributed differently in different regions of the state. The distribution of the site variables is useful for a qualitative examination of the landslide potential for a given site. The discriminant analysis was used to derive mathematical functions that assigned a given set of site variables to the landslide material most likely to produce a landslide in a select region of Northern Idaho. Using different selection techniques, snow load and precipitation were identified as the two most important site characteristics for distinguishing landslides associated with different earth-materials.

I recommend that a validation of the discriminant functions derived in this study be used to determine the accuracy of the group assignments. It also would be helpful to construct a simplified model which would derive one discriminant function to determine the likelihood of developing a landslide at a given site regardless of the material type. Further discrimination based on groups of landslides in specified slope intervals and elevation intervals may aid in prediction capabilities.

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The purpose of this thesis is to evaluate the relation between landslides in Idaho and several related site conditions. In this landslide study I gathered information describing known landslide sites in order to attain two goals. The first goal was to evaluate the number of failures associated with earth-materials. The second goal was to determine the site characteristics that are most likely to promote failure in these materials. The scope of the study involves an analysis of the site conditions from over 1500 landslides. The initial data gathering was completed for the Landslide Inventory of Idaho. This inventory took place during a one year period from November 1986 through November 1987 and was funded by the Idaho Geological Survey with matching funds from the U.S. Geological Survey. The procedures used to compile the data are explained further in the Idaho Geological Survey report: "Landslides of Idaho," (Adams and Breckenridge, in progress).

The objective of the inventory was to produce a landslide map at a scale of 1:500,000, with an accompanying report summarizing landslide occurrence. Information sources included both published and unpublished material. The initial stage of the inventory concentrated on available literature with the aid of bibliographic references and field notes on file at the Idaho Geological Survey. The literature search included a review of theses, maps and reports which specifically mentioned landslide locations in Idaho. The majority of the landslide locations came from interviews of the field personnel listed in Appendix A.

Specific information from each landslide site was gathered on the following nine characteristics:

1* ELEVATION
2* SLOPE
3* ASPECT
4* ROCK TYPE OR MATERIAL ORIGIN
5* PRESENCE OF FORMATIONAL CONTACT
6* PRESENCE OF MAPPED FAULT
7* SQUARE MILE AREA
8* PRECIPITATION
9* SNOW LOAD

Many of these characteristics were not available at the time of the personal interviews. Several, or in many cases, all of the above characteristics were obtained from topographic and geologic maps. The precipitation and snow load values were added after the completion of the landslide inventory project. For convenience I will refer to this data gathering process as "data collection."

During the course of the inventory I began to notice that for a given group of landslides in a similar region, no single site characteristic, or variable, seemed to explain landsliding. Rather, a group of variables most likely influenced the stability in different regions to different degrees. I applied the multivariate discriminant analysis to delineate between groups of site variables that seem to best describe landslides in particular material types.

PREVIOUS WORK ON LANDSLIDE OCCURRENCE

Stability Analysis

It is important in any study of landslides to review the basic mechanical process used to describe failure. In general, the mechanics of a failure combines the driving forces and resisting forces in a slope mass. A mathematical model is used as a tool to combine these forces and to evaluate the stability of a slope in terms of a factor of safety. Alternately, the model can be used to back calculate and estimate earth parameters at the time of failure. This type of evaluation equates the driving forces or shearing forces due to water and gravity with the resisting forces of soil strength, cohesion and friction, (Hunt, 1984).

Mass movement is a progressive process in which the shear strength of a material decreases relative to the shear stress until resisting forces are less than the driving forces. In reference to this continuing process Terzaghi (1950) pointed out that a slope is exposed to many degrading climatic conditions over a long period. He stressed that it is more likely that a slope fails from a gradual decrease in shear strength than by extreme conditions occurring at the time of failure. Because of this perspective, it is reasonable to assert that a change in any combination of the following three site parameters will affect the equilibrium of a slope.

* slope geometry
* surface water and or groundwater conditions
* material strength

Other Landslide Investigations

Several authors, Zaruba and Mencl 1969; Swanston and Swanson 1976; Megahan et al. 1978; Prellwitz et al. 1983; Roth 1983; Rice et al. 1985; and Hammond et al. 1988, have shown that the study and selection of site characteristics is useful for landslide prediction. Current methods for analyzing landslide occurrence rely on the hypothesis that a group of interactive site conditions promote mass movement. These conditions apply to a predictive model that is developed for a particular region or locality. With this model in mind, researchers collect measurements of site parameters to study slope failure conditions. Applying data from known landslides, a reasonable inference about the relative landslide potential can be successfully deduced.

The measurement and collection of site characteristics at landslide locations in the Western United States has centered around the forest industry. The correlation between landslides and vegetation shows that a decrease in the vegetative cover increases landslide activity (Swanson and Swanston 1977; Megahan et al. 1978; Wu and Swanston 1980; and McHugh 1986). This process decreases stability by removing the bonding strength of roots and increasing the water retained by the soil. Monitoring the saturation of earth-material and the resulting elevated pore water pressures is helpful in predicting earth and debris flows. Workers in California studying the incidence of debris flows found that the effect of storm intensity is an important tool for prediction (Wieczorek, 1987).

It is important to note that the method of choosing or defining what features to identify as landslides can affect the conclusions of an analysis. One landslide study in Idaho measured several characteristics at landslide locations. The conclusion stated; "The single most important factor found contributing to landslides in the Northern Rocky Mountains was road construction, accounting for 58% of the landslides" (Megahan et al., 1978, p. 137). There is general agreement in the literature that road building contributes to landslides, (Gonsior and Gardner, 1971 and Cook, 1984). However, the conclusion cited above is misleading because the authors did not clarify what types of features were being measured; in their study a major proportion of the landslide sites are also road fill failures. Considering that information from fill failures was collected, it would not seem too surprising that roads accounted for 88% of all landslides in the study areas (Megahan et al., 1978).

COMPILATION OF LANDSLIDE DATA

The term landslide refers to a variety of mass-movement involving the transport of "naturally occurring" earth-materials. Varnes' (1978) classification proved useful in describing the earth-material at the failure sites. The data was gathered from individual failure sites using several sources and map scales. The mapped earth-material associated with landsliding is used as the key indicator for significant landslide potential. The precipitation map (Miller et al., 1974) and the snow load map (Sack and Sheikh-Taheri, 1986) help to estimate the water available at landslide locations.

Definition of Landslides

Landslide is a general term for a variety of mass movement types that involve down slope transport of "naturally occurring" earth-materials. The term describes several types of mass movement which may or may not include actual sliding as a mechanism for ground failure. It is important to distinguish "slope failures" as those failures related to mans activities; "landslides" will refer to mass movement which occurs as a failure in "natural material." Certainly, many of the landslides in this study relate to activities such as vegetation removal, disruption of surface or ground water flow, and alteration of other site characteristics. Because of the stated purpose of this study I excluded landslides from the data base if the features were obviously and chiefly man related. I propose that a simple inventory of site conditions from known landslides coupled with a careful data analysis can direct an investigator to a particular earth-material that has significant landsliding potential.

I do not wish to imply that this type of analysis can replace a detailed site investigation. The complexity to which past environmental changes have influenced landsliding is best addressed on a case by case, site specific level. Mass movement can depend on many interacting conditions. Thus it is impossible, on a state-wide level, to distinguish all of the causes that may promote failure. Therefore the data base used for this thesis includes site features that are compatible with a preliminary stability study of an area with known landslides. The complete list of definitions assigned to each site characteristic collected for this study is in Appendix B.

Landslide Classification Scheme

The classification system presented by Varnes (1978) is shown in abbreviated form in Table 1. Varnes' complete classification (1978) proved valuable during the initial stages of data collection. I would like to point out two important features concerning the complete classification. First, the Type of Movement is Varnes' primary category. The lack of inventory information in many of these Type of Movement categories forced me to use the Type of Material as the main division for classification. I collected information for both categories but found that most people interviewed were not familiar enough with the Type of

Table 1: Abbreviated Classification of Landslides.

TYPE OF MOVEMENT	TYPE OF MATERIAL		
	ROCK	Coarse	Fine
FALLS	Rock fall	Debris fall	Earth fall
TOPPLES	Rock topple	Debris topple	Earth topple
SLIDES — ROTATIONAL	Rock slump	Debris slump	Earth slump
SLIDES — TRANSLATIONAL	Rock slide Block slide	Debris slide Block slide	Earth slide Block slide
LATERAL SPREADS	Rock spread	Debris spread	Earth spread
FLOWS	Rock flow (deep creep)	Debris flow	Earth flow (soil creep)
COMPLEX: Two or more principle types of movement.			

Adapted from Varnes, 1978.

Movement definitions and chose to select familiar terms such as slump or slide.

The second feature of the classification concerns the importance of the selection the Type of Material as a basis for classifying landslides. Varnes states that the type of material involved in the failure is chosen based on the state of the material before initial movement. This is important because any correlations between a landslide and the site conditions should include the material failing at the site at the time of movement. This material type may, after analysis, prove useful in predicting landslides in some areas. Unlike a geologic map which concentrates on the present state of the mappable site material there are advantages to a system which forces the investigator to consider the site material, mechanisms and conditions at the time of landsliding. This is particularly true if one has come to rely on a collection of maps and air photographs for landslide reconnaissance.

Zaruba and Mencl (1969, p.1) discuss these two perspectives in the following statement;

> Landslide phenomena are usually studied from two different points of view. .... Geologists study sliding phenomena as one of the significant exogenic denudation processes, with respect to the causes of their origin, their courses and the resulting surface forms. The approach of engineers and engineering geologists is quite different. They investigate the slopes from the point of view of the safety of the constructions to be erected on them. Therefore, they endeavor to ascertain in advance the proneness of slopes to sliding to determine the maximum angle of excavated slopes and to develop methods for a reliable assessment of the stability of slopes, as well as the controlling and corrective measures needed. ... The best results of landslide studies can be achieved only by the combination of both of

> these approaches. The quantitative determination of the stability of slopes by the methods of soil mechanics must be based on a knowledge of the geological structure of the area, the detailed composition and orientation of strata, and the geomorphological history of the land surface. On the other hand, geologists may obtain a clearer picture of the origin and character of sliding processes by checking their considerations against the results of static analysis and the research done by means of soil and rock mechanics.

I have collected information on material type in two ways by; a) using Varnes' material divisions and b) noting the mapped geologic material or earth-material. This second material description proved to be an important category for the statistical models discussed later.

Estimating the Water Available at Each Site

The precipitation available as rain or snow in a geographic location can influence the stability of a particular landslide. I chose two sources of information to represent water conditions at each landslide site. These two sources were; the 50 year mean recurrence interval (MRI) 6 hour precipitation map by Miller et al. (1974) and the Normalized Snow Load (NSL) map developed by Sack and Sheikh-Taheri (1986), also based on the 50-year MRI. The MRI is the average interval, in years, within which a given magnitude event will be equaled or exceeded. So that the 50 year MRI signifies that a given map value will occur on the average once in 50 years or have a probability of 1 in 50 of occurring in any given year.

In order to assign precipitation and snow load values to specific landslide sites I used the FORTRAN Kriging program presented in Jones

(1988). Kriging is a statistical weighted averaging technique which relies on the spatial dependence of the mapped data evaluated by the variogram. I applied a BASIC variogram program in order to assess the spatial dependance of the precipitation and NSL map values. Variograms for the two maps are included in Appendices E-1 and E-2. I divided each map into blocks in order to assign kriged values to all of the landslide sites in the selected database. With the proper block size, a search radii of approximately 60 kilometers for the precipitation map and 150 kilometers for the NSL map permitted the program to collect more than enough points to effectively fit a spherical model to the values for the variograms. This method was useful in assigning values to each individual landslide location using the Universal Transverse Mercator Grid (UTM) system. The grid coordinates were used in order to facilitate plotting of landslide points and obtain Kriged values using distances which plot on non-converging lines, as opposed to latitude and longitude which converge at the poles (see Jones, 1988, page 22).

The precipitation and NSL maps were digitized in blocks using the UTM grid in order to establish a computer file containing a set of x, y location points and an assigned z value representing the particular map value. These points formed the data file for the Kriged precipitation or snow load estimate at the landslide locations.

SUMMARY OF LANDSLIDE CHARACTERISTICS

Sampling error introduced during the classification of landslides was caused by confusion of terms and lack of specific information supplied by those interviewed. The site characteristics collected from many sources were chosen for various reasons related to past research on landslides. The earth-material was the major division for grouping landslides. The site variables are distributed differently in different regions of the state. The distribution of continuous variables for the five groups of landslide materials are useful for estimating failure potential.

Landslide Types- Identified by Material and Movement

The number of landslides classified in this study is shown Table 2. Sampling error was introduced during the personal interviews where terms such as slump or slide were chosen for classification because of a familiarity on the part of those interviewed. I suspect that the more unfamiliar terms were avoided. This became clear during the review of photographs received near the end of the landslide inventory project. Many of the landslides classified as earth slumps during the interviews could be described from the photographs as earth slides or complex landslides according to Varnes (1978). In many cases not enough information was known about the type of material at the failure surface, thus the earth and debris classifications are likely in error. The information concerning the type of landslides in Idaho is presented with these sources of error in mind.

Table 2: Number of Landslides Classified Using Varnes' (1978) Landslide Types.

TYPE OF MOVEMENT	TYPE OF MATERIAL				
	ROCK	DEBRIS	EARTH	TOTALS	PERCENT
FALLS	13	0	0	13	3.1
TOPPLES	5	11	0	16	3.9
SLIDES	41	80	2	125	30.1
SLUMPS	0	0	127	127	30.6
LATERAL SPREADS	0	0	2	2	.5
FLOWS	0	38	43	81	19.5
AVALANCHES	0	51	0	51	12.3
TOTALS	59	180	174	415	
PERCENT	14.2	43.9	41.9		

Note: 28 complex and 1088 unclassified types not included.

The spatial distribution of landslide occurrence for Varnes' divisions of rock, earth and debris material is included in the figures of Appendix F. Table 3 shows the total square mile area contained by landsliding for each group.

Site Characteristics Collected for Each Landslide

The collection of data from several scales and sources influenced the accuracy of the values representing each site characteristic. The published and unpublished sources of information come from three distinctly different groups;

* geologic maps and reports
* field maps from individual accounts
* field notes and recollections from individuals

Most often the characteristics; longitude, latitude, elevation and slope angle were obtained in the laboratory from 15 minute and 7 1/2 minute quadrangles. The Idaho Geological Survey's Landslide Report Form (Appendix C) and the data file format (Appendix D-1) served as effective organizing tools. I coded the data files for statistical analysis using the group numbers shown in Appendix D-2. The aspect of the landslide was coded in the data base by a 1, 2, 3 or 4 for NW, NE, SE, SW respectively. The aspect was treated as a directional vector for the discriminant analysis. The designations for NW, NE, SE, SW were in degrees of 315, 45, 135 and 225 respectively. The actual values assessed during

Table 3: Square Mile Area Contained by Types of Landslides.

TYPE OF MATERIAL	TYPE OF MOVEMENT				
	ROCK	DEBRIS	EARTH	TOTALS	PERCENT
FALLS	.612	0	0	.612	2.7
TOPPLES	.093	.028	0	.301	1.4
SLIDES	2.137	7.900	.022	10.059	44.0
SLUMPS	0	0	5.947	5.947	26.0
LATERAL SPREADS	0	0	.062	.062	.3
FLOWS	0	.851	1.852	2.703	11.8
AVALANCHES	0	3.157	0	3.157	13.8
TOTALS	2.842	12.116	7.883	22.841	
PERCENT	12.4	53.0	34.5		

Note: This table does not include 327.988 square miles contained by 28 complex and 1088 unclassified types.

discrimination involved a pair of transformed numbers applying the sine and cosine function to each vector as shown in Appendix D-2. Varnes' material types; rock, earth, debris were coded 1, 2, or 3 with an additional category 4 for complex and unclassified features.

The errors that developed using Varnes' terminology prompted the use of categories defined by the mapped material groups. I grouped the mapped rock type or material origin into five basic categories; 1) igneous extrusive, 2) igneous intrusive, 3) metamorphic, 4) sedimentary and 5) surficial (Appendix D-2). These groups will be referred to as the "landslide material groups" in the remainder of this thesis. This represents the actual material existing along the surface of failure or, in cases where information is lacking, the mapped geologic material.

The characteristics from each landslide site relate to the site parameters as shown below;

GEOMETRY	STRENGTH	WATER
Elevation	Rock Type/Origin	Precipitation
Slope Angle	Formation Contact	Snow Load
Slope Aspect	Fault	
Failure Area		

Many of these characteristics likely influence each other to some degree. For instance, one would expect elevation to roughly correlate with the maximum snow accumulation in a region.

Geometry

For this study, the actual geometric proportions at a landslide site relate the size, area and attitude of a failure mass. These attributes are important for an accurate evaluation of the potential stability.

Elevation: In the studies previously mentioned the average elevation proved to be a key to identifying landslides controlled by more than one site characteristic. Williamson (1965) noted that certain groups of elevations bracketed mass movement in terrain with deposits from alpine glaciation in the Cascade Mountains of Oregon. He successfully used this "key" to help identify earth-materials and slope segments susceptible to failure. Elevation also roughly corresponds to precipitation. In general, rain and snow increase with a rise in elevation. Swanson and Swanston (1977) found that in the western part of the Cascade Mountains the "middle elevations" receive high intensity precipitation and snow melt during major storm events. This is the case in Idaho particulary during "warm rain on snow" events, (see Gonsior and Gardner, 1971, p. 13).

Slope Angle: Engineers and geologists often use the slope angle, in relation to the weight of the mass, as an indication of the stability of a site. In particular Gonsior and Gardner (1971, p.32) noted that the stability of "both natural and artificial slopes steeper than 35 degrees is largely due to temporary sources of additional strength such as live tree roots." Megahan et al. (1978) reported that 60 percent of the landslides studied in two areas of Idaho occurred on slopes of about 30 degrees while 90 percent were on slopes less than 41 degrees. Rice et al. (1985, p.778) found that the slope angle improved the landslide prediction model for the English Peak Area in Northwest California. In the Dunnigan Creek, Idaho region Scanlan (1986, p.46) reports that "for design purposes any slope over 30 degrees should be suspect. In areas of known shearing, [a] 25 degree [slope angle] should be considered potentially dangerous." Experienced engineering geologists working in Northern Idaho have found that debris type landslides are less frequent on slope angles greater than 60 to 70 degrees, (Agar, 1987, personal communication).

Slope Aspect: Slope aspect has been reported to correlate with landsliding in some regions of the state, (Wilson, 1987, personal communication). Prellwitz et al. (1983) suggests that the aspect of a slope may play a role in landslide potential.

Square Mile Area: The total area for each landslide was collected as part of the original inventory. The size of a landslide may relate to other factors measured and it might be possible to predict the size of a failure. However, I did not explore that possibility.

Strength

Rock Type and Earth-material: The strength of a rock or soil mass depends on several things. First there may be a relation between mapped rock type and the landslide material at the site of failure. The question then arises concerning the exact relation between these mapped materials and failure. It is often stated in published literature that a landslide "occurred in" some particular rock type. This is misleading in the sense that a landslide often intersects many material types and failure may relate to a) the rock type mapped at that site b) the material along the failure surface or c) a combination of these material strengths. For instance, many of the earth slumps identified during the inventory are reported to have moved along a failure surface in colluvium, (Agar, 1987, personal communication and Hultman, 1988).

According to several authors, Swanson and Swanston, 1977; Megahan et al. 1978; Clayton et al., 1979; and McHugh, 1986, the relative strength of certain rock types and their weathering products is a principle determination for the material strength along the failure surface. Landslides that fail in rock, such as a rock slide would depend on the strength of the rock mass, lithologic character, degree of weathering, amount and orientation of discontinuities and a myriad of other characteristics of the host rock. This association between the mapped rock type and strength does not necessarily exist for an earth slump or debris flow because failure may occur in a material that is not directly related to the mapped rock unit at the location of the failure.

I collected measurements in order to evaluate the number of failures associated with earth-materials and to determine the degree of influence of site characteristics which are most likely to promote failure in these materials. The bar chart in Figure 1 depicts the number of landslides collected in association with igneous rock. The complete distribution of associated earth-materials is included in the graphs of Appendix G and shown on the pie chart inset of Figure 1. Recording the mapped earth-material proved the most convenient and reliable way to categorize each

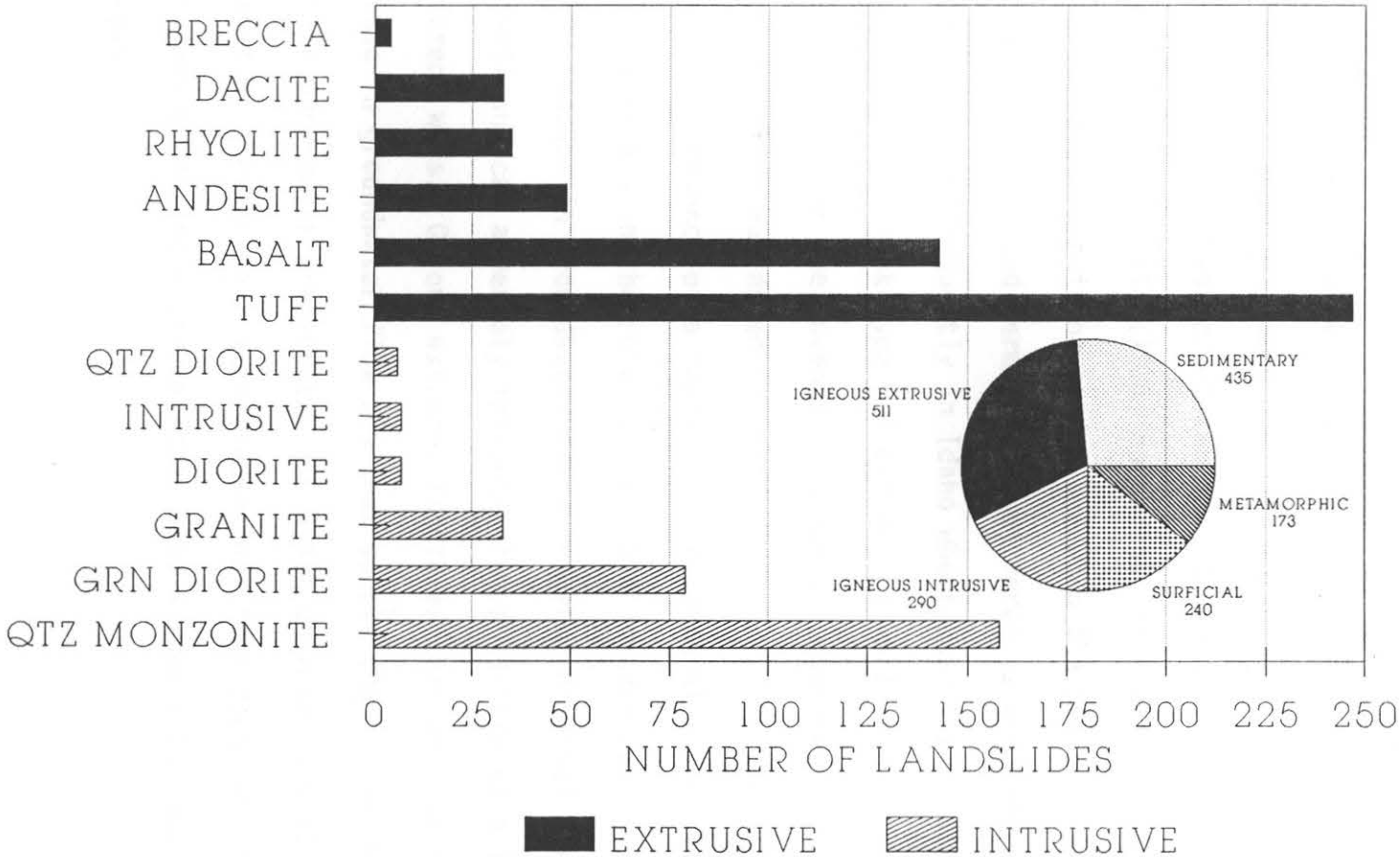


Figure 1: **Number of Landslides Associated With Igneous Rock and Pie Chart Showing Total in Each Material Group.**

failure. I would like to point out that I have attempted to define the material likely to exist along the failure plane whenever possible. However, there is often wide variability in strength for many of the earth-materials gathered from maps. For instance, a site mapped as Tuff may contain many interbeds of differing lithologic character and origin.

Formational Contact: Roth (1983) notes that the formational contact creates a potential condition of failure when the plane or zone failing occurs where strength and permeability differences are the greatest. This association appears frequently in Idaho where basalt rock overlies an older more weathered rock type. I did not collect the stratigraphic rock type associations for the inventory database. However, the presence of a formational contact was noted.

Faulting: The presence of a fault or shear zone at a landslide site can indicate a weakness in the rock mass or this feature may serve as a source for changes in groundwater and other environmental conditions. These conditions can adversely influence the stability at a landslide in two different ways. On one extreme, fractures that are "open" allow for an increase in groundwater flow and thus supply the failure mass with an increase in pore water pressures. The other extreme case is the development of a relatively impermeable zone from gouge and filling along the fractures producing a barrier that also allows a buildup of pore water pressure.

Water

Precipitation: Terzaghi (1950) asserted that the most common causes for a decrease in shearing resistance in a material is the increase in pore water pressure and the progressive decrease in shear strength. Recent studies in California by Ellen and Fleming (1987) have identified a relation between heavy rainfall and debris flows. The increase in pore water pressure and the subsequent decrease in shear strength due to the buoyant force of water and the reduction in capillary tension affects the stability at the location of a potential slide. Precipitation becomes particularly important when there is enough water to saturate the entire earth-material to cause elevated pore pressures. Wieczorek (1987) indicates that the intensity, or amount per hour, and the duration of a precipitation event are related to some types of landsliding.

<u>Snow load:</u> The snow load, included in the data base in units of pounds per square foot (psf), is meant to estimate of the amount of water available during thaw at any particular landslide. Day and Megahan (1976) noted that a rain-on-snow storm in 1974 caused considerable landsliding on the Clearwater National Forest in Northern Idaho. The significance of the amount of snow likely to fall in an area is similar to the precipitation "mechanism" previously discussed. The rate of melting and the amount of water available as snow would dictate the degree of influence on mass movement. Megahan (1984, p.1) states that for many mountainous regions in Idaho the piezometric levels "are caused by snowmelt rather than rainfall and are not the result of fluctuations in permanent groundwater levels." As previously mentioned I used the NSL Map by Sack and Sheikh-Taheri (1986) to assign the snow load to each landslide in the database.

The development of the NSL map made use of about 50 years of historical information from 514 stations in Idaho, Montana, Oregon, and Washington. Annual snow load maxima were extrapolated beyond the historical record. Sack and Sheikh-Taheri (1986) selected the value of snow load accumulation with a .02 probability of being exceeded in any one year from a cumulative frequency distribution function. Thus the 50-year MRI is the 2 percent probability of exceeding a value shown on the map in any given year, (Sack and Sheikh-Taheri, 1986). In this thesis, the NSL value was converted to a pressure by multiplying the NSL by the site elevation. This "snow pressure" is intended to approximate the average equivalent water likely to accumulate as snow in any given year at a landslide in a 50 year period. From these precipitation and snow load values it is possible to evaluate the relative amounts of water available at each landslide.

Summary Graphs of Selected Characteristics

Bar graphs and cumulative frequency curves for elevation, slope, precipitation and snow load are presented in Appendices H and I, according to the five material categories. These plots are divided into two different groups: 1) the set of landslides in the entire state (Appendix H), and 2) a subset (Appendix I) consisting of those landslides in a select area (see Appendix F-1) in Northern Idaho. Examples of these plots for landslides associated with sedimentary rock are given in Figures 2 and 3.

Statistical distributions of the variables in the subset are different from those in the set that represents the entire state. This

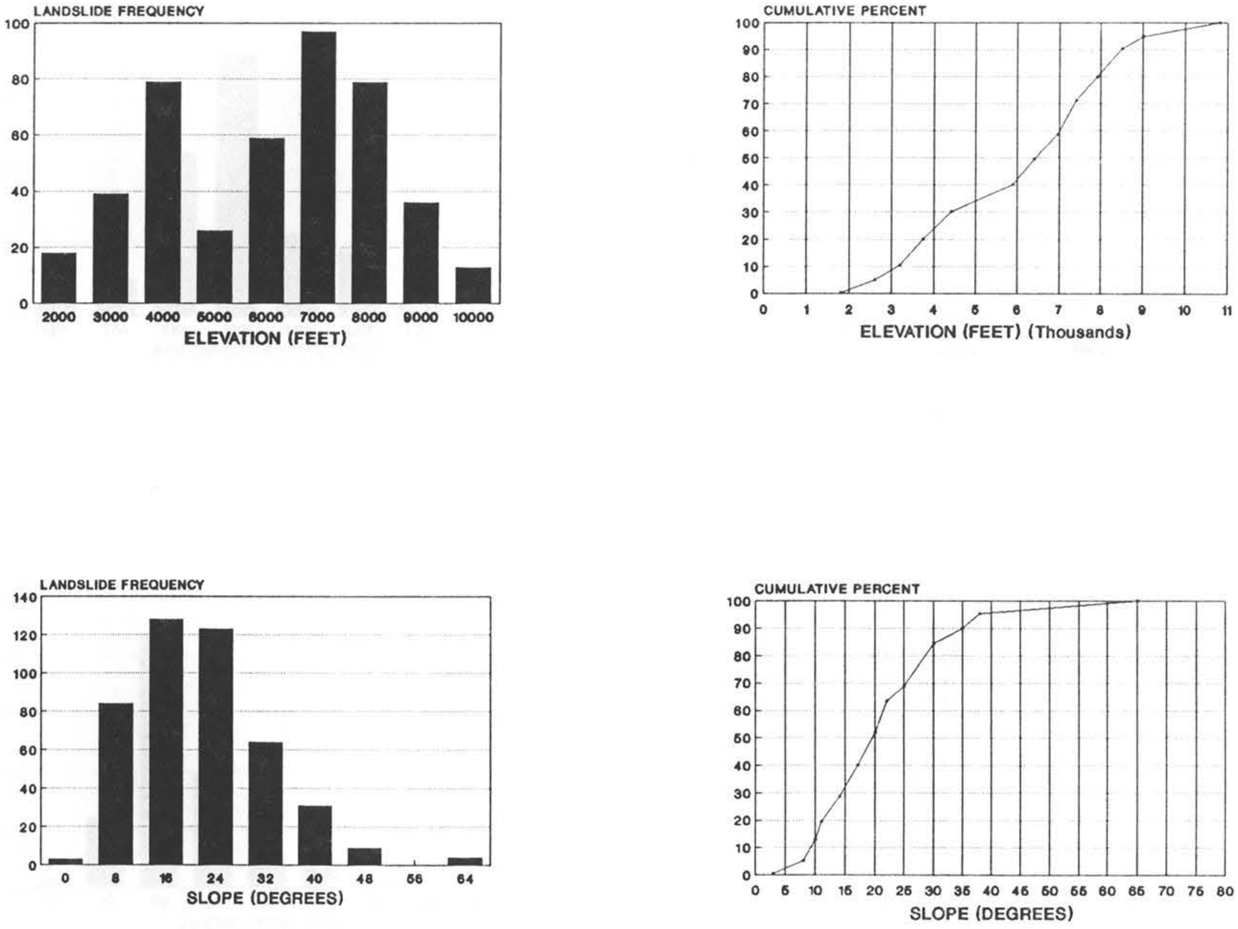


Figure 2: Elevation and Slope Angle for Landslides Associated with Sedimentary Rock in Idaho.

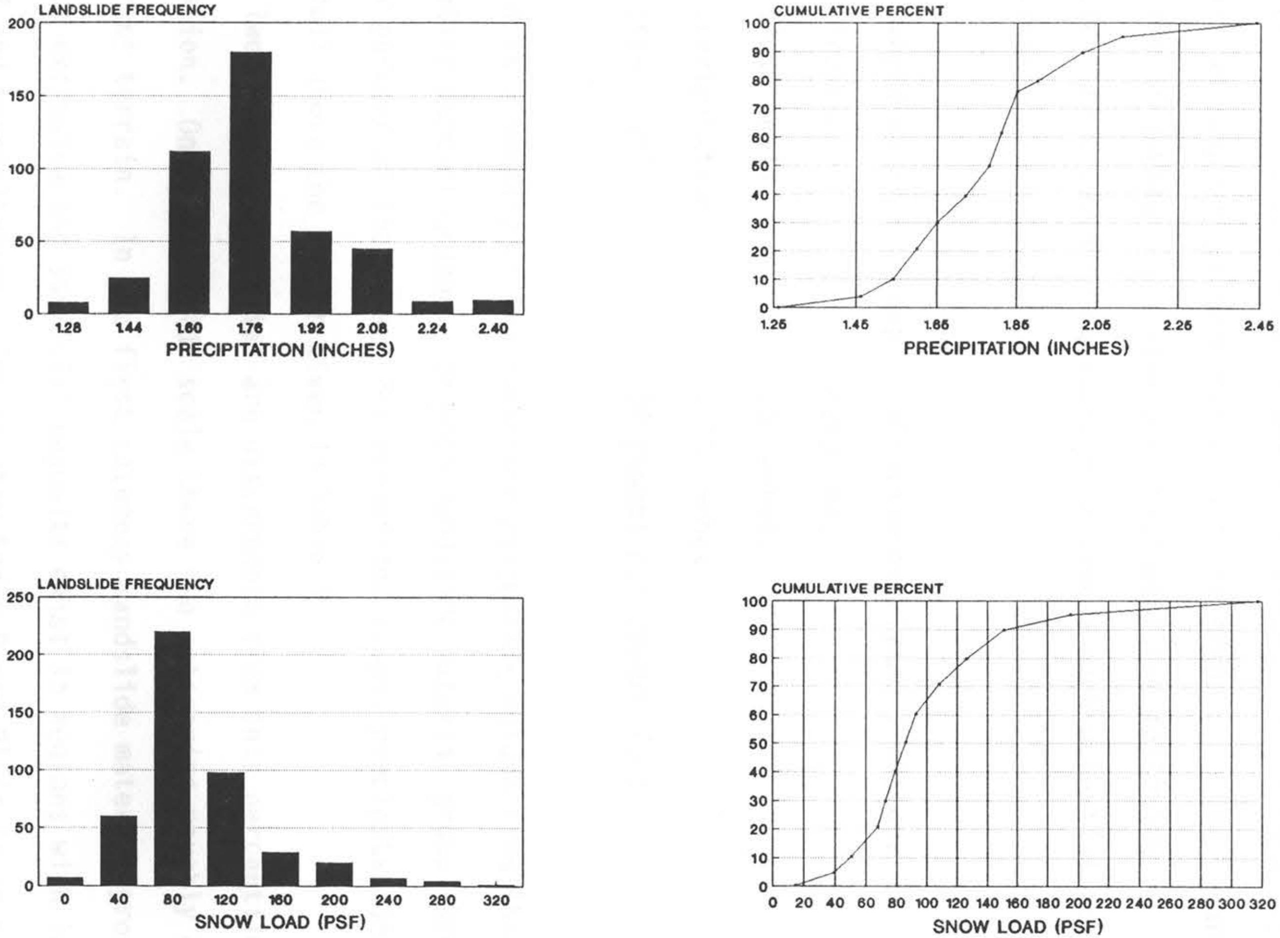


Figure 3: Precipitation and Snow Load for Landslides Associated with Sedimentary Rock in Idaho.

difference likely is caused by local environmental, physiographic and material conditions. To qualitatively evaluate the landslide potential at a particular site one can examine the graphs for the locality of interest and mapped geologic material. For example, using Figures 2 and 3, a site of unknown landslide potential with the following characteristics would be considered to have a high potential for landslides;

mapped material group:	colluvium overlying limestone
elevation:	6000 feet
slope angle:	20 degrees
precipitation:	1.75 inches
snow load:	80 pounds per square foot

Table 4 is a summary of the twentieth percentile values from the cumulative percent graphs. In each landslide material group shown, eighty percent of the values for elevation, slope, precipitation and snow load fall above the number given in Table 4.

Two general categories are discernable from this percentile evaluation. On a state wide scale these two categories roughly describe different terrain. In the first category landslide material groups of igneous extrusive and surficial deposits exist in regions with less relief and precipitation. The greater Snake River Plain is an example of a region mapped as containing igneous extrusive and surficial materials. Landslides classified by the second category containing

Table 4: Summary of Selected Twentieth Percentile Values.

ENTIRE STATE OF IDAHO

	ELEVATION	SLOPE	PRECIPITATION	SNOW LOAD
IGNEOUS EXTRUSIVE	3500	10	1.60	45
SURFICIAL	3000	8	1.55	50
IGNEOUS INTRUSIVE	3700	14	1.80	70
METAMORPHIC	2500	17	1.75	70
SEDIMENTARY	3700	11	1.60	70

SELECTED REGION OF NORTHERN IDAHO

	ELEVATION	SLOPE	PRECIPITATION	SNOW LOAD
IGNEOUS EXTRUSIVE	1500	10	1.59	30
SURFICIAL	1200	17	1.59	22
IGNEOUS INTRUSIVE	3200	17	2.00	155
METAMORPHIC	2300	19	1.76	80
SEDIMENTARY	2400	17	1.60	85

igneous intrusive and metamorphic material groups tend to be associated with regions of higher relief and larger amounts of precipitation. Central Idaho contains a large proportion of materials from the second group. This region of Idaho also receives notably higher precipitation particularly in the form of snow as reflected by the cumulative graphs in Appendix H and Appendix I. The twentieth percentile values for the sedimentary material are intermediate between these two categories.

Considering that the higher regions in the state generally accumulate more moisture. One would expect that landslides would occur through a broad range of elevations in regions of high moisture. This is the case for the category of landslides associated with igneous intrusive and metamorphic rock, landslides occur over a wide range of elevations. I would like to emphasize that in many cases landslides may not directly correlate with the mapped landslide material group and that some unmeasured characteristic or special combination of conditions may create the most unstable environment.

Interpretation of Variables

Numerous analogies can be drawn about landslide occurrence from the bar graphs and plots of Appendices H and I. In this section I will outline a few of the more obvious trends between the landslide occurrence and the physical environment. Naturally, landslides associated with a particular material group are found where that material exists. As an example, this simple analogy can be applied to the bimodal bar graph in Appendix H-7 where the distribution of elevations for landslides reflects the occurrence of mapped sedimentary formations in the state. The location, age and stage of weathering for the five material groups also has a major effect on the distribution of landslides at various elevations and slope angles.

We usually find little soil available for failure in regions of relatively extreme weather conditions such as we find in the higher elevations of Idaho. With this line of reasoning one would expect to find few landslides at high elevations where there is an absence of material covering rock. In looking at the data representing the materials of intrusive and metamorphic terrain in Appendices H-3 and H-5 the bar graphs are skewed to the right. This indicates that most of the landslides are occurring at lower elevations and slope angles. The concentration of landslides at the lower slope angles also points to the fact that most of the steeper areas in these material groups have lost the material available for failure. Since rock related failures were not well represented in the data base and these failures are usually concentrated on steep slopes, we see even fewer landslide events for the higher values of slope angle.

Most of the graphs showing the distribution of snow load values for failures in Appendix H are skewed to the right. This is a reflection of a) the amount of area in Idaho covered by the lower snow load values and b) the fact that high snow loads often occur in regions of high elevation. This means that the distributions for elevation will roughly correspond to snow and we find most landslides where there are low snow loads because the failures were found to occur at lower elevations as previously mentioned. One should take note that there is a danger in applying this relation over the entire state because several of the higher regions in Southern Idaho receive little snow in comparison to Northern Idaho.

Entire State of Idaho

Eighty percent of the landslides associated with igneous extrusive and surficial deposits tend to occur where;

* elevations are greater than 3000 feet
* slope angles are greater than 8 degrees
* precipitation values are greater than 1.55 inches
* snow loads are greater than 45 pounds per square foot

For category two, landslides assigned to igneous intrusive and metamorphic material groups, eighty percent of the values are found where;

* elevations are greater than 2500 feet
* slope angles are greater than 14 degrees
* precipitation values are greater than 1.75 inches
* snow loads are greater than 70 pounds per square foot

Selected Area in Northern Idaho

Similar comparisons can be made in the lower part of Table 4 for the selected area of Northern Idaho. The first category has consistently lower values than the second. The igneous extrusive and surficial material groups contain 80 percent of the landslide occurrence above 1200 feet. The igneous intrusive and metamorphic material groups contain eighty percent of the landslides above an elevation of 2300 feet. This is reasonable since the material of the second category is often exposed in the higher elevations of Northern Idaho. I do not consider the percentiles for the surficial material group to be reliable estimates because of the small sample size.

Slope Aspect

Figure 4 is a bar graph showing the relative frequency of failure for natural slopes in the four selected directions of slope aspect. The slope aspect for landslides is uniformly distributed in each direction measured. Figure 5 shows the relative frequency of landslides and slope aspect for each material group in North Idaho. These graphs show that there is a slight directional preference in a) the northern quadrants for landslides associated with igneous materials and b) the eastern quadrants for landslides associated with the sedimentary material group.

Precipitation and Snow Load

Before estimating the map values the two dimensional, omnidirectional variograms generated for each digitized map block required a preliminary check to assure that no digitized point was entered more than once. Since the variogram program checks distances between points, the distance between two points with the same coordinates results in a division by zero. Many variograms showed a slight "hump" reflecting a local dome of map values. This effect is shown in the graph for the precipitation map block 11, Appendix E-1. Several of the variograms may warrant a power

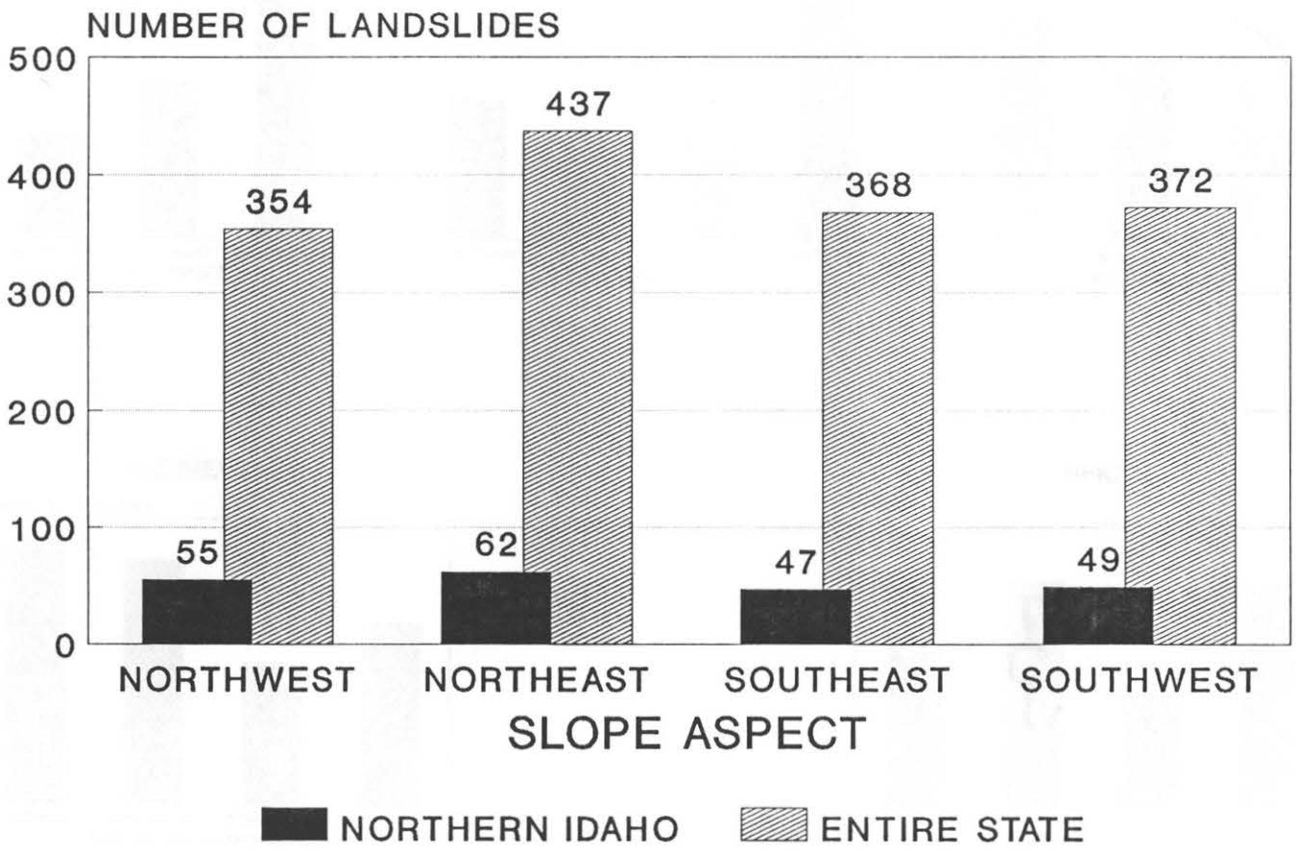


Figure 4: Distribution of Landslide Slope Aspect

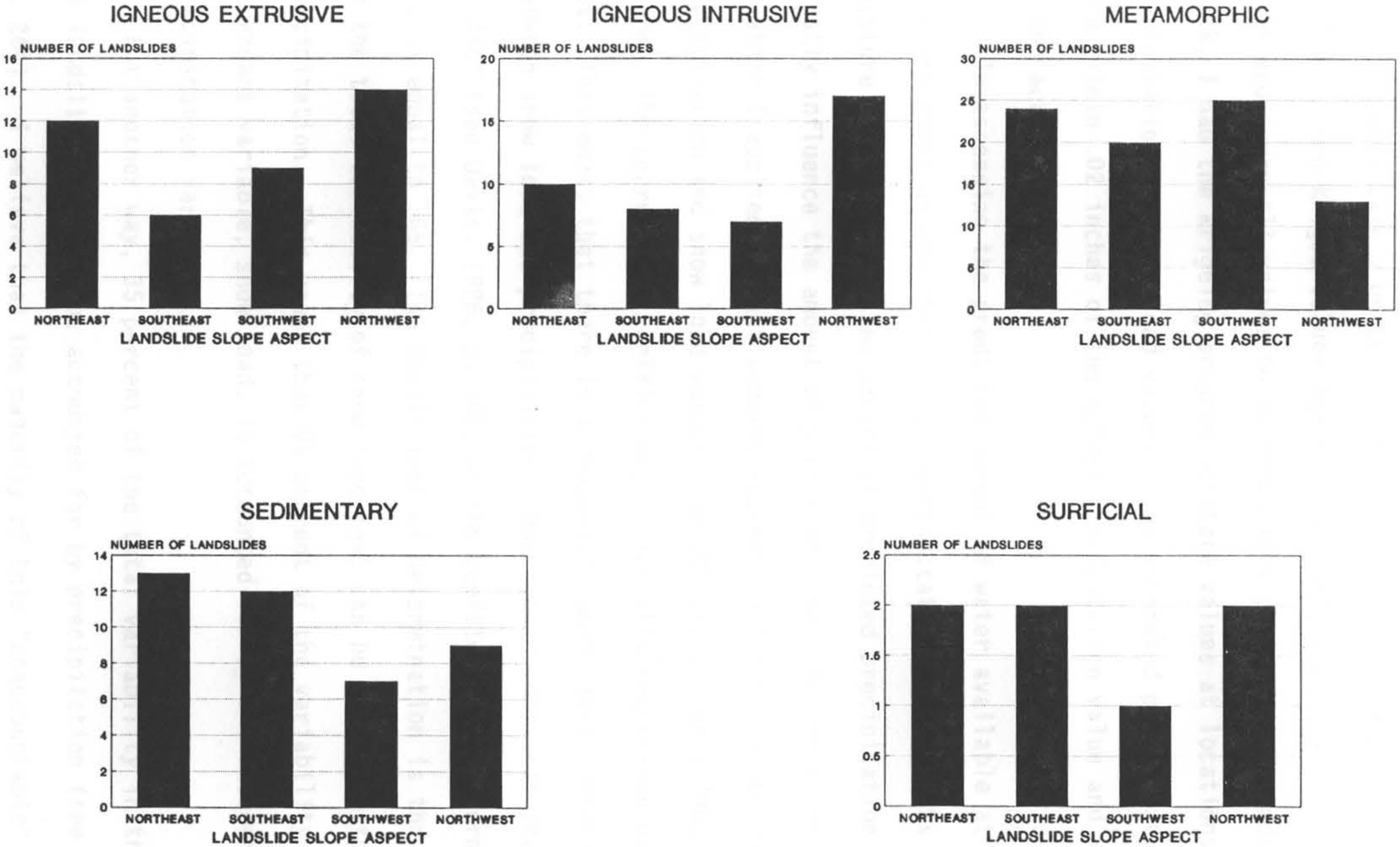


Figure 5: Distribution of Aspect for North Idaho Landslide Material Groups.

model to facilitate a better fit to the data. However, I checked a minimum of ten kriged values against the landslide locations in each map block and found all values to be reasonably close. As an additional check, I had the krigeing program estimate values at locations with known precipitation and snow load values. The estimated precipitation values were within .02 inches of the actual precipitation value and within .001 of the actual NSL value.

In assessing the predicted amount of water available at a landslide site one might assume that because precipitation measurements include moisture from snow that the amount of predicted precipitation would greatly influence the amount of predicted snow. To check this implied relation I applied a least squares regression fit to 213 pairs of precipitation and snow load values from the set of landslides in Northern Idaho. The correlation coefficient, r, for this regression was equal to .81. This means that there is a reasonably good linear relationship between snow load and precipitation. One should note that the "goodness of fit" (see Davis, 1986, p. 182) or the coefficient of determination, r^2, is equal to .65. The coefficient of determination is the proportion of the total variability of snow load that can be accounted for by precipitation. This means that 65 percent of the variability in the dependant variable, snow load, is accounted for by the independent precipitation variable.

Put another way, 35 percent of the total variability in the snow load at landslide sites is not accounted for by precipitation (see Ott, 1984, p. 264). I believe that the majority of this "unaccountable" variability is caused by two factors. First, snow load values are widely scattered in relation to the precipitation values. Second, the precipitation values I used were from the 50 MRI 6 year precipitation map. These precipitation values are typically used to represent the high intensity spring and summer storms which do not contain much precipitation in the form of snow.

STATISTICAL MODEL

The multivariate discriminant analysis is applied to problems where several measurements are collected for a given category of samples. The multivariate problem is envisioned using spatial coordinates in multidimensional space. The analysis used in this thesis develops a group of functions that can be used to assign a set of variables from each landslide to a landslide material group. The development of the discriminant functions were made by using the Statistical Analysis for Science (SAS, 1985). The analysis of landslides in Northern Idaho correctly assigned the surficial, igneous extrusive and intrusive material groups with reasonable success.

Discriminant Analysis

The multivariate problem of landslide occurrence is best considered as an analysis of several dimensions in space. The set of observed values for variables from landslides in this study, as Davis (1986) points out for multivariate data in general, are represented by spatial coordinates along certain dimensions. The discriminant analysis "selects" a linear combination of variables that produces the maximum difference between the predefined groups. Specifically, the analysis computes an axis orientation that minimizes the ratio of the difference between a pair of group multivariate means to the multivariate variances within the groups. In our case this linear combination, or discriminant function, transforms an original set of landslide measurements into a discriminant score. This score represents the position of the sample along a new line described by the linear discriminant function.

The two assumptions made in the derivation of the function are: 1) a normal distribution of variables and 2) homogeneity of variance. Harris (1975, p.231) indicates that these two assumptions rarely are valid for any real set of data. He asserts that even though an assumption is used in deriving a test for validity this does not mean that a violation of the original assumptions invalidates the function. Harris also reports that strong mathematical and empirical evidence are available to suggest that the discriminant analysis is not very sensitive to these assumptions.

In more simplified terms, the discriminant functions are used in this thesis to assign a collection of variables from a landslide to defined landslide material groups. The functions are derived by searching for a specific orientation of axes along which the group in question has the greatest separation from all other groups. The entire data set then is re-evaluated and each individual set of variables is assigned to a group based on the location (score) on the new axis described by the function. The success frequencies for the assignments are presented in the form of a table showing the number and percent of correctly assigned landslides.

In order to apply the discriminant analysis I selected the eight continuous and categorical variables for each matching landslide material group as shown in Table 5.

Table 5. Variables used in the Discriminant Analysis.

FUNCTION VARIABLES	METHOD OF MEASURE	TYPE
elevation	feet	continuous
slope	degrees	continuous
aspect	quadrant	categorical
formation contact	yes/no	categorical
faulting	yes/no	categorical
square mile area	square miles	continuous
precipitation	inches	continuous
snow load	pounds/square foot	continuous

The general form of the discriminant function was:

$$X_n = W_1A_1 + W_2A_2 + W_3A_3 \ . \ . \ . \ W_zA_z + C$$

Where: X = material group
W = coefficient or weight
A = site variable
C = constant
n = number of landslide material groups
z = number of site variables

Johnson and Winchern (1982, p.518) note that inclusion of qualitative, or categorical, variables often may prove useful in a discriminant function. They also warn that little theoretical basis exists to support "mixed" correlations.

Stepwise Selection of Variables

I applied the stepwise, discriminant analysis computer program STEPDISC available in SAS to make a selection of the variables having the most discriminating power. The first variable chosen is the most important single variable having the largest F test for regression based on a selected level of significance. The variable chosen next is combined with the first to form the pair that has the largest F and best improves the discrimination between groups. The selection of the variables with the largest F statistic proceeds, and some variables may be removed, until the next variable chosen adds little discriminating power to the model at the chosen level of significance. (Hair et al. 1979 and Ott, 1984).

I ran this selection process on landslide data from the area in Northern Idaho described earlier and outlined in Appendix F-1. The stepwise selection provided the following variables, in descending order of discriminating power, at the chosen 0.15 level of significance:

1 snow load
2 precipitation
3 formation contact
4 slope angle

As a word of caution, Johnson and Wichern (1982) have stated that the stepwise discriminant analysis may not select all of the most important variables. I consider these four variables the most important in this study for distinguishing between landslides associated with the five landslide material groups. To illustrate the idea of discriminating power the bar graph of Figure 6 presents the snow load distribution for three material types. As an example, a snow load of 50 psf in Figure 6 distinguishes mass movement likely associated with an igneous extrusive rock type.

I applied a canonical analysis using the program CANDISC (SAS, 1985) to cross validate the selected variables. Eighty percent of the

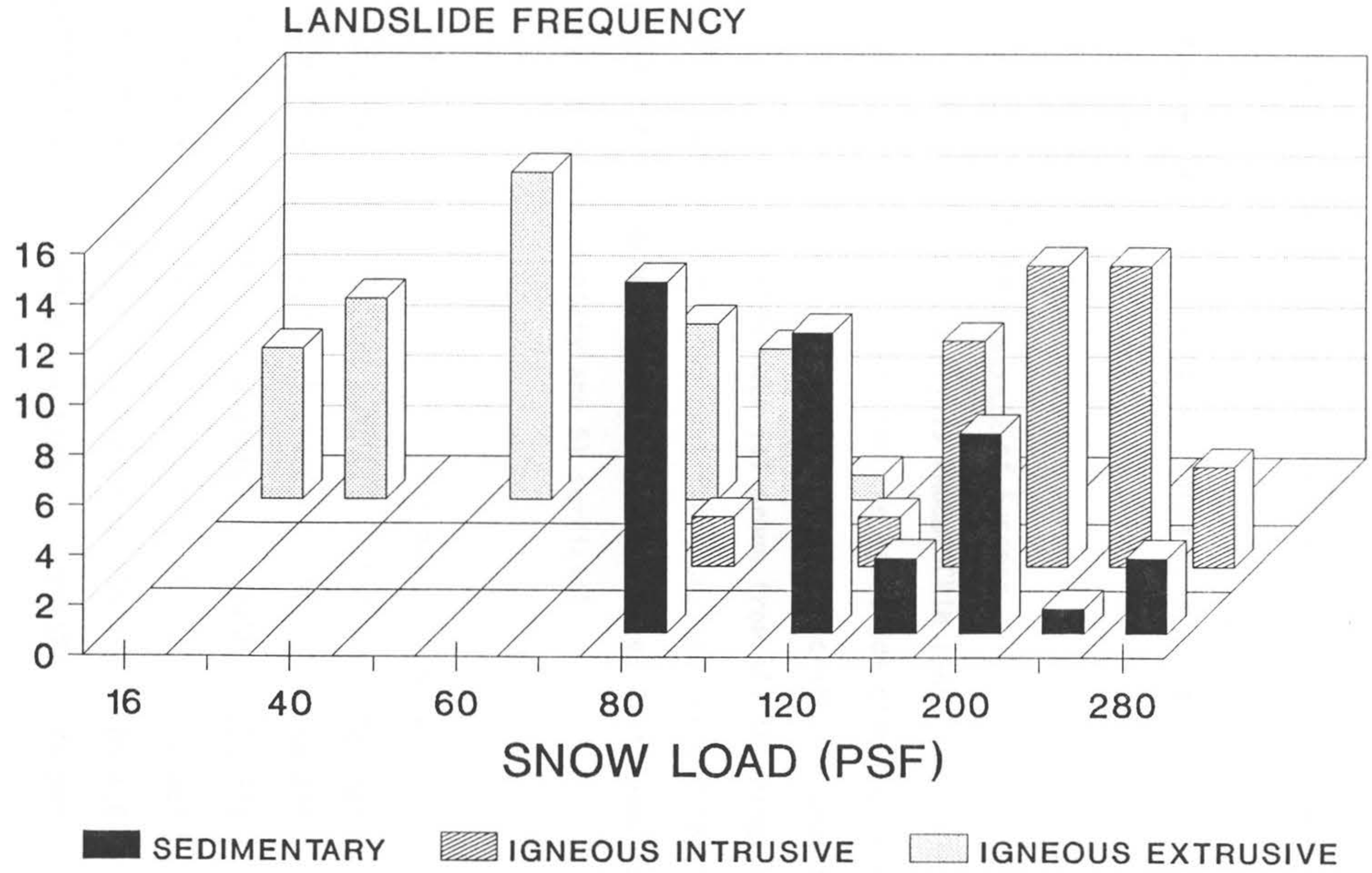


Figure 6: Example of Snow Load Values Assisting in the Distinction Between Three Selected Material Groups.

separation between the material groups was captured by the first canonical function. In relation to distinguishing material groups, this function identified a correlation between the variables of snow load and precipitation at the 0.01 level of significance. The program also identified snow load, precipitation, formational contact and slope angle at the 0.15 level of significance.

Discriminant Functions and Analysis of Success

I used the discriminant analysis PROCDISCRIM (SAS, 1985) to derive the discriminant functions and assign the landslide site characteristics into five groups. The discriminant functions describe the greatest separation for each landslide material group from all the other groups. Table 6 shows the linear discriminant functions and derived coefficients for the five material groups: 1) igneous extrusive, 2) igneous intrusive, 3) metamorphic, 4) sedimentary and 5) surficial.

Table 6: Discriminant Functions for Five Material Groups.

SCORE	SNOW LOAD	PRECIPITATION	CONTACT	SLOPE	CONSTANT
X_1 =	-.187(SN) +	101.476(P) +	5.644(C) -	.104(SP) -	84.376
X_2 =	-.157(SN) +	107.486(P) +	5.812(C) -	.023(SP) -	101.574
X_3 =	-.161(SN) +	103.548(P) +	5.871(C) -	.023(SP) -	93.068
X_4 =	-.158(SN) +	98.637(P) +	6.368(C) -	.019(SP) -	85.114
X_5 =	-.177(SN) +	96.849(P) +	3.499(C) -	.020(SP) -	76.902

With these equations the program analyzed the data from each landslide site to calculate five discriminant scores. The function that provided the highest score for each site identified the group to which the landslide characteristics have the greatest resemblance. After assigning all the landslides to groups, the success of this discrimination was checked against the classified value given in the data base. The assignment summary is shown in Table 7.

Table 7: Summary of Discriminant Analysis Success.

		NUMBER / PERCENT CLASSIFIED IN MATERIAL GROUP					
		1	2	3	4	5	TOTALS
ACTUAL MATERIAL GROUP IN DATABASE	1	**31/76**	0/0	1/2	1/2	8/19	41/100
	2	0/0	**30/71**	10/23	1/2	1/2	42/100
	3	11/13	35/43	**17/21**	12/15	7/9	82/100
	4	0/0	5/12	11/27	**18/44**	7/17	41/100
	5	1/14	0/0	0/0	0/0	**6/86**	7/100

As seen in the success frequencies, the four site variables best distinguish landslides associated with surficial material (group 5), where 86 percent of the occurrences were placed correctly. The analysis correctly assigned 76 and 71 percent of the landslides associated with igneous extrusive (group 1) and igneous intrusive (group 2) rock respectively. This model was less successful in discriminating landslides in metamorphic (group 3) and sedimentary (group 4) terrain.

The relative group assignment success can be attributed to the lack of similarities between some of the material groups. Table 8 is a summary of the percentile values for the four variables used to discriminate North Idaho landslide occurrence based on material types. In reviewing Table 8, the fiftieth percentile for the variables in the metamorphic and sedimentary categories are similar. This likeness decreases the discriminating power of the discriminant functions.

Table 8. Summary of Percentile Values for Landslide Site Variables from a Selected Area of Northern Idaho.

	SNOW LOAD (psf)	PRECIPITATION (in.)	CONTACT PRESENT (% yes)	SLOPE ANGLE (degrees)
PERCENTILE:	90/50/10	90/50/10		90/50/10
IGNEOUS EXTRUSIVE	75/45/11	1.81/1.63/1.58	51	27/15/6
IGNEOUS INTRUSIVE	260/205/140	2.20/2.14/1.98	28	40/28/11
METAMORPHIC	260/170/60	2.28/2.00/1.62	22	37/25/14
SEDIMENTARY	220/125/75	2.03/1.86/1.58	14	37/25/12
SURFICIAL	90/35/24	1.69/1.61/1.58	86	28/23/13

SUMMARY

The purpose of this thesis is to evaluate the relation between landslides in Idaho and several related site conditions. In this landslide study I gathered information about known landslide sites in order to attain two goals. The first goal was to evaluate the number of failures associated with earth-materials. The second goal was to determine the site characteristics that are most likely to promote failure in these materials. I propose that a reconnaissance level inventory of site conditions from known landslides coupled with a careful data analysis can direct an investigator to a particular earth-material that has significant landsliding potential.

The methods used in this study were based on a set of nine interactive site conditions collected during an inventory of known landslides in Idaho, (Adams and Breckenridge, in progress). The landslides were categorized by the "naturally occurring" materials in two ways using; 1) Varnes' rock, earth and debris types and 2) mapped geologic material units. The data describing each landslide site were gleaned from both published and unpublished notes and maps. The precipitation and snow load values were assigned after the initial inventory using a weighted averaging technique based on the spatial dependence of the values.

The selection of the landslide site characteristics was dependant on the scale of the inventory and on various sources of knowledge concerning the relations between slope stability, site geometry, material strength

and water conditions. The landslide material group was the major division for classification and site variables for these groups are distributed differently in different regions of the state. The distribution of variables is useful for a qualitative examination of the landslide potential for a given site or region. The discriminant analysis was applied to derive mathematical functions that used a given set of site variables in order to determine the landslide material most likely to produce a landslide. The discriminant functions developed in this thesis help to evaluate the failure potential for landslide material groups in a select region of Northern Idaho. The discriminant functions for surficial, igneous extrusive and igneous intrusive material groups have the best success for correct assignment with the given set of variables.

CONCLUSIONS AND RECOMMENDATIONS

Snow load and precipitation are identified as the two most important site characteristics for distinguishing landslides associated with different earth-materials. It is likely that earth-materials in the state vary in a way similar to the geographic distribution of snow load and precipitation. Specifically, some rock types are more resistant depending on the age, and comprise the steeper and higher regions in Idaho. Terzaghi (1950), however, implied that precipitation in the form of rain or snow is a principle agent to the progressive decrease in shear strength of earth-materials. I believe that a prerequisite for initiation of landslides in Idaho is the sudden increase in porewater pressure brought about by melting snow. The typical rain on snow event in Idaho is a precursor to landsliding and therefore a predictive model for landslides in Idaho should attempt to incorporate snowmelt and precipitation intensity.

In conclusion; precipitation, particularly in the form of snow, is a key factor in recognizing material types likely to be associated with slope failure in Idaho. This analysis of landslide occurrences in North Idaho can be successfully used to discriminate the landslide material group most likely to produce a landslide given the information on snow load, precipitation, formational contact and slope angle. Similar analyses in other select regions of Idaho would most likely result in an equal degree of success provided that a large enough number of landslide samples were obtained. It is prudent to warn that the distribution of variables may be different in other regions of Idaho. This variability is due to local environmental factors that may effect the selection of the variables having the most power for discrimination.

In retrospect I would recommend several changes in the methods and a more thorough examination of the possible interaction between variables. A validation of the discriminant functions derived in this study would help to determine the accuracy of the group assignments. This could be done with the random removal of a portion of the data set as described in Johnson and Wichern (1982, p. 490). This technique requires that the initial discriminant function is derived with a portion of the data set. The functions are checked by evaluating the success frequencies of group assignments for the withheld data set.

It also would be helpful to construct a simplified model which would derive one discriminant function to determine the likelihood of developing a landslide at a given site regardless of the material type. This would best be accomplished using a method similar to the ones described by Rice et al. (1985) or Roth (1983). These models use a regular grid to locate sample sites for a data set that has no known landslide occurrence. This set of variables would form a group to be compared with the group of known landslides.

Further discrimination based on groups of landslides in specified slope intervals may aid in prediction capabilities. Megahan et al. (1978) recognized that slope gradients vary according to slope position and that landslide frequency increases from the upper to lower portions of a slope. Similarly, intervals of elevation should be used for discrimination. A more rigorous analysis might include a series of discriminant analysis deleting one variable for each run in order to check the success for group assignments. These suggestions are a few of the many additions that could be combined in a thorough multivariate analysis and may require more time than is acceptable for a reconnaissance level identification of landslide susceptibility.

REFERENCES CITED

Adams, W.C. and Breckenridge, R.M., Landslides of Idaho, Idaho Geological Survey Surficial Map and Report Series, scale 1:500,000, in progress.

Agar, G., 1987, Personal communication, U.S. Forest Service, Idaho Panhandle National Forest, Idaho.

Clayton, J.L., Megahan, W.F. and Hampton, D., 1979, Soil and Bedrock Properties: Weathering and Alteration Products and Processes in the Idaho Batholith, U.S. Forest Service Research Paper Int-237, 55 pages.

Cook, K.B., 1984, Landslide Hazard Assessment Along a Portion of U.S. Highway 95, Idaho County, Idaho, M.S. Thesis, Washington State University, 85 pages.

Davis, J.C., 1986, Statistics and Data Analysis in Geology, John Wiley and Sons, New York, 646 pages.

Day, N.F., and Megahan, W.F., 1976, "Landslide Occurrence on Mountainous Terrain in North-Central Idaho: a Progress Report, 1974-75"; in Proceedings of the 14th Symposium on Engineering Geology and Soils Engineering, pages 85-105.

Ellen, S.D. and Fleming, R.W., 1987, "Mobilization of Debris Flows from Soil Slips, San Francisco Bay Region, California"; in Geological Society of America, Reviews in Engineering Geology, Vol. VII, pages 31-40.

Gonsior, M.J. and Gardner, R.B., 1971, "Investigation of Slope Failures in the Idaho Batholith", U.S. Forest Service Research Paper Int-97, 33 pages.

Hair, J.F., Jr., Anderson, R.E., Tatham, R.L. and Grablowsky, B.J., 1979, Multivariate Data Analysis, Petroleum Publishing Company, Tulsa, Oklahoma, 360 pages.

Hammond, C.J., Miller, S.M. and Prellwitz, R.W., 1988, Estimating the Probability of Landslides Using Monte Carlo Simulation; in Proceedings of the 24th Symposium on Engineering Geology and Soils Engineering, pages 317-331.

Harris, R.J., 1975, A Primer of Multivariate Statistics, Academic Press, Inc, New York, N.Y., 332 pages.

Hultman, W., 1988, Geotechnical Investigation of the Grouse Creek Slope Failure, M.S. Thesis, University of Idaho, 131 pages.

REFERENCES CITED (CONTINUED)

Hunt, R.E., 1984, Geotechnical Engineering Investigation Manual, McGraw-Hill, Inc., New York, N.Y., 983 pages.

Johnson, R.A. and Wichern, D.W., 1982, Applied Multivariate Statistical Analysis, Prentice-Hall Inc., New Jersey, 594 pages.

Jones, A.L., 1988, Spatial and Temporal Analysis for Idaho Earthquake Hazard Assessments, M.S. Thesis, University of Idaho, 73 pages.

McHugh, M.H., 1986, Landslide Occurrence in the Elk and Sixes River Basins, Southwest Oregon, M.S. Thesis, Oregon State University, 106 pages.

Megahan, W.F., Day, N.F. and Bliss, T.M., 1978, Landslide Occurrence in the Western and Central Northern Rocky Mountain Physiographic Province in Idaho; in Fifth North American Forest Soils Conference, Fort Collins, Colorado, August 1978, pages 116-139.

Megahan, W.F., 1984, Snowmelt and Logging Influence on Piezometric Levels in Steep Forested Watersheds in Idaho; in Soil Reinforcement and Moisture Effects on Slope Stability, Transportation Research Record 965, pages 1-8.

Miller, J.F., Frederick, R.H. and Tracey, R.J., 1974, Precipitation-Frequency Atlas of the Western United States, National Oceanic and Atmospheric Administration Atlas 2, Vol. V Idaho, 43 pages.

Ott, L., 1984, An Introduction to Statistical Methods and Data Analysis, Prindle, Webber and Schmidt Publishers, Boston Massachusetts, 775 pages.

Prellwitz, R.W., Howard, T.R. and Wilson, W.D., 1983, Landslide Analysis Concepts for Management of Forest Lands on Residual and Colluvial Soils, Transportation Research Record 919, pages 27-36.

Rice, R.M., Pillsbury, N.H. and Schmidt, K.W., 1985, A Risk Analysis for Using Discriminant Functions to Manage Logging Related Landslides on Granitic Terrain; in Forest Science, Society of American Foresters, Vol. 31, No. 3, pages 772-784.

Roth, R.A., 1983, Factors Affecting Landslide Susceptibility in San Mateo County, California; in Bulletin of the Association of Engineering Geologists, Vol. XX, No. 4, pages 353-372.

REFERENCES CITED (CONTINUED)

Sack, R.L. and Sheikh-Taheri, A., 1986, Ground and Roof Snow Loads for Idaho, University of Idaho, 42 pages.

SAS Institute Inc., 1985, Statistical Analysis for Science Users Guide, Cary, N. C., 1290 pages.

Scalan, T.M., 1986, Geology and Landslide Hazards of the Dunnigan Creek 7 1/2 Minute Quadrangle, Boise County, Idaho, Moscow, M.S. Thesis, University of Idaho, 68 pages.

Swanson, F.J. and Swanston, D.S., 1977, Complex Mass-Movement Terrains in the Western Cascade Range, Oregon; in Reviews in Engineering Geology, Geological Society of America, Vol. III, pages 113-124.

Swanston, D.N. and Swanson, F.J., 1976, Timber Harvesting, Mass Erosion and Stepland Forest Geomorphology in the Pacific Northwest; in Coates, D.R., (ed.), Geomorphology and Engineering: Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa., pages 199-221.

Terzaghi, K., 1950, Mechanism of Landslides; in Engineering Geology, Geological Society of America, Berkey Volume, pages 83-123.

Varnes, D.J., 1978, Slope Movement Types and Processes; in Landslides: Analysis and Control; in Shuster, R.L., Krizek, R.J., (eds.), Transportation Research Board, National Academy of Sciences, Special Report 176, Washington, D.C., pages 11-33.

Wieczorek, G.F., 1987, Effect of Rainfall Intensity and Duration on Debris Flows in Central Santa Cruz Mountains, California; in Reviews in Engineering Geology, Geological Society of America, Vol. VII, pages 93-114.

Williamson, D.A., 1965, Areal Slide Investigation; Green Peter Dam, Reports and Tables, unpublished report for the U.S. Army Corps of Engineers.

Wilson, W.D., 1987, Personal communication, U.S. Forest Service, Clearwater National Forest, Idaho.

Wu, T.H. and Swanston, D.N., 1980, Risk of Landslides in Shallow Soils and its Relation to Clearcutting in Southeastern Alaska; in Forest Science, Vol. 26, No. 3, pages 495-510.

Zaruba, Q., and Mencl, V., 1969, Landslides and Their Control, Elsevier, New York, and Academia, Prague, 205 pages.

APPENDIX A

INDIVIDUALS CONTRIBUTING LANDSLIDE DATA

Idaho Department of Transportation, Division of Highways

Bryant Brown, 1987, Unpublished Field Notes, Division of Highways.

Pat Lightfield, 1987, Unpublished Field Notes, Division of Highways.

Bob Smith, and Tri Buu, 1987, Unpublished Field Notes and Reports, Division of Highways, Boise.

Dick Sorenson, 1987, Unpublished Field Notes, Department of Highways, District 4.

Jim Winger, 1987, Unpublished Field Notes, Division of Highways, District 5.

Idaho Geological Survey

Wayne Adams, 1987, Unpublished Field Notes, Idaho Geological Survey.

Bill Bonnichson, 1987, Unpublished Field Notes, Idaho Geological Survey.

Roy Breckenridge, 1987, Unpublished Field Notes, Idaho Geological Survey.

Kurt Othberg, and Steve Wood, 1987, Unpublished Field Notes, Idaho Geologic Survey.

Carl Savage, 1973, Unpublished Engineering Geology Maps and Field Notes of the Coeur d'Alene area, Idaho, Idaho Bureau of Mines and Geology.

Individuals

Glen Embree, 1987, Unpublished Field Notes and Maps, Ricks College.

Robert Howard and Chris Beck, Howard Consultants Incorporated, 1987, Geotechnical Evaluation of Lane County Landfill, Idaho, 14 pages.

U.S. Army Corps of Engineers

LeeAnn Pugh, 1987, Unpublished Field Notes, Army Corps of Engineers.

U.S. Bureau of Land Management

Ted Carrol, 1987, Unpublished Field Notes, Bureau of Land Management.

Gene Decker, 1987, Unpublished Field Notes, U.S. Bureau of Land Management, Boise District Office.

David Fortier, 1987, Unpublished Field Notes, Bureau of Land Management, Cour d'Alene District Office.

Alan Harkness, 1987, Unpublished Field Notes, U.S. Bureau of Land Management, Boise District Office.

David Jeppson, 1987, Unpublished Field Notes, Bureau of Land Management, Idaho Falls District.

Kurt Koch, 1987, Unpublished Field Notes, Bureau of Land Management, Burley District Office.

Norm Satter, 1987, Unpublished Field Notes, Bureau of Land Management.

Ted Weasma, 1987, Unpublished Field Notes, U.S. Bureau of Land Management, Boise District Office.

Tom Woodward, 1987, Personal Communication, Bureau of Land Management, Boise District Office.

U.S. Forest Service

George Agar, 1987, Unpublished Field Notes, Idaho Panhandle National Forest.

Norm Bare, 1987, Unpublished Field Notes, Caribou National Forest.

Dave Gilman, 1987, Unpublished Field Notes, Salmon National Forest.

Hamilton,R., 1987, Unpublished Field Map, Salmon National Forest.

Gary Jackson, 1987, Unpublished Field Notes, Salmon National Forest.

Rich Kennedy, 1983, Unpublished Field Notes, NezPerce National Forest.

Walt Megahan, 1987, Unpublished Field Data, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Duane Monte, 1987, Unpublished Field Notes and Maps, Challis National Forest.

Jerry Nehoff, Jim Northrup, and Bill Beach, 1987, Unpublished Field Notes, Idaho Panhandle National Forest.

Earl Olson, 1987, Unpublished Field Maps, U.S. Forest Service, Region 4.

Ken Radek, 1987, Unpublished Field Notes and Maps, Targhee National Forest.

Rees.T.H., and Madenka,G., 1987, Unpublished Field Maps, Challis National Forest.

Dale Wilson, 1987, Unpublished Field Notes, Clearwater National Forest.

U.S. Geological Survey

Stuart Gutenburger, 1987, Unpublished field notes, Water Resources Division, Sandpoint.

APPENDIX B

DEFINITIONS OF SITE CHARACTERISTICS

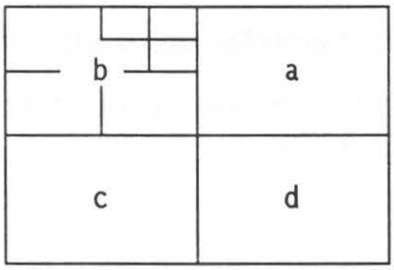
MREF: Landslide Map reference number penciled in and circled on the reference map or notes.

BIB: The chronologic reference number from the preliminary bibliography.

LAT.: The latitude of the approximate center of the mass. In thousandths of a degree, e.g. 44.413.

LONG.: The longitude of the approximate center of the mass. Same degree of accuracy as latitude.

T R SEC: The Township, Range, and Section that contains the majority of the mass. The section number is followed by a maximum of three letters to denote the quarter sections, see the example below:



e.g. T27N R4E SECTION 27 b,a,d is entered as: 27N 4E 27 bad

ELEV: Elevation of the adjacent "natural" ground closest to the center of mass in feet. (i.e. 2700)

SLOPE: The text in this column refers to the average degree inclination of the "undisturbed" ground. This is used to estimate the "natural slope" near where movement has occurred, (e.g. not the slope of the actual mass). Notice that this will be difficult to measure on small map scales.

ASP: Aspect of the slope is the compass quadrant toward which the slope faces. Enter a maximum of two letters such as; N,S,E,W, or NW,NE,SW,SE.

TYPE: See the attached abbreviations summary for types of mass movement. These abbreviations are to be entered only when field verified or documented. See Varnes (1978).

LITH: See the attached abbreviations summary for rock types or origin abbreviations of the underlying material at the site occupied by the mass. (If more than one formation is contained by the site boundaries, choose the formation which is most likely to have a lower shear strength or leave this column blank.)

C?: Contact present.

"Y" denotes that a formational contact intersects the middle half of the mass.

"N" denotes that a formational contact does not intersect the middle half

of the mass.

F?: Fault present.

"Y" denotes that a fault intersects the mass.

"N" denotes that a fault does not intersect the mass.

S MI: Is used as an approximate measure of the square mile area of the mass measured to the thousandth of a square mile. (e.g. 0.052 S MI)

APPENDIX C

LANDSLIDE REPORT FORM

MASS MOVEMENT INFORMATION REPORT
Idaho Geological Survey
Morrill Hall, Room 332
Moscow, Idaho 83843

Name______________
Organization______
Date______________
Phone_____________

Location of Feature (as T14N-R3E-SEC23) ______________________________

Location in Section

Major Road______________________________

County____________ Quadrangle Map______________
(attach copy of map showing location if possible)

Elevation (feet) ______________________________
Natural Slope (degrees) ______________________________
Azimuth Direction Slope Faces ______________________________
Vegetative Cover ______________________________

Lithology____
(type of materials; e.g., colluvial soil over limestone)

Type of Feature (see attached examples, check best answer)

____ Rock fall
____ Rock slump
____ Rock slide
____ Rock glacier
____ Earth slump
____ Earth slide
____ Earth flow
____ Complex
____ Debris slide
____ Debris flow
____ Debris avalanche

The feature is: (check best answer)

____ Active
____ Natural
____ Inactive
____ Man-induced

Date of Last Movement, or age (if known)__________________

Estimate:
Area (sq. ft.)________ Cost of Damage________________
Cost for Repair________________

Cause of Movement (stream cut, road cut failure, etc.)
____

Include additional comments or information on reverse.

APPENDIX D-1

EXAMPLE OF INVENTORY DATA FILE

REF	LAT	LONG	T	R	SEC	ELEV	SLOPE	ASP	TYPE	LITH	C	F	SQ_MI
** DATA BY BIBLIOGRAPHICAL ENTRY 56													
56	45.81	115.91	29N	4E	36 BC	4100	10	E	LS	QTZT	.T.	.F.	0.160
56	45.71	115.99	27N	4E	5 B	5000	13	N	LS	SHST	.F.	.F.	0.130
** Subtotal **													
													0.290
** DATA BY BIBLIOGRAPHICAL ENTRY 57													
57	45.71	116.37	27N	1E	E CC	3000	9	SE	LS	BA	.T.	.T.	0.160
57	45.67	116.29	27N	1E	14 D	2200	13	S	LS	BA	.F.	.T.	0.190
57	45.67	116.27	27N	1E	3 D	2100	13	S	LS	BA	.F.	.T.	0.400
** Subtotal **													
													0.750
** DATA BY BIBLIOGRAPHICAL ENTRY 63													
63	44.88	114.34	19N	18E	10 A	7000	4	N	LS	TUFF	.F.	.F.	2.400
63	44.95	114.31	19N	18E	26 B	6600	7	E	LS	TILL	.F.	.T.	1.380
63	44.93	114.15	19N	20E	31 B	6900	10	SE	LS	AND	.T.	.T.	0.250
63	44.94	114.09	19N	20E	27 C	7800	15	SE	LS	TUFF	.F.	.F.	0.250
63	44.90	114.01	18N	21E	7 D	5200	11	N	LS	AND	.F.	.F.	0.690
63	44.88	114.07	18N	20E	14 C	7000	11	NE	LS	AND	.F.	.T.	1.190
63	44.90	114.07	18N	20E	11 B	6200	10	NE	LS	AND	.T.	.T.	1.880
63	44.90	114.28	18N	18E	12 D	78001	19	NW	LS	QTZT	.F.	.F.	0.130
63	44.93	114.30	19N	18E	36 BC	7000	9	W	LS	TUFF	.F.	.F.	0.280
63	44.92	114.34	18N	18E	3 B	7100	10	N	LS	TUFF	.F.	.T.	1.940
63	44.89	114.32	18N	18E	15 A	6800	12	NE	LS	QTZT	.F.	.T.	0.630
63	44.82	114.48	17N	17E	5 D	6400	21	NW	LS	TUFF	.T.	.T.	0.500
63	44.81	114.14	17N	20E	7 D	7400	9	E	LS	TUFF	.F.	.T.	1.060
63	44.77	114.05	17N	20E	25 C	7500	13	NW	LS	TUFF	.F.	.T.	0.440
63	44.76	114.02	17N	21E	31 A	7600	14	E	LS	TUFF	.F.	.F.	0.630
63	44.75	114.02	16N	21E	6 A	7500	15	E	LS	TUFF	.F.	.F.	0.810
63	44.68	114.32	16N	18E	34 AB	8000	33	NE	LS	RHYO	.T.	.F.	0.160
63	44.63	114.83	15N	13E	14 AC	8200	22	NE	LS	TUFF	.T.	.F.	0.090
63	44.66	114.55	15N	16E	2 AC	7000	15	E	LS	TUFF	.F.	.T.	0.370
63	44.60	114.50	15N	17E	30 BB	8100	21	SE	LS	TUFF	.T.	.F.	0.060
63	44.59	114.32	15N	18E	34 A	6100	33	SE	LS	AND	.T.	.T.	0.560
63	44.60	114.31	15N	18E	27 A	6200	7	E	LS	AND	.T.	.F.	0.160
63	44.59	114.12	15N	20E	29 CA	5600	10	SE	LS	DACI	.F.	.F.	0.500
63	44.56	114.36	14N	18E	8 B	6500	17	NW	LS	DACI	.F.	.T.	0.880
63	44.51	114.34	14N	18E	28 B	6900	11	NW	LS	DACI	.F.	.F.	0.190
63	44.50	114.40	14N	17E	36 BD	7400	7	W	LS	DACI	.T.	.F.	0.190
63	44.51	114.44	14N	17E	27 D	7500	11	NW	LS	DACI	.F.	.T.	3.880
63	44.48	114.47	13N	17E	9 B	8000	6	N	LS	TUFF	.F.	.F.	0.810
63	44.49	114.36	13N	18E	4 B	8500	11	W	LS	SLAT	.F.	.F.	0.630
63	44.48	114.32	13N	18E	3 DC	6500	5	SE	LS	BA	.F.	.T.	0.190
63	44.26	114.26	13N	19E	31 B	6600	7	E	LS	BA	.F.	.T.	0.130
63	44.41	114.28	13N	18E	36 B	6200	13	E	LS	TUFF	.F.	.F.	0.340
63	44.40	114.37	13N	18E	31 C	8200	7	E	LS	QTZT	.F.	.F.	0.130
63	44.41	114.43	13N	17E	23 D	8800	9	NW	LS	TUFF	.F.	.F.	0.750
63	44.52	114.45	13N	17E	28 D	9000	7	E	LS	DACI	.F.	.T.	0.940
** Subtotal **													
													25.42

APPENDIX D-2

ABBREVIATIONS AND CODES USED IN DATA BASE

ASPECT

NAME	DEGREES	CODE	CODES FOR DISCRIMINANT ANALYSIS VECTOR	SINE	COSINE
NORTHWEST	270 - 0	1	315	-.71	+.71
NORTHEAST	0 - 90	2	45	+.71	+.71
SOUTHEAST	90 - 180	3	135	+.71	-.71
SOUTHWEST	180 - 270	4	225	-.71	-.71

VARNES' MATERIAL TYPE

NAME	CODE
ROCK	1
EARTH	2
DEBRIS	3
COMPLEX	4
UNCLASSIFIED	4

MAPPED GEOLOGIC MATERIAL

NAME	CODE
IGNEOUS EXTRUSIVE	1
IGNEOUS INTRUSIVE	2
METAMORPHIC	3
SEDIMENTARY	4
SURFICIAL	5

PRESENCE OF FORMATIONAL CONTACT

YES = 1

NO = 2

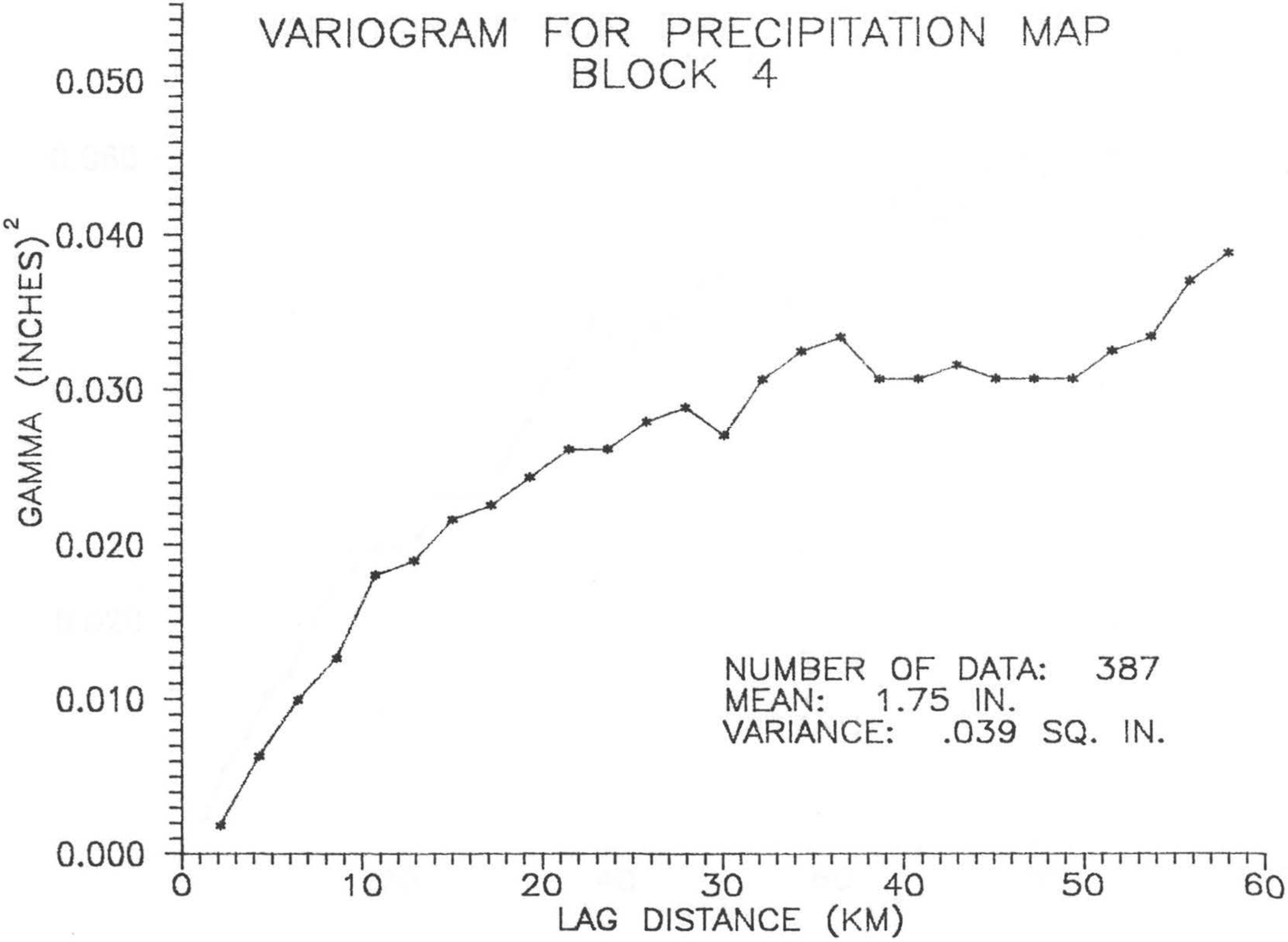
PRESENCE OF A MAPPED FAULT

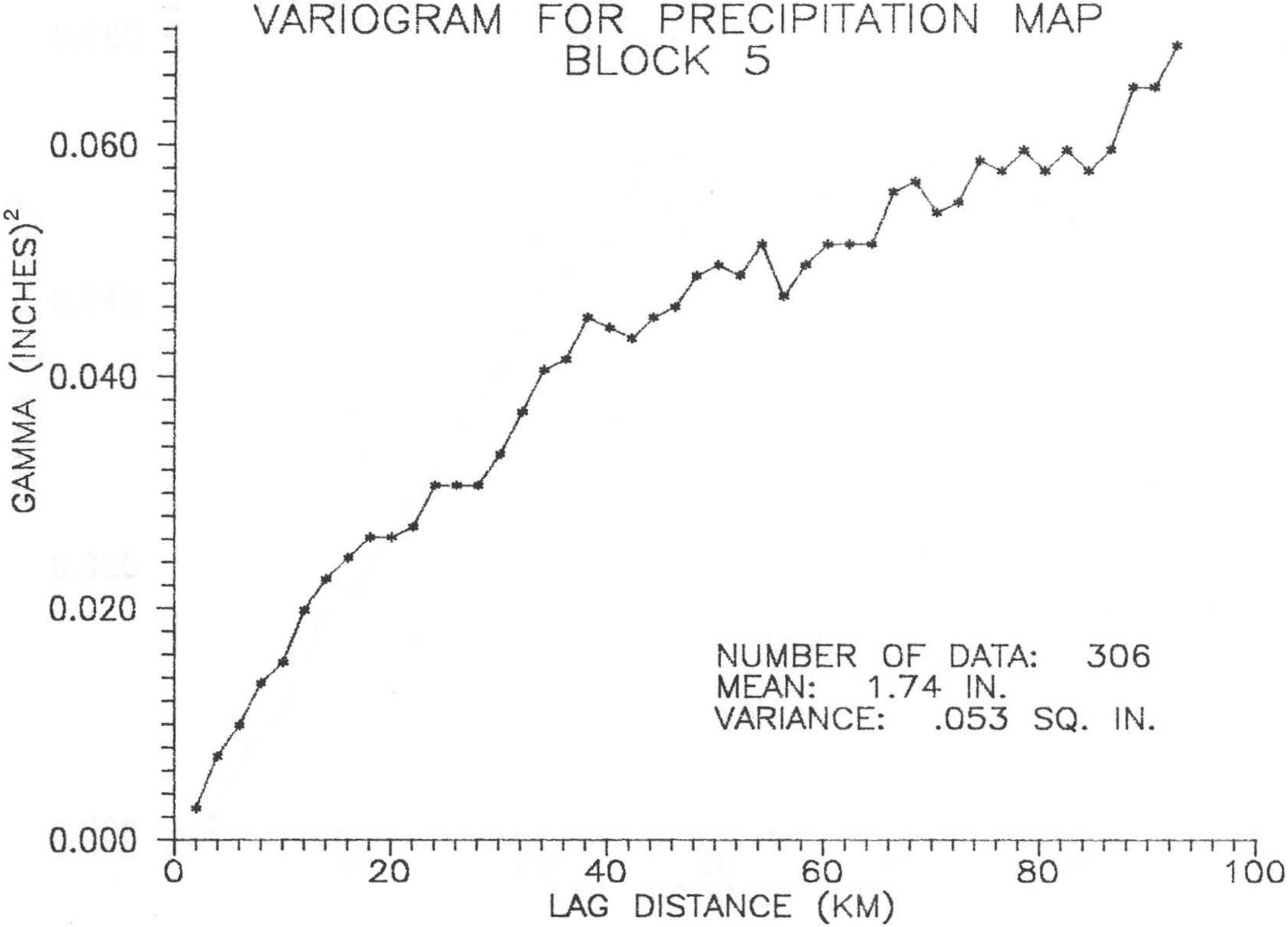
YES = 1

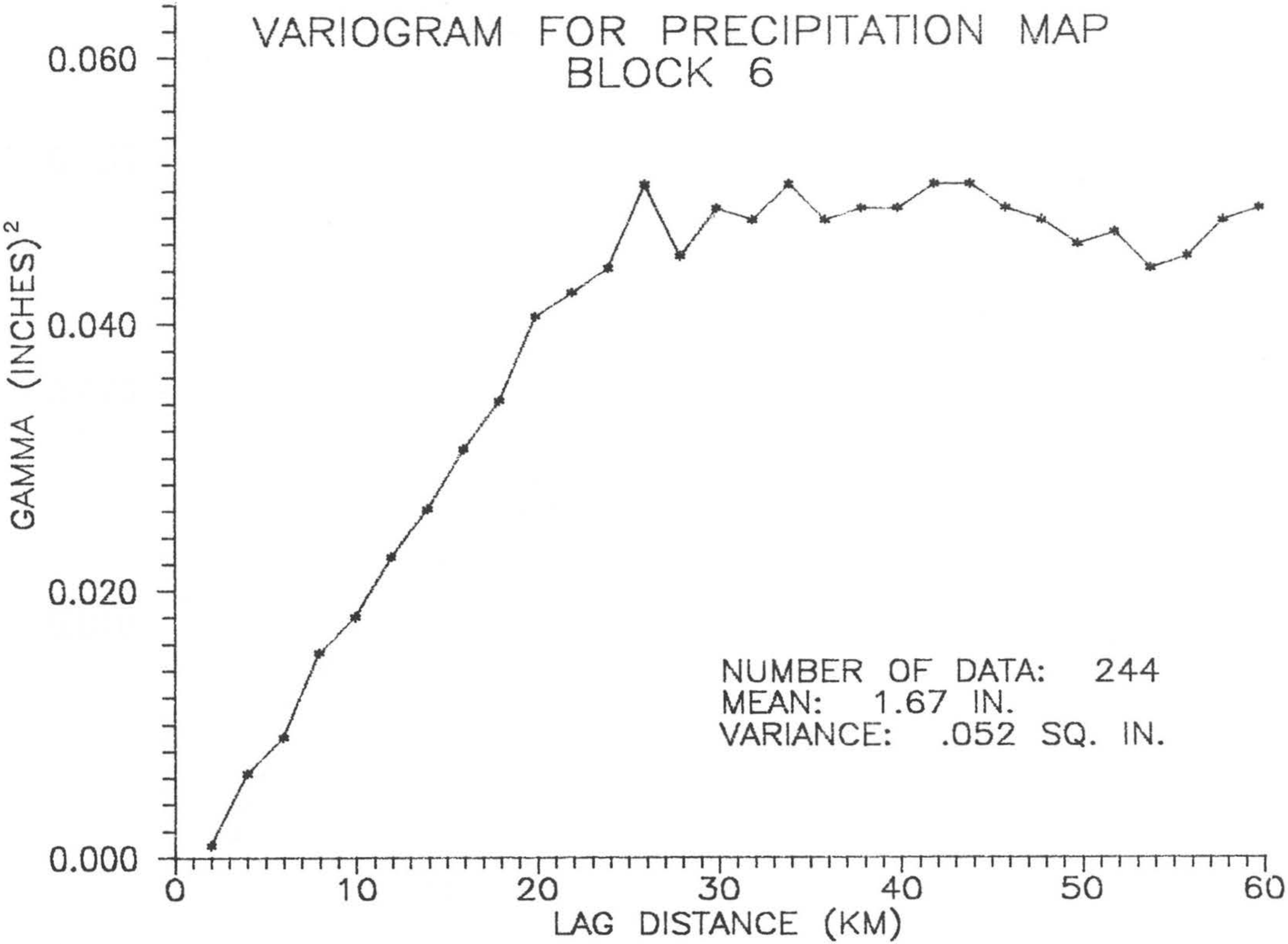
NO = 2

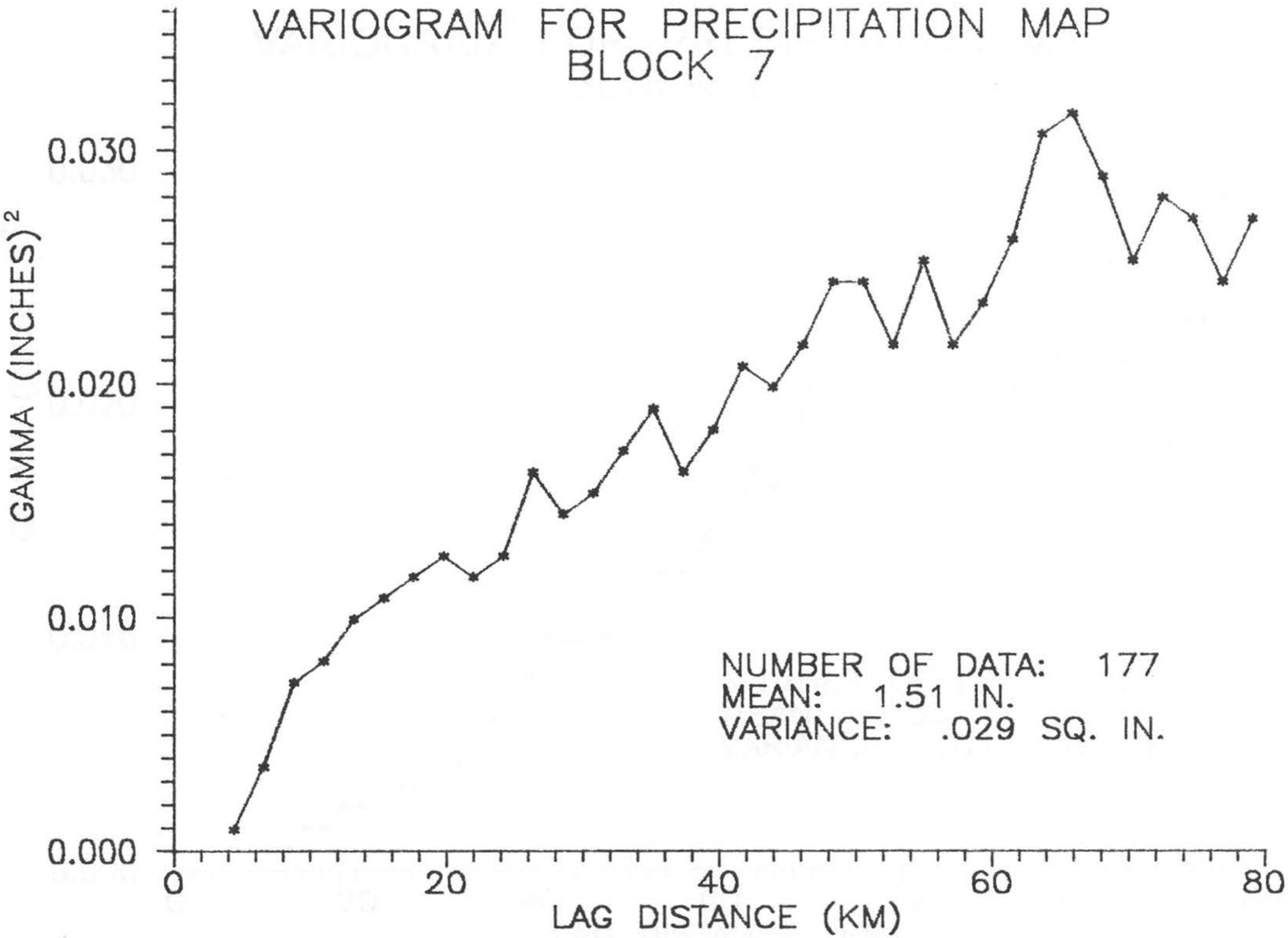
APPENDIX E-1

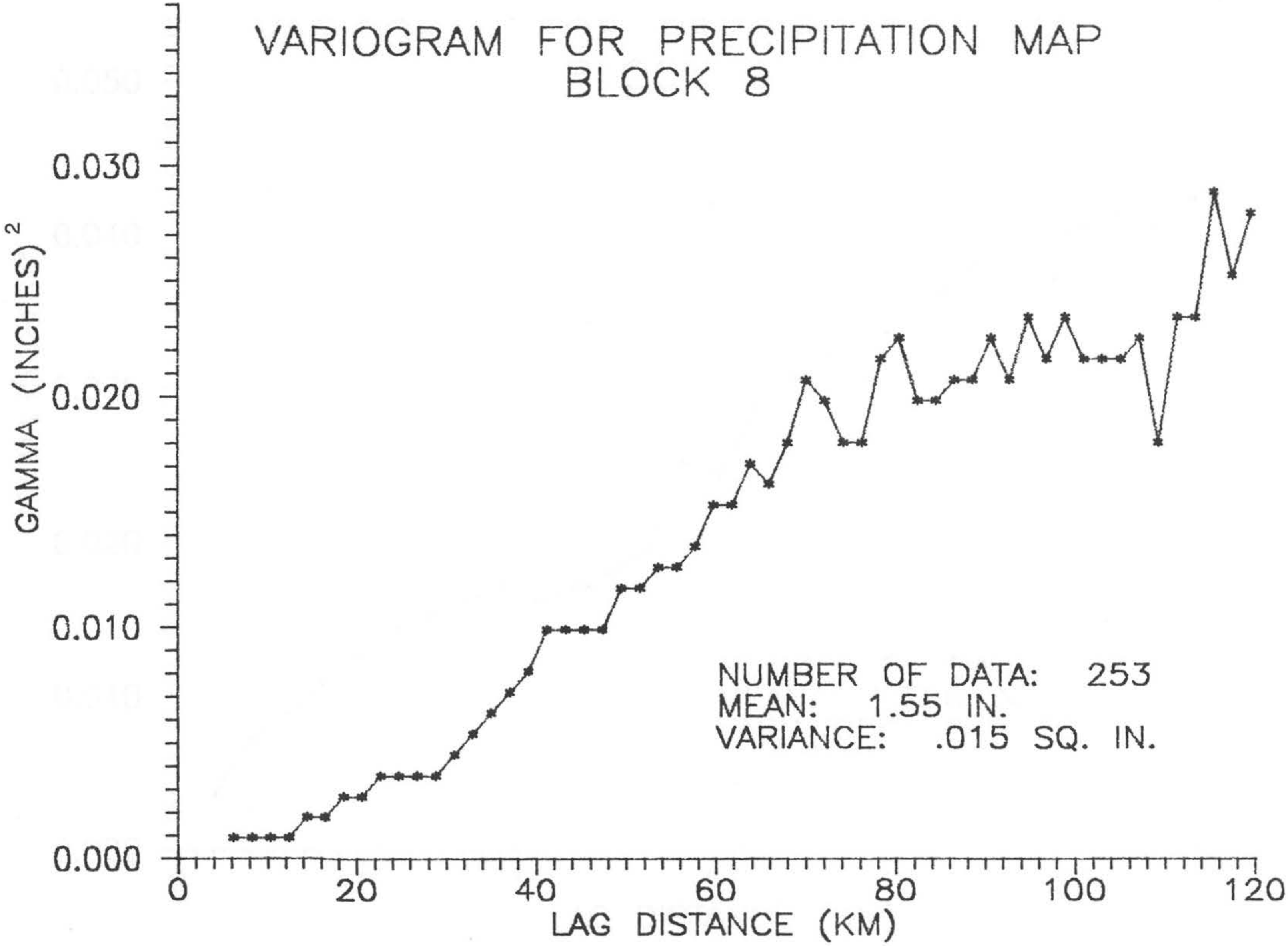
VARIOGRAMS FOR PRECIPITATION MAP

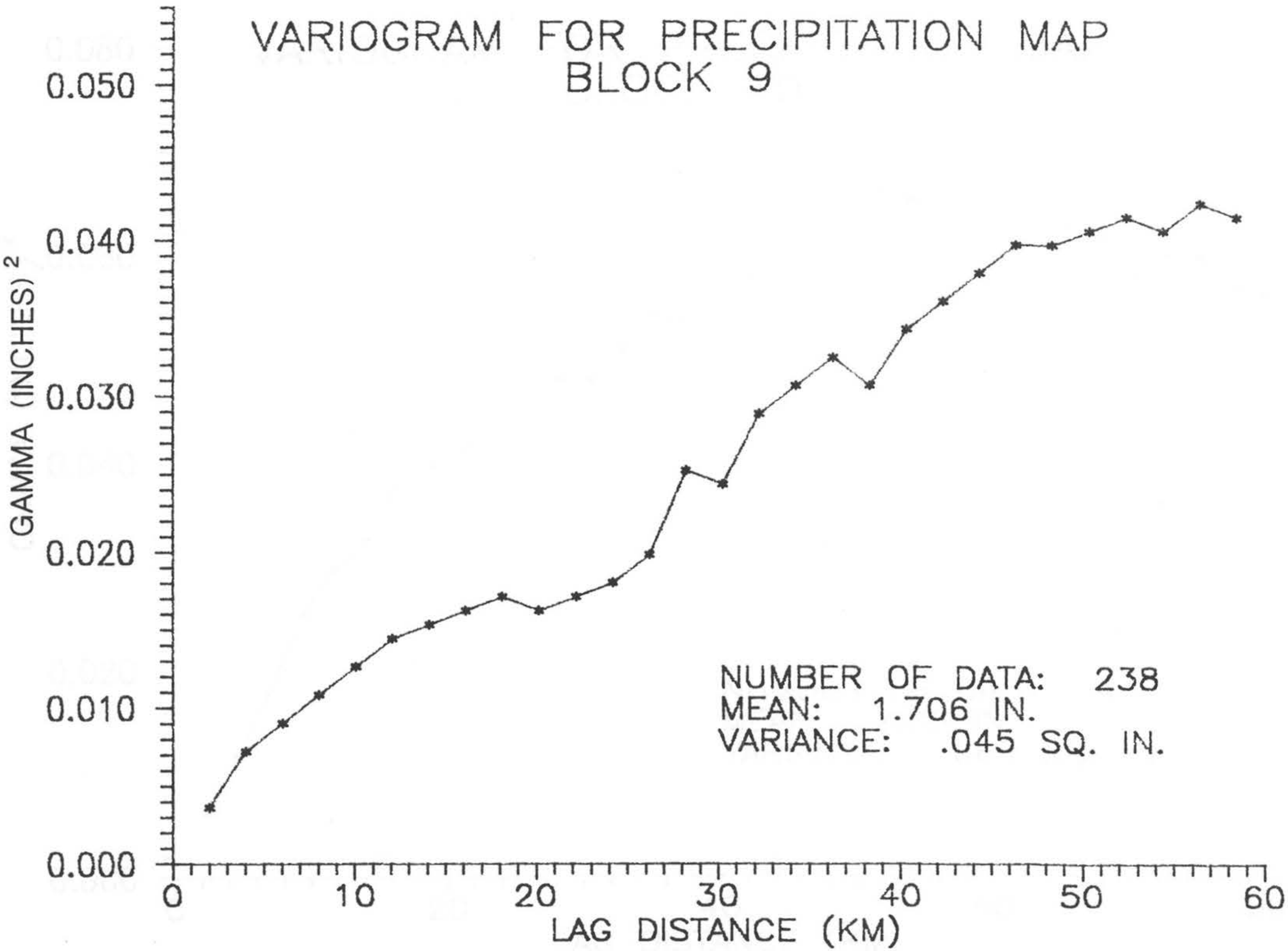

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 4
GAMMA (INCHES)²
0.050
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
50
60
LAG DISTANCE (KM)
NUMBER OF DATA: 387
MEAN: 1.75 IN.
VARIANCE: .039 SQ. IN.

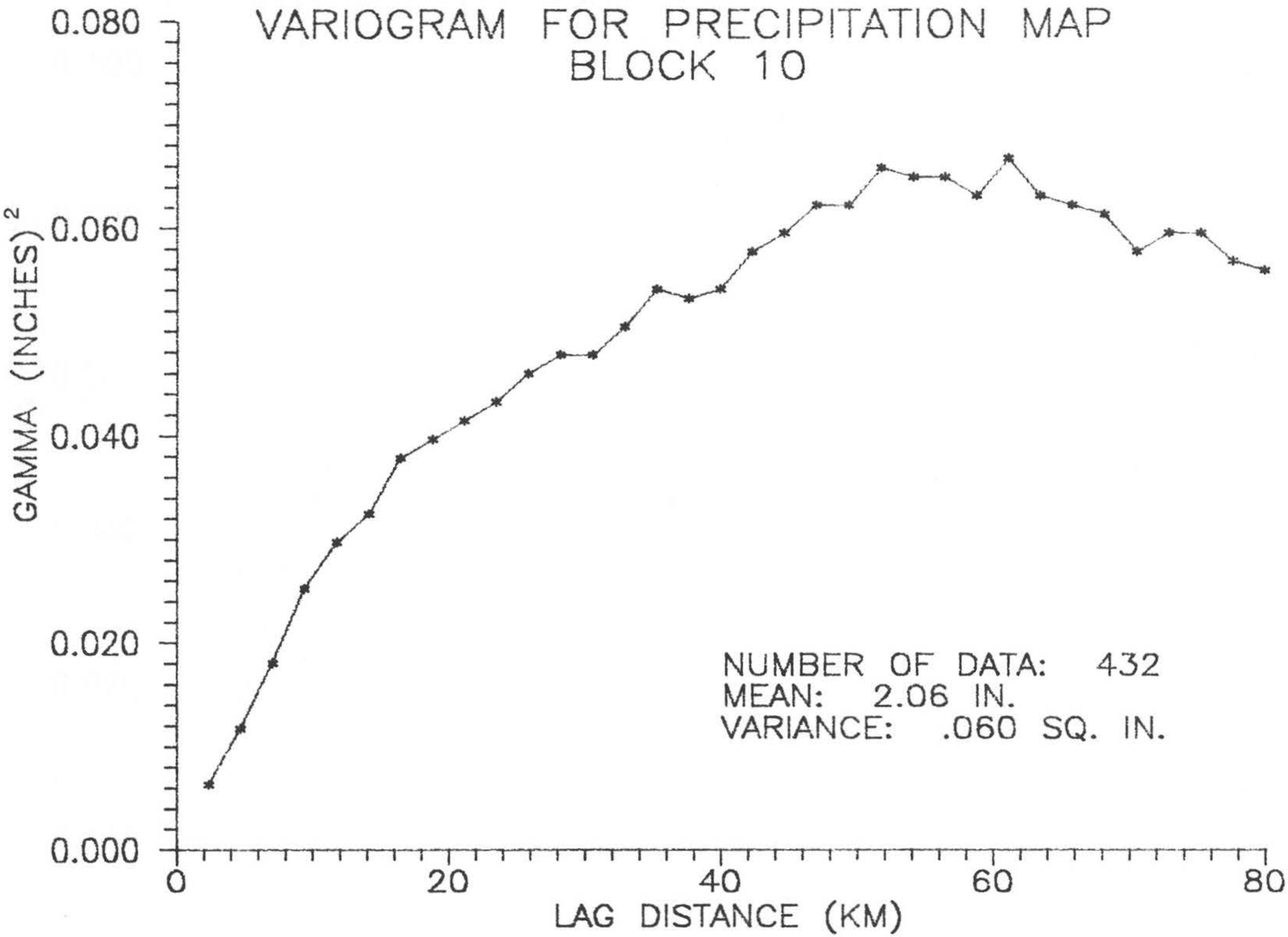

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 5
GAMMA (INCHES)^2
0.000
0.020
0.040
0.060
0
20
40
60
80
100
LAG DISTANCE (KM)
NUMBER OF DATA: 306
MEAN: 1.74 IN.
VARIANCE: .053 SQ. IN.

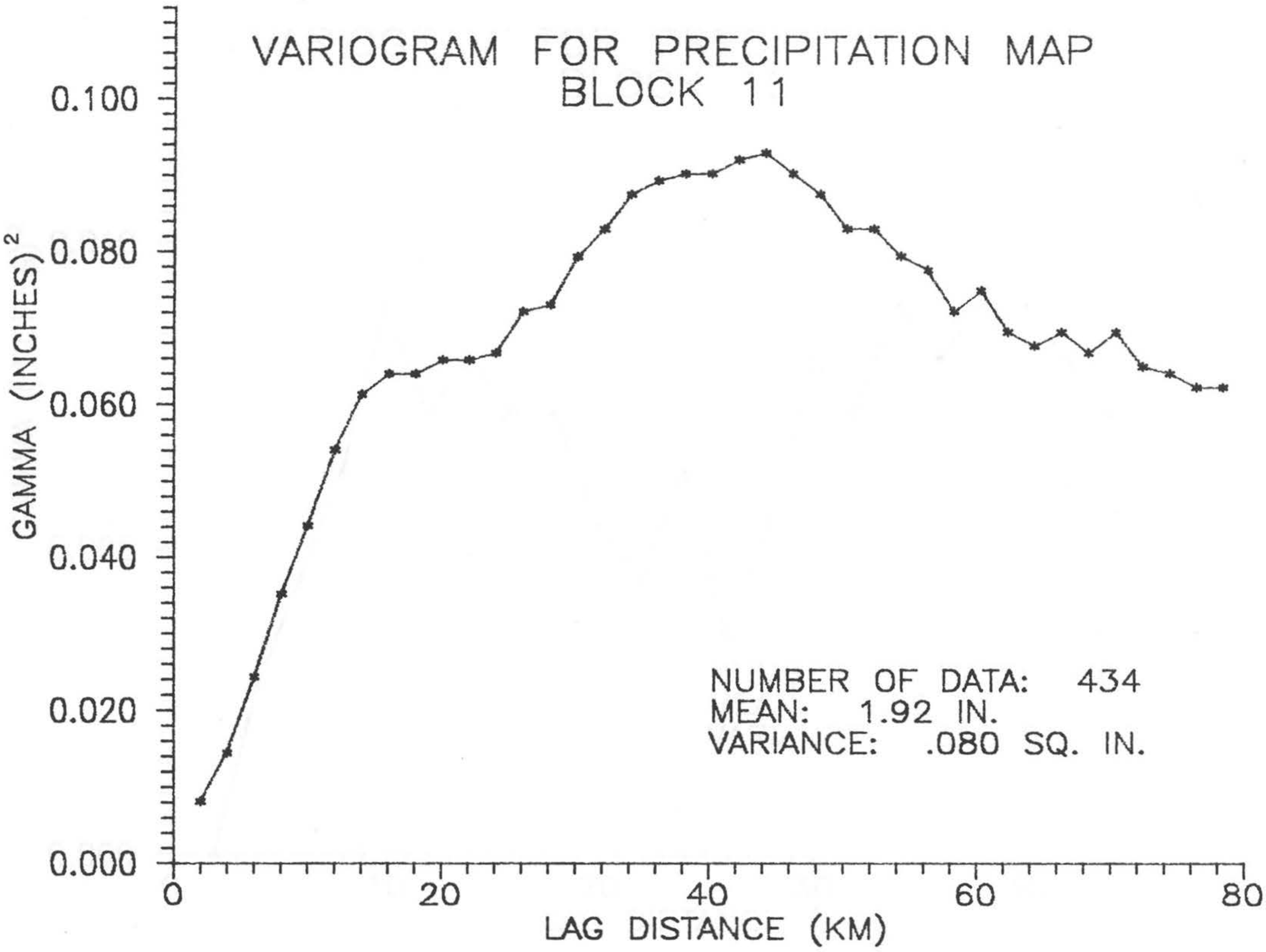

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 6
GAMMA (INCHES)^2
0.060
0.040
0.020
0.000
0
10
20
30
40
50
60
LAG DISTANCE (KM)
NUMBER OF DATA: 244
MEAN: 1.67 IN.
VARIANCE: .052 SQ. IN.

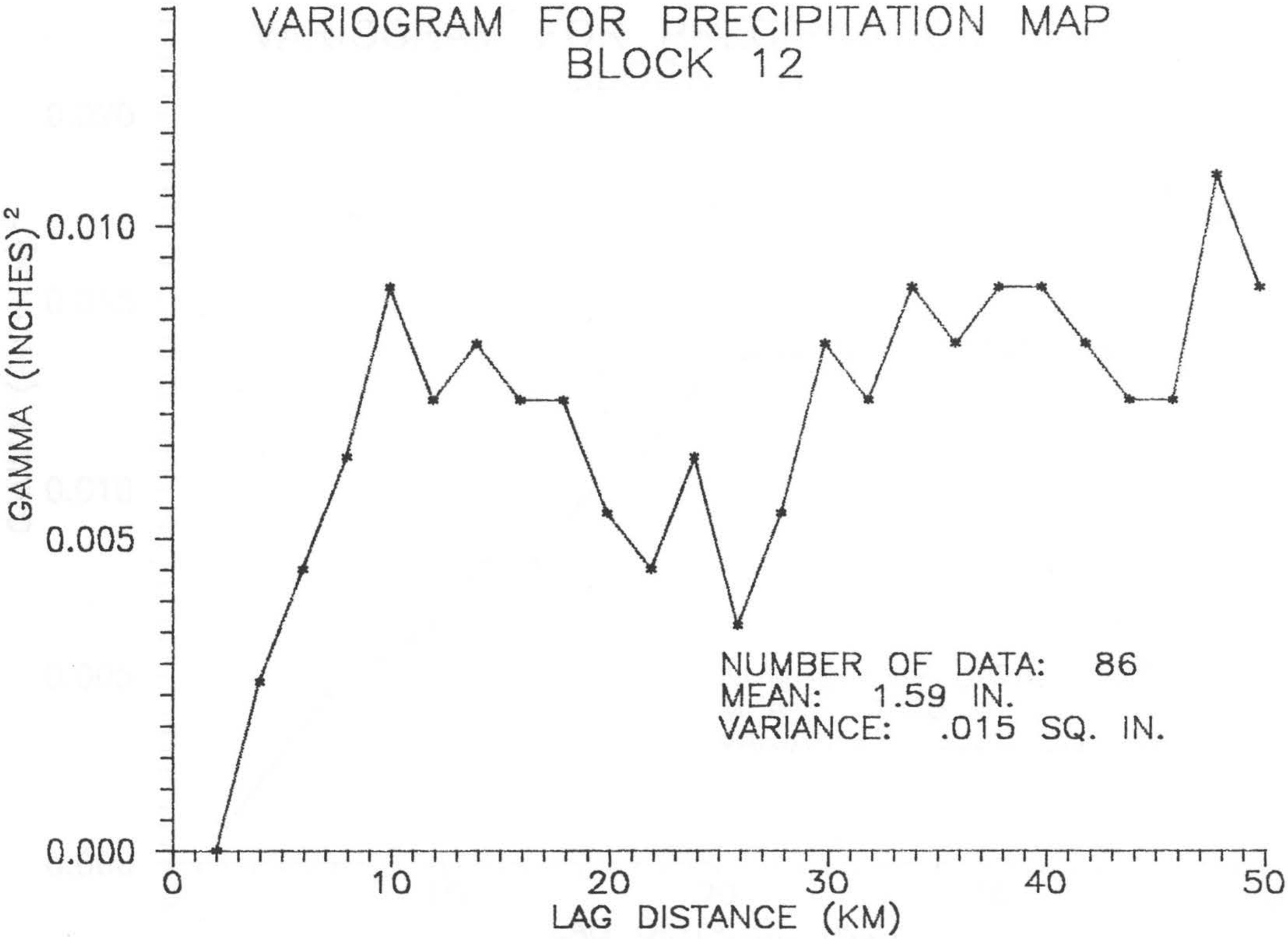

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 7
GAMMA (INCHES)²
0.030
0.020
0.010
0.000
0
20
40
60
80
LAG DISTANCE (KM)
NUMBER OF DATA: 177
MEAN: 1.51 IN.
VARIANCE: .029 SQ. IN.

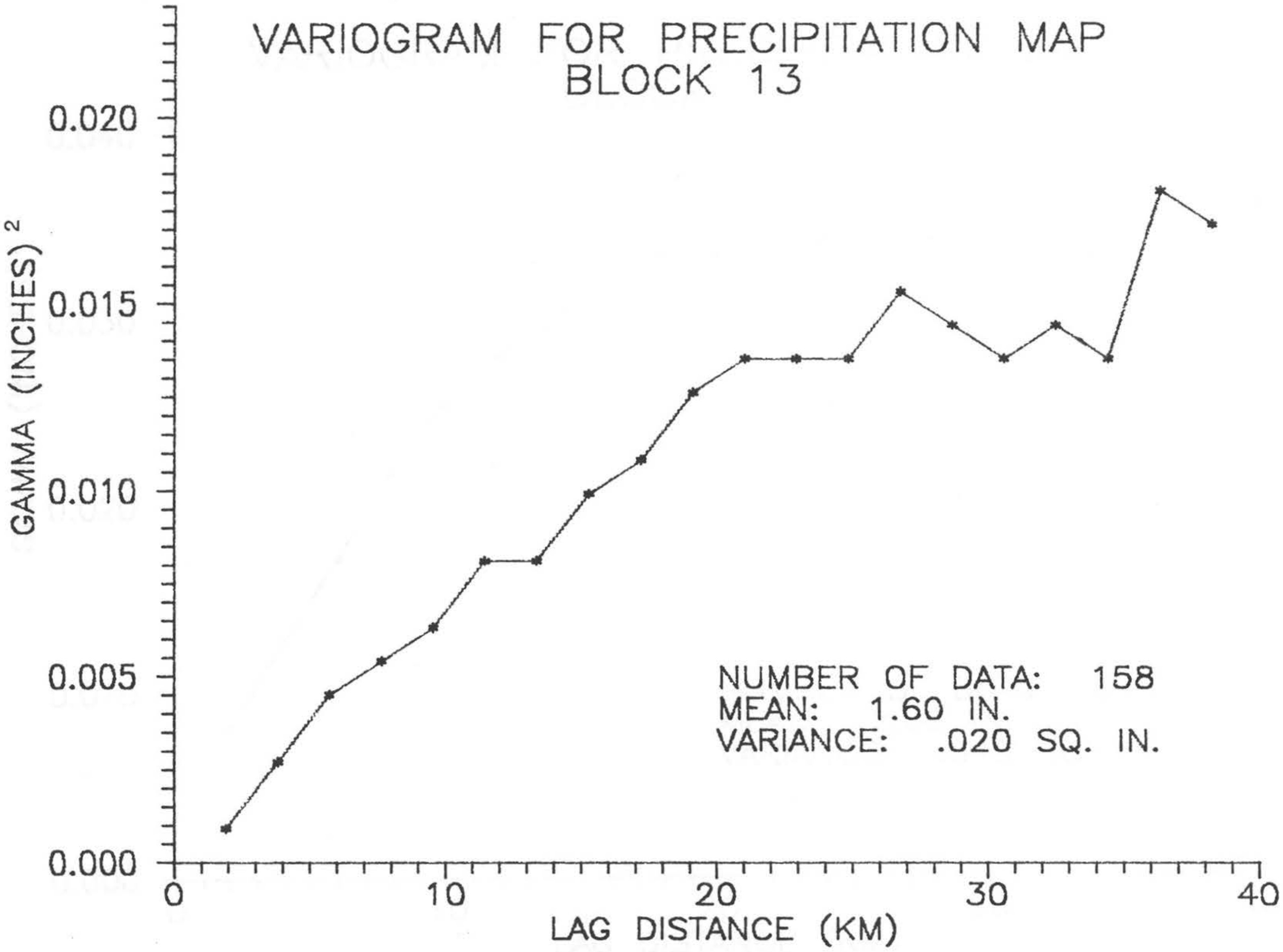

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 8
GAMMA (INCHES)²
0.030
0.020
0.010
0.000
0
20
40
60
80
100
120
LAG DISTANCE (KM)
NUMBER OF DATA: 253
MEAN: 1.55 IN.
VARIANCE: .015 SQ. IN.

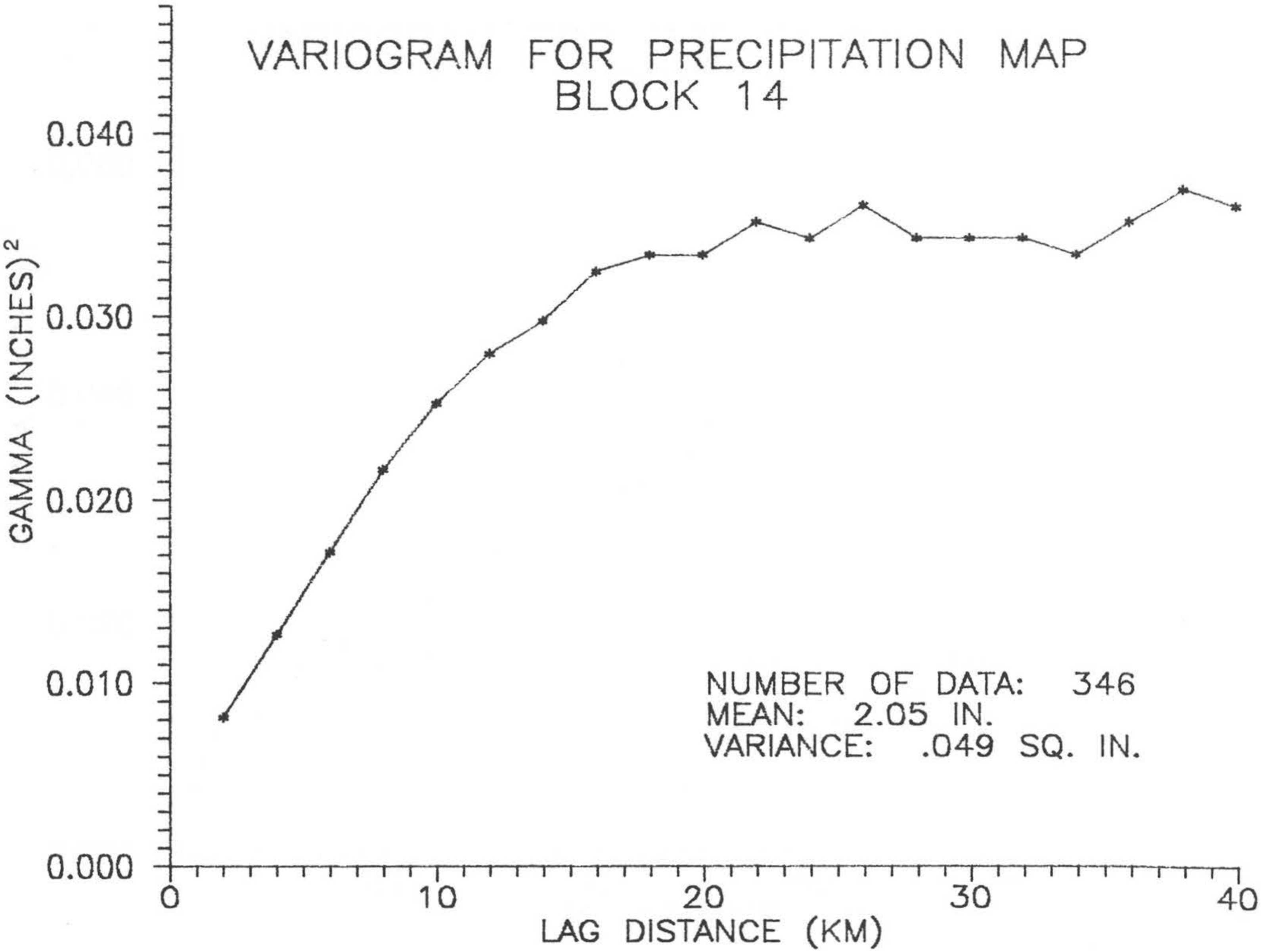

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 9
GAMMA (INCHES) 2
0.050
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
50
60
LAG DISTANCE (KM)
NUMBER OF DATA: 238
MEAN: 1.706 IN.
VARIANCE: .045 SQ. IN.

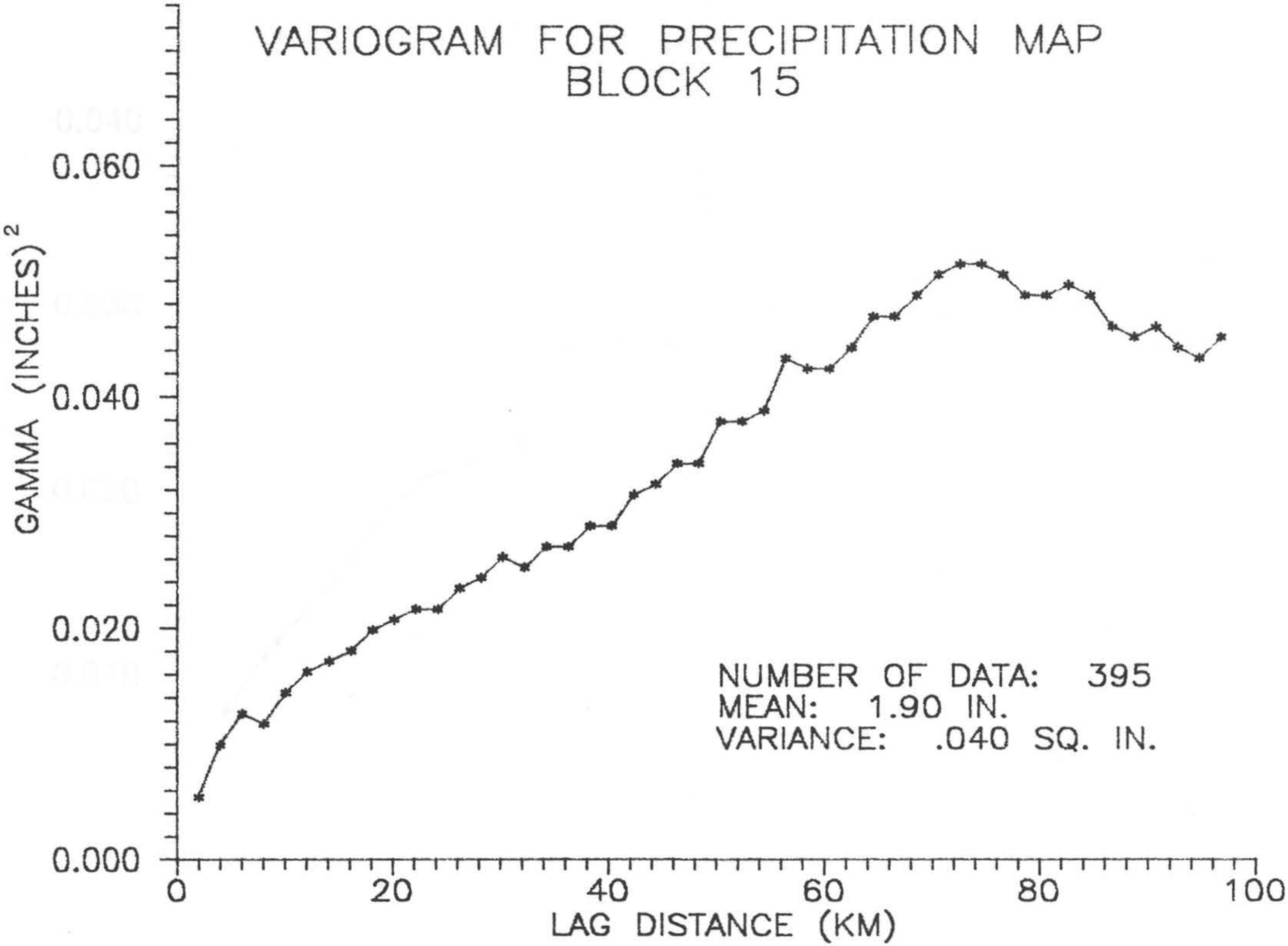

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 10
GAMMA (INCHES)²
0.080
0.060
0.040
0.020
0.000
0
20
40
60
80
LAG DISTANCE (KM)
NUMBER OF DATA: 432
MEAN: 2.06 IN.
VARIANCE: .060 SQ. IN.

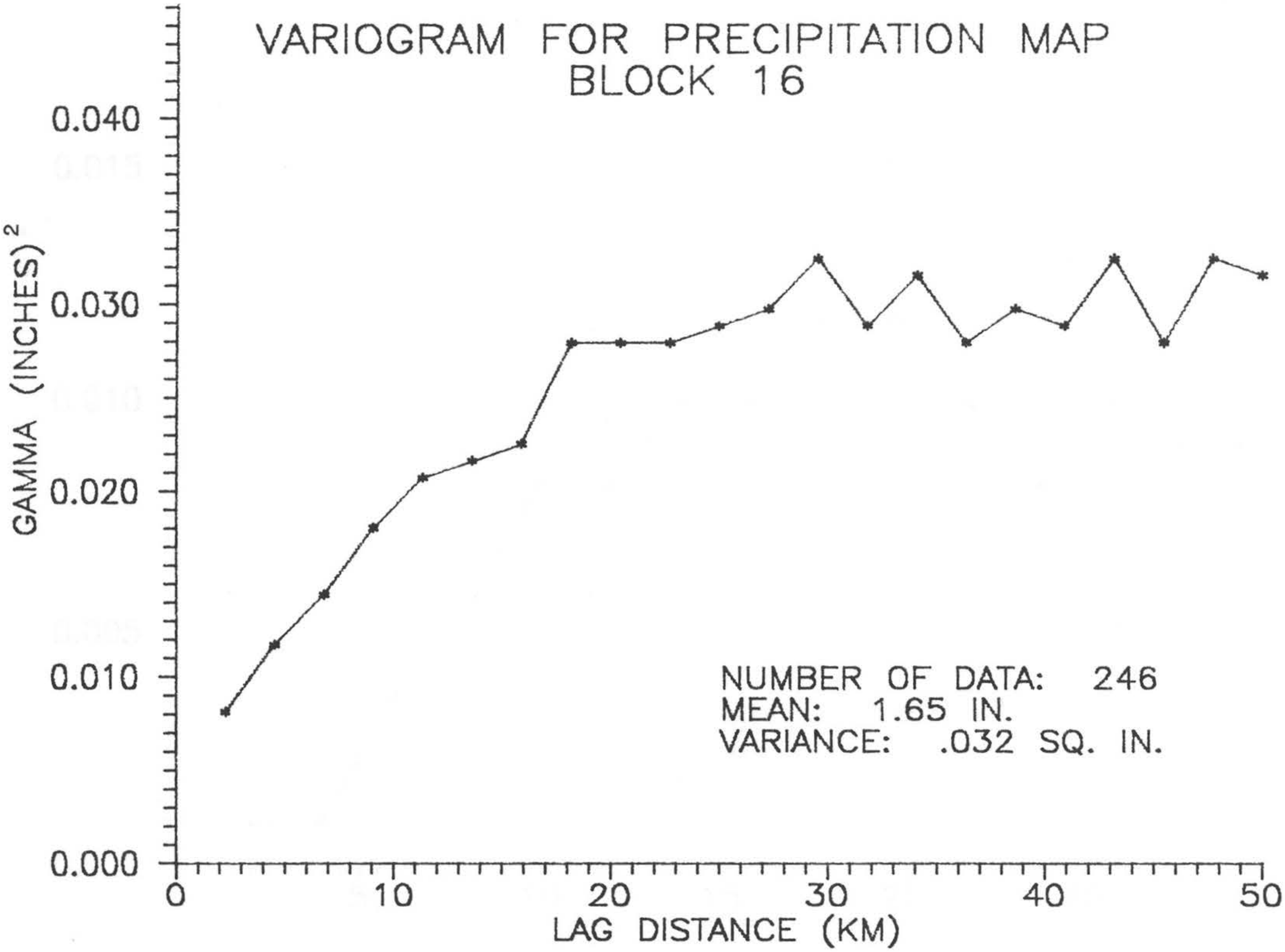

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 11
GAMMA (INCHES)^2
0.100
0.080
0.060
0.040
0.020
0.000
0
20
40
60
80
LAG DISTANCE (KM)
NUMBER OF DATA: 434
MEAN: 1.92 IN.
VARIANCE: .080 SQ. IN.

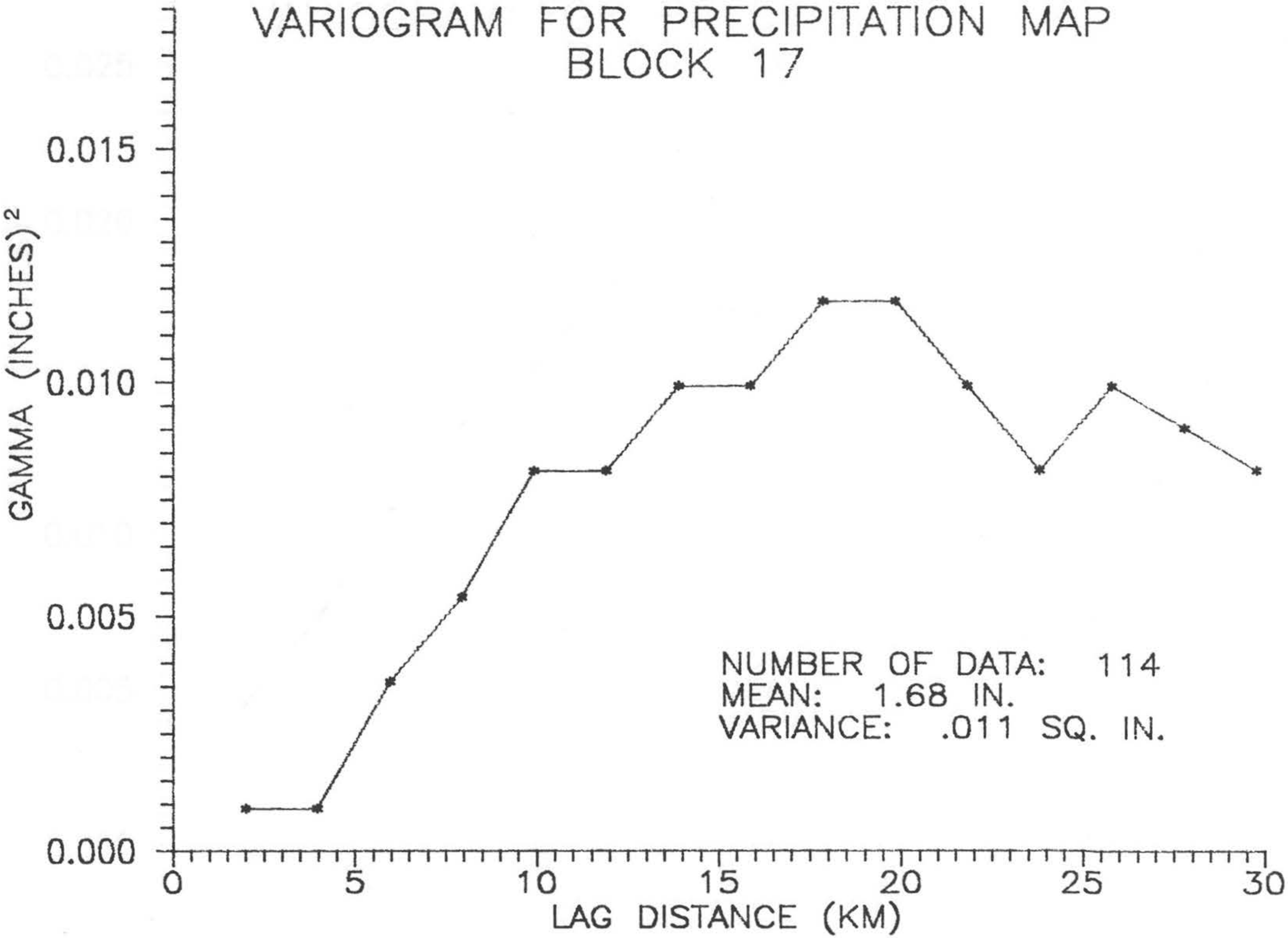

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 12
GAMMA (INCHES)^2
0.010
0.005
0.000
0
10
20
30
40
50
LAG DISTANCE (KM)
NUMBER OF DATA: 86
MEAN: 1.59 IN.
VARIANCE: .015 SQ. IN.

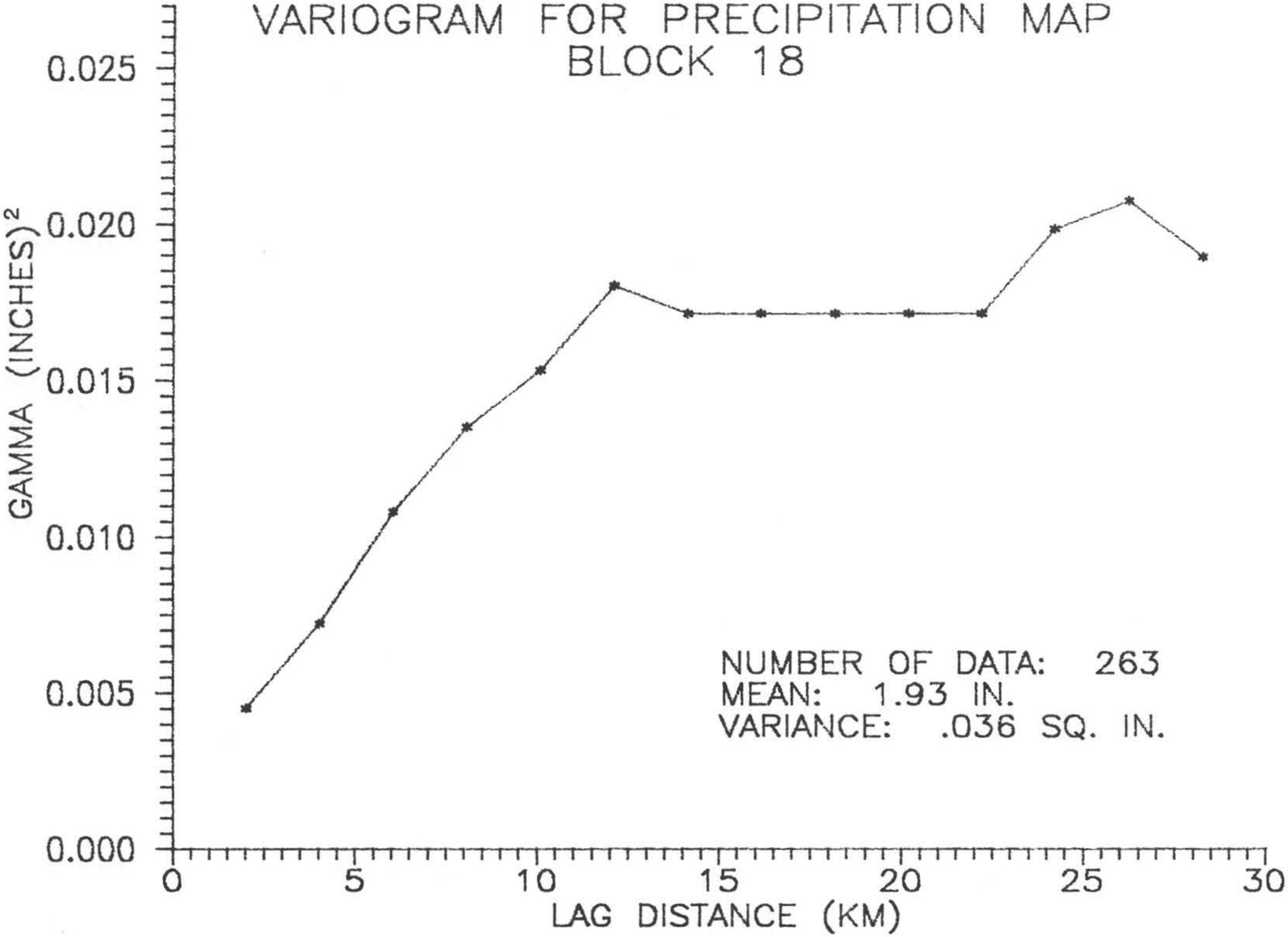

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 13
GAMMA (INCHES)²
0.020
0.015
0.010
0.005
0.000
0
10
20
30
40
LAG DISTANCE (KM)
NUMBER OF DATA: 158
MEAN: 1.60 IN.
VARIANCE: .020 SQ. IN.


VARIOGRAM FOR PRECIPITATION MAP
BLOCK 14
GAMMA (INCHES)²
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
LAG DISTANCE (KM)
NUMBER OF DATA: 346
MEAN: 2.05 IN.
VARIANCE: .049 SQ. IN.

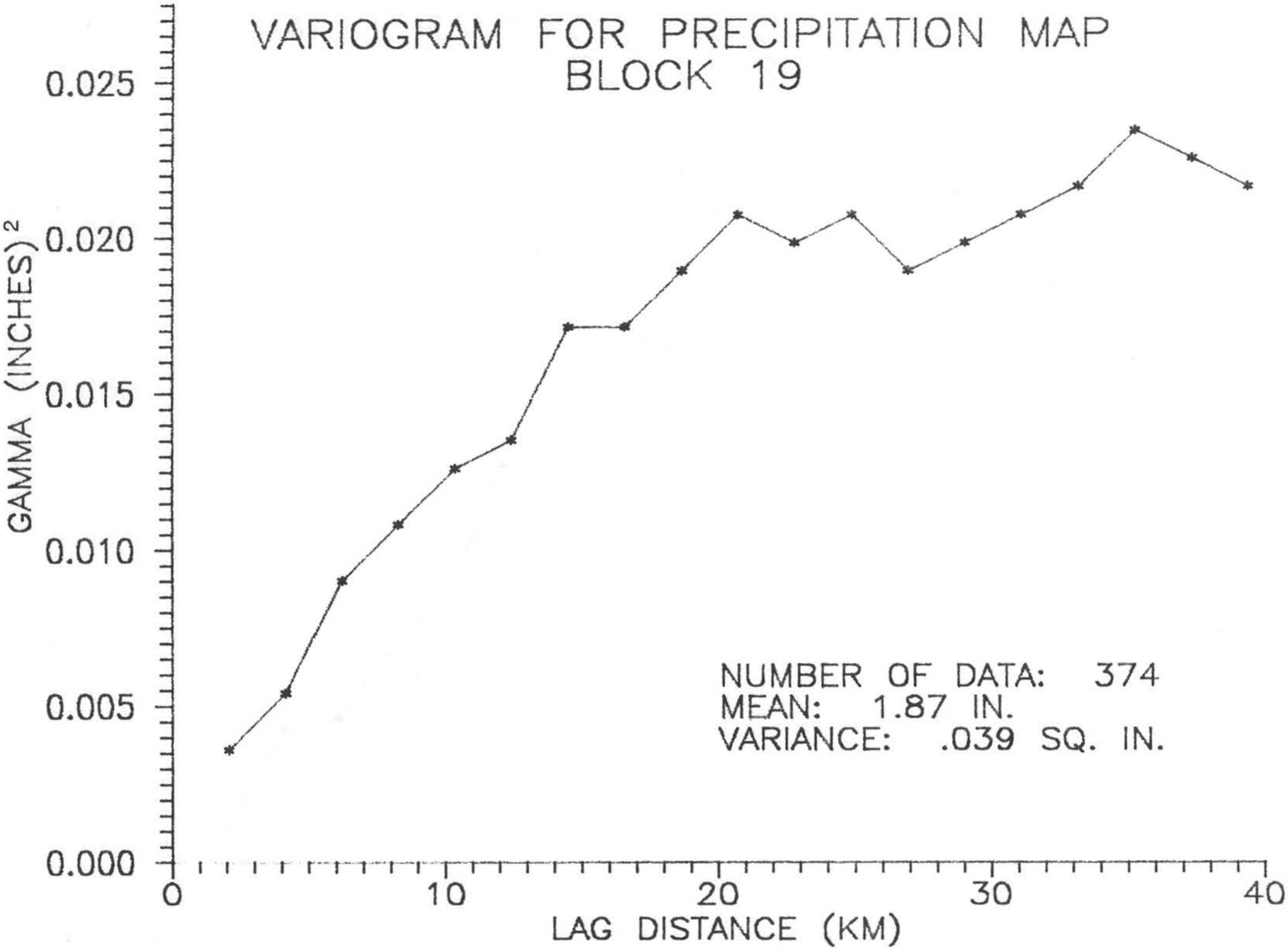

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 15
GAMMA (INCHES)²
0.000
0.020
0.040
0.060
0
20
40
60
80
100
LAG DISTANCE (KM)
NUMBER OF DATA: 395
MEAN: 1.90 IN.
VARIANCE: .040 SQ. IN.

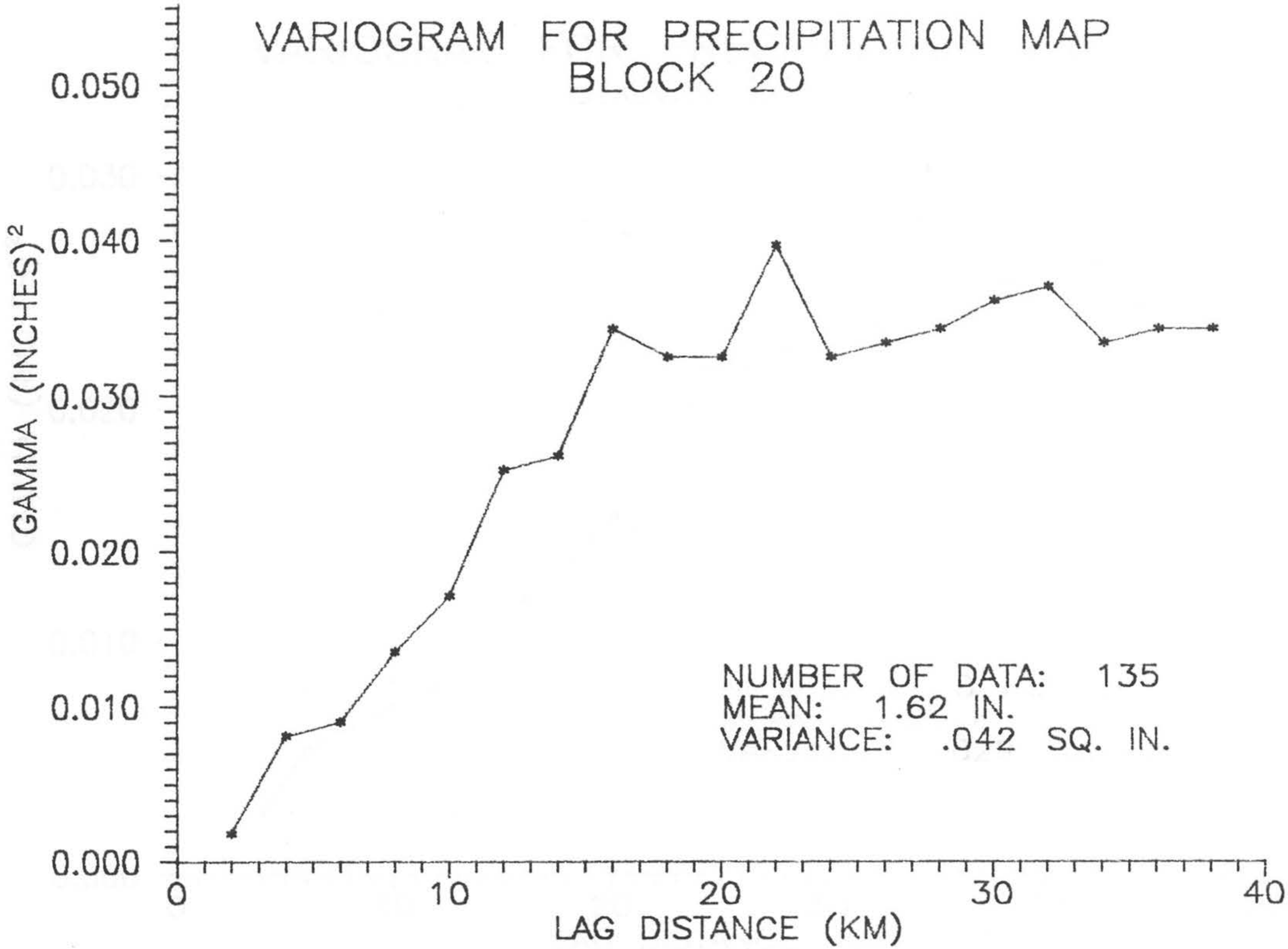

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 16
GAMMA (INCHES)²
0.040
0.030
0.020
0.010
0.000
NUMBER OF DATA: 246
MEAN: 1.65 IN.
VARIANCE: .032 SQ. IN.
0
10
20
30
40
50
LAG DISTANCE (KM)

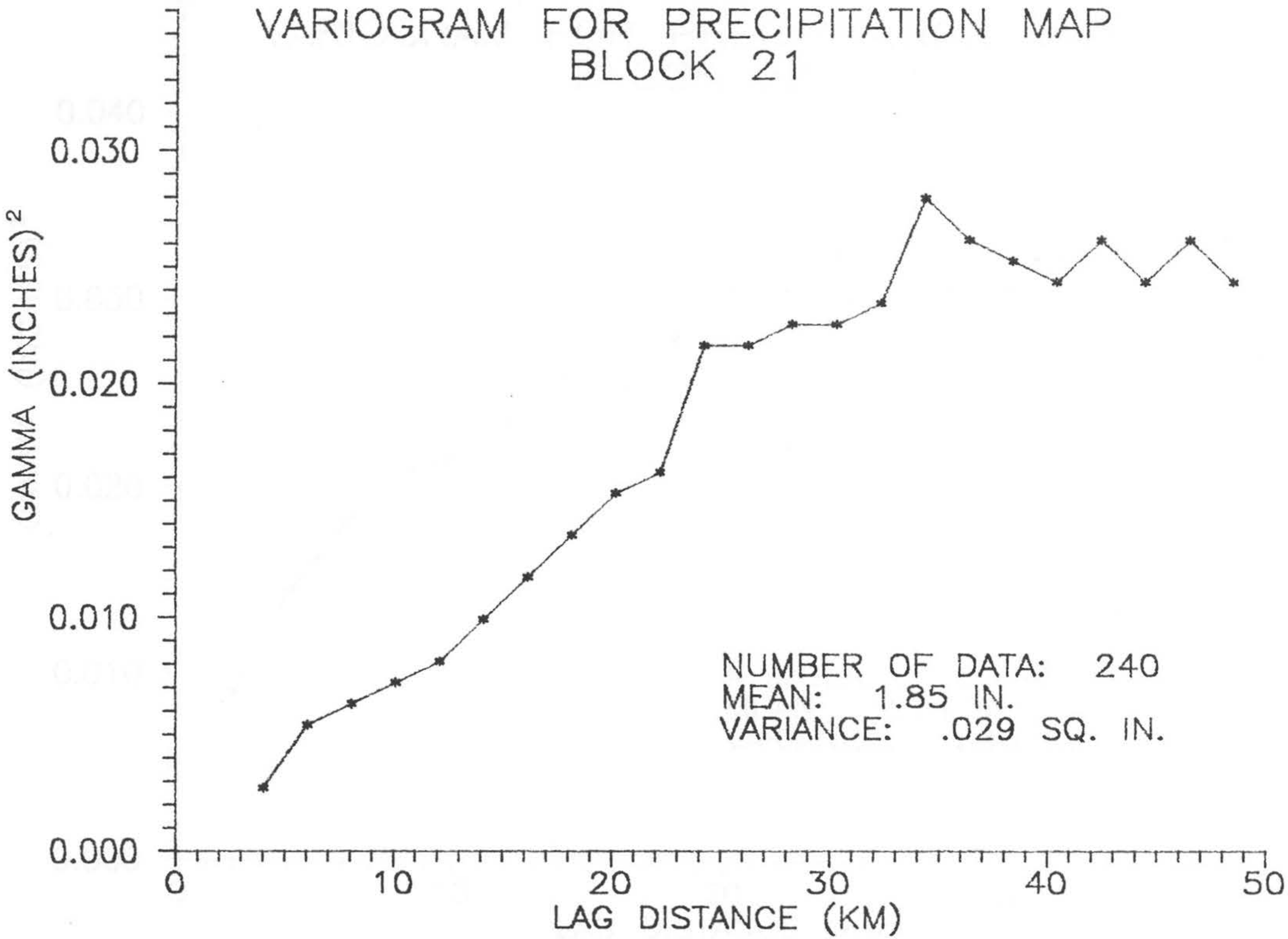

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 17
GAMMA (INCHES)²
0.015
0.010
0.005
0.000
NUMBER OF DATA: 114
MEAN: 1.68 IN.
VARIANCE: .011 SQ. IN.
0
5
10
15
20
25
30
LAG DISTANCE (KM)

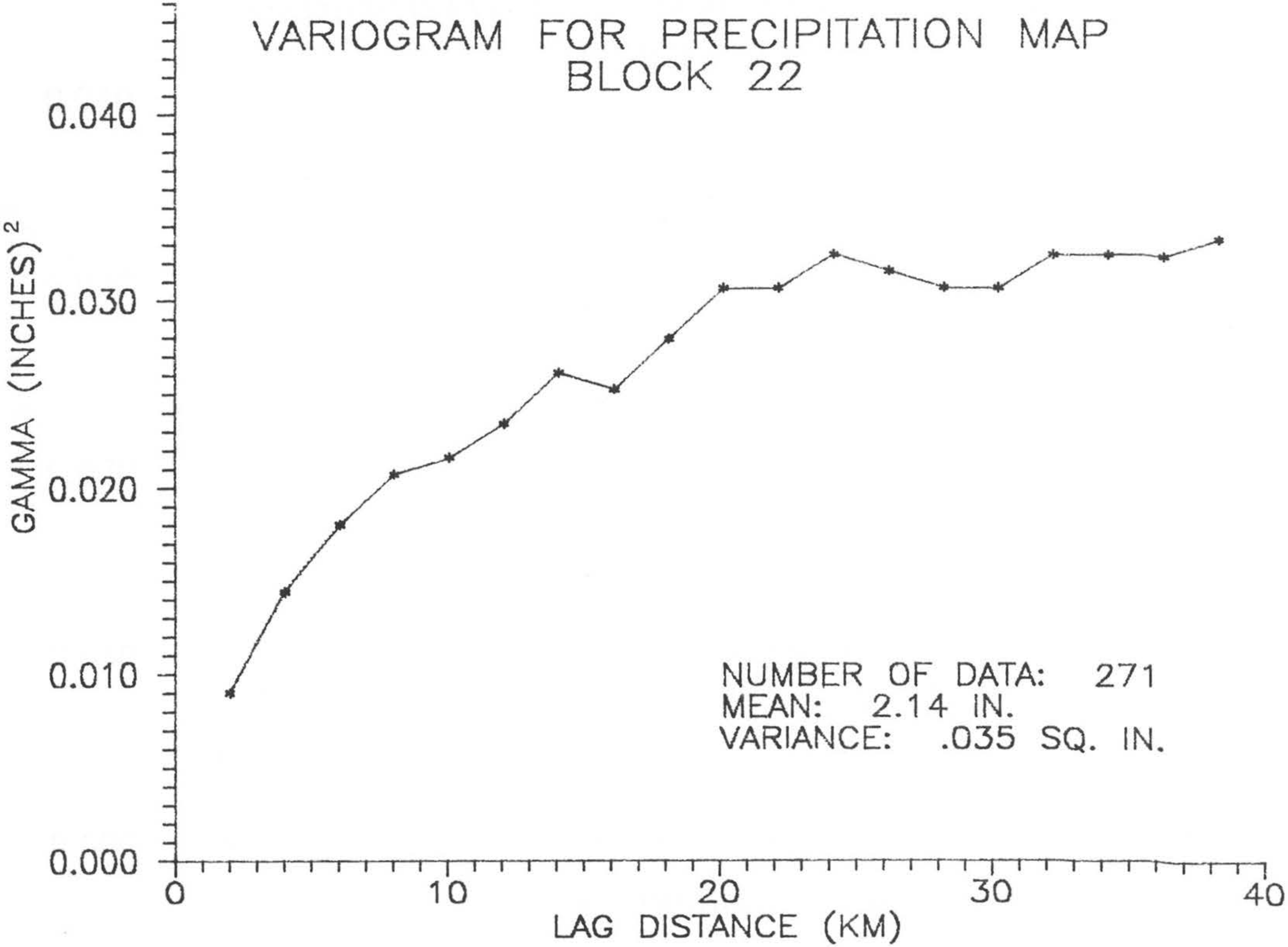


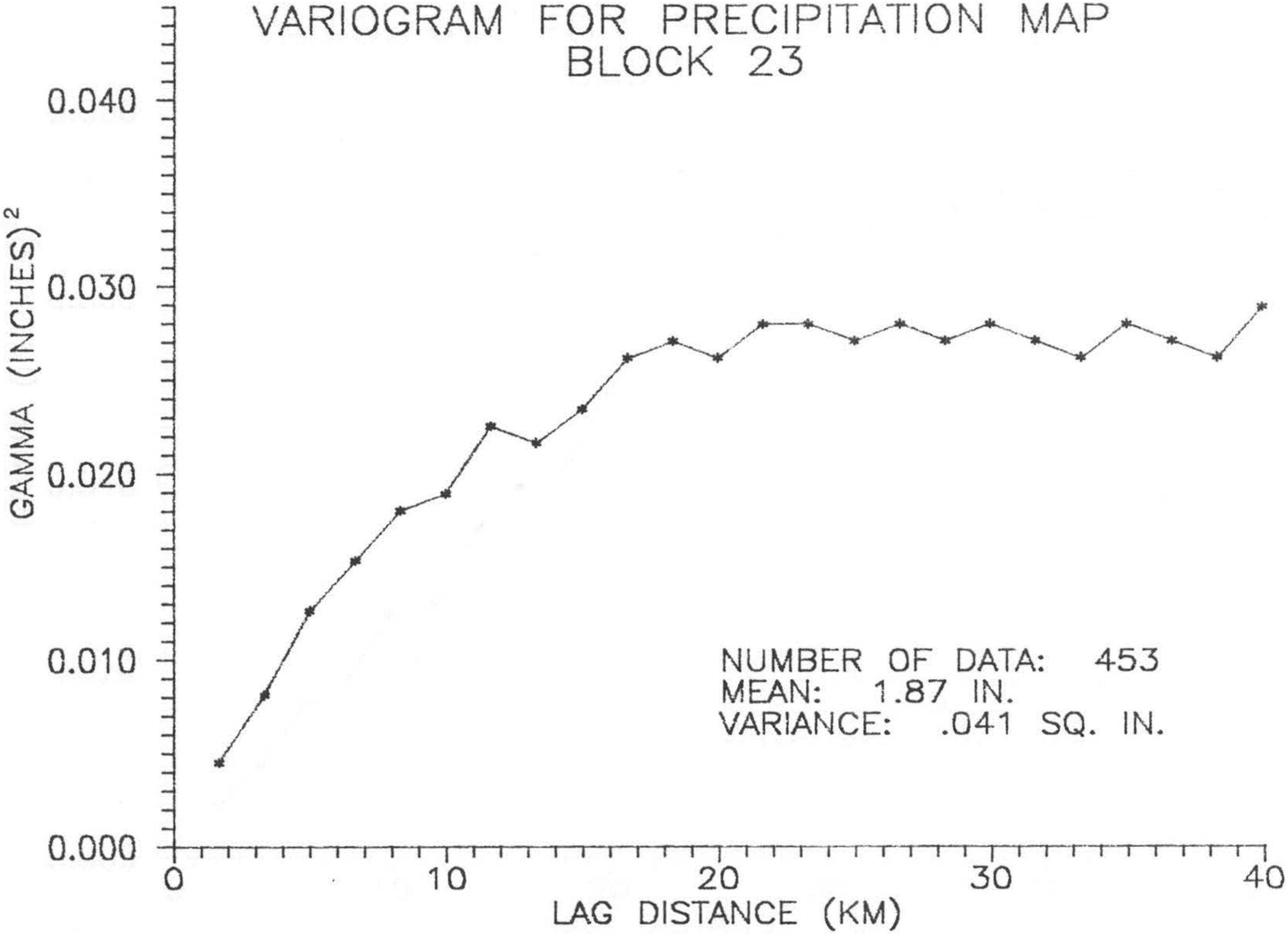
VARIOGRAM FOR PRECIPITATION MAP
BLOCK 18
GAMMA (INCHES)²
0.025
0.020
0.015
0.010
0.005
0.000
NUMBER OF DATA: 263
MEAN: 1.93 IN.
VARIANCE: .036 SQ. IN.
0
5
10
15
20
25
30
LAG DISTANCE (KM)

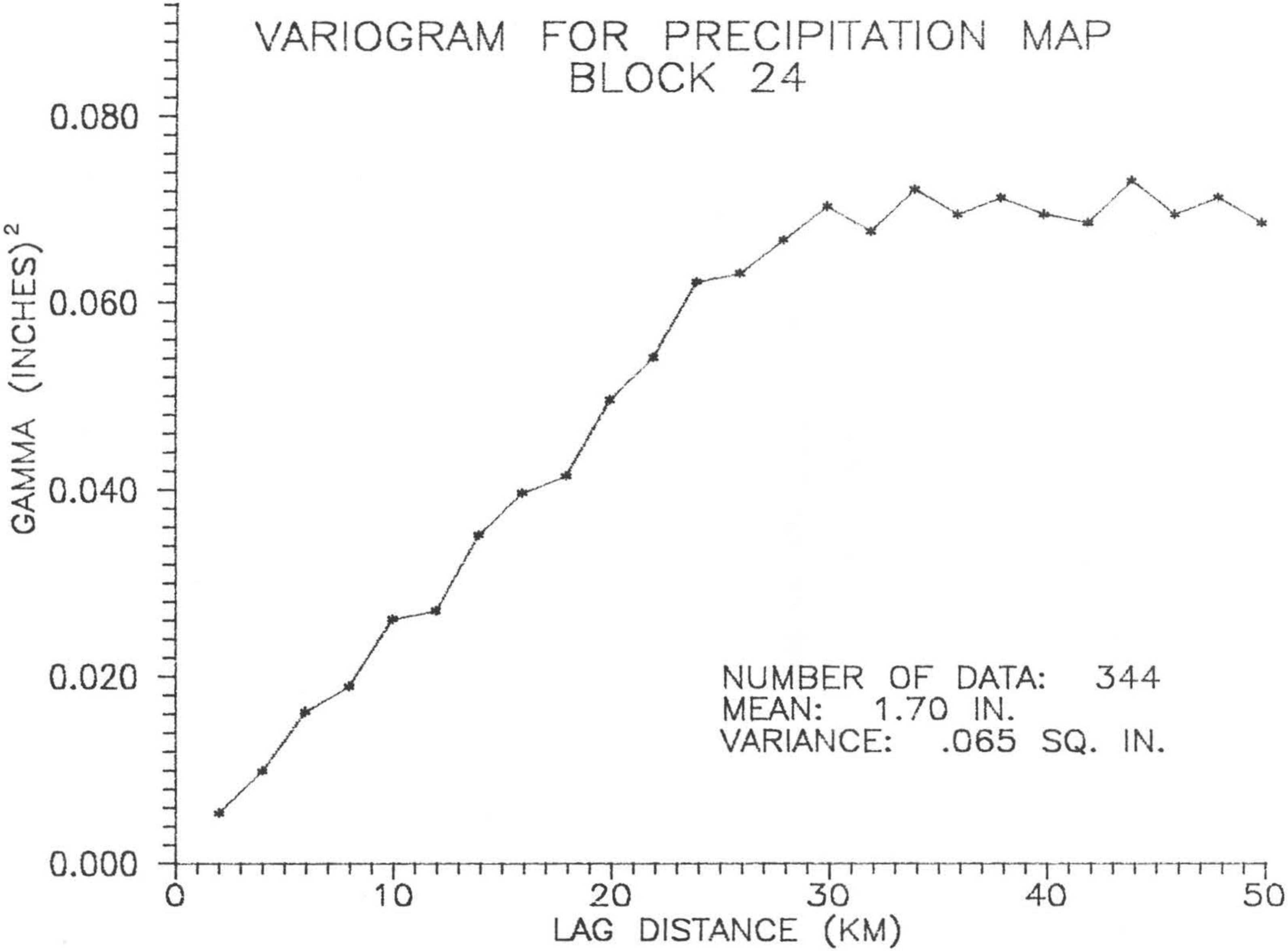

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 19
GAMMA (INCHES)²
0.025
0.020
0.015
0.010
0.005
0.000
NUMBER OF DATA: 374
MEAN: 1.87 IN.
VARIANCE: .039 SQ. IN.
0
10
20
30
40
LAG DISTANCE (KM)


VARIOGRAM FOR PRECIPITATION MAP
BLOCK 20
GAMMA (INCHES)²
0.050
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
LAG DISTANCE (KM)
NUMBER OF DATA: 135
MEAN: 1.62 IN.
VARIANCE: .042 SQ. IN.


VARIOGRAM FOR PRECIPITATION MAP
BLOCK 21
GAMMA (INCHES)²
0.030
0.020
0.010
0.000
0
10
20
30
40
50
LAG DISTANCE (KM)
NUMBER OF DATA: 240
MEAN: 1.85 IN.
VARIANCE: .029 SQ. IN.

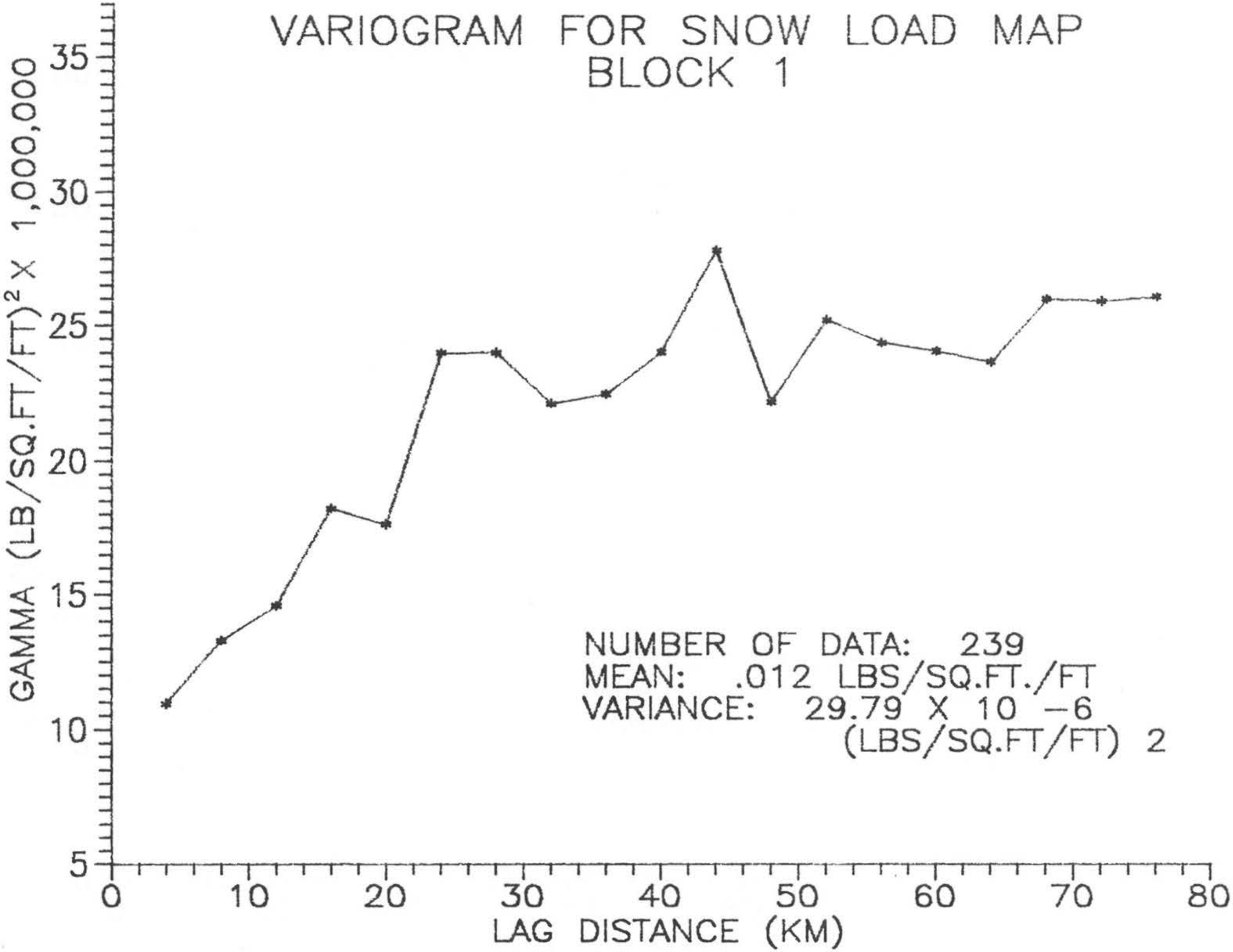

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 22
GAMMA (INCHES)²
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
LAG DISTANCE (KM)
NUMBER OF DATA: 271
MEAN: 2.14 IN.
VARIANCE: .035 SQ. IN.


VARIOGRAM FOR PRECIPITATION MAP
BLOCK 23
GAMMA (INCHES)²
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
LAG DISTANCE (KM)
NUMBER OF DATA: 453
MEAN: 1.87 IN.
VARIANCE: .041 SQ. IN.

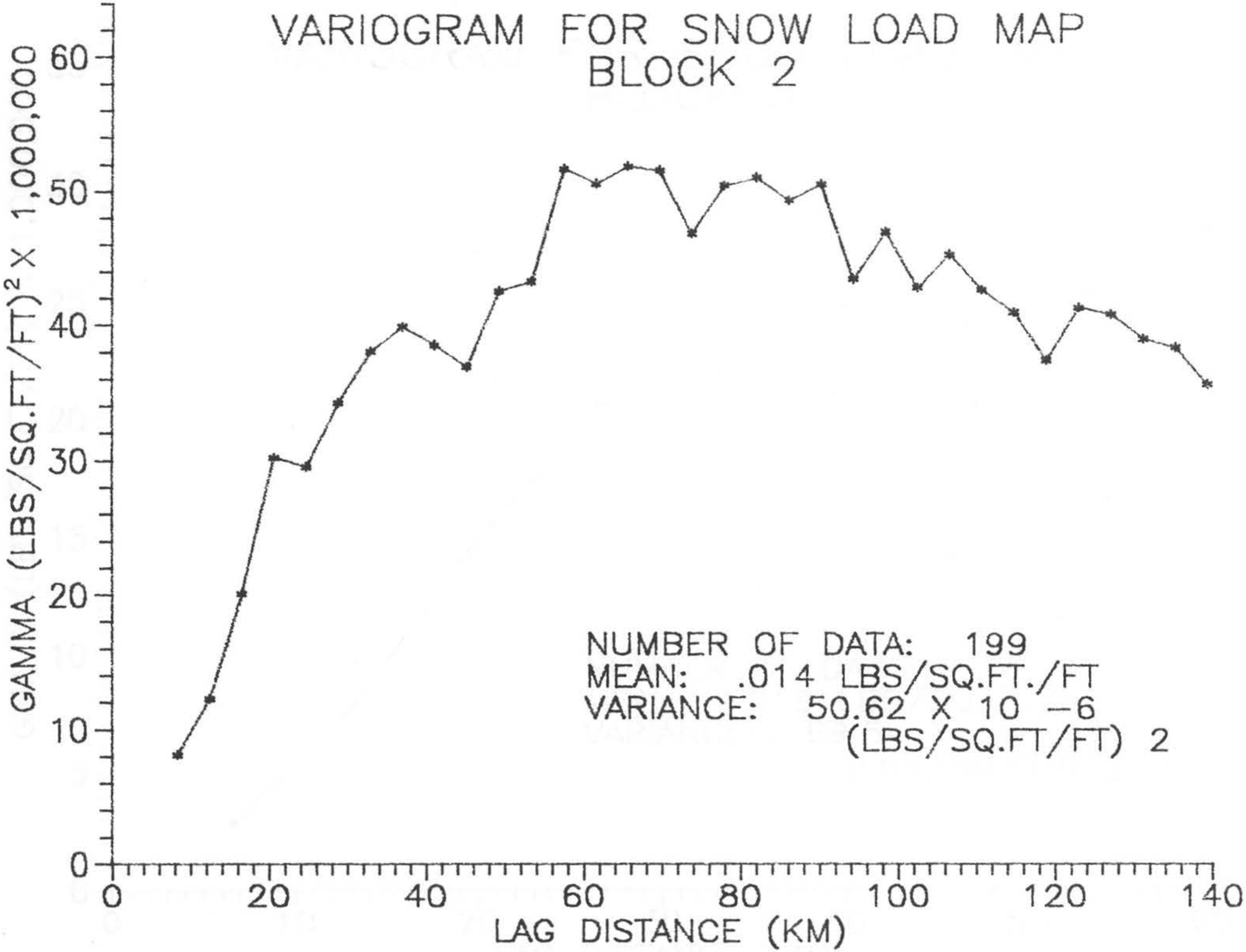

VARIOGRAM FOR PRECIPITATION MAP
BLOCK 24
GAMMA (INCHES)²
0.080
0.060
0.040
0.020
0.000
0
10
20
30
40
50
LAG DISTANCE (KM)
NUMBER OF DATA: 344
MEAN: 1.70 IN.
VARIANCE: .065 SQ. IN.

APPENDIX E-2

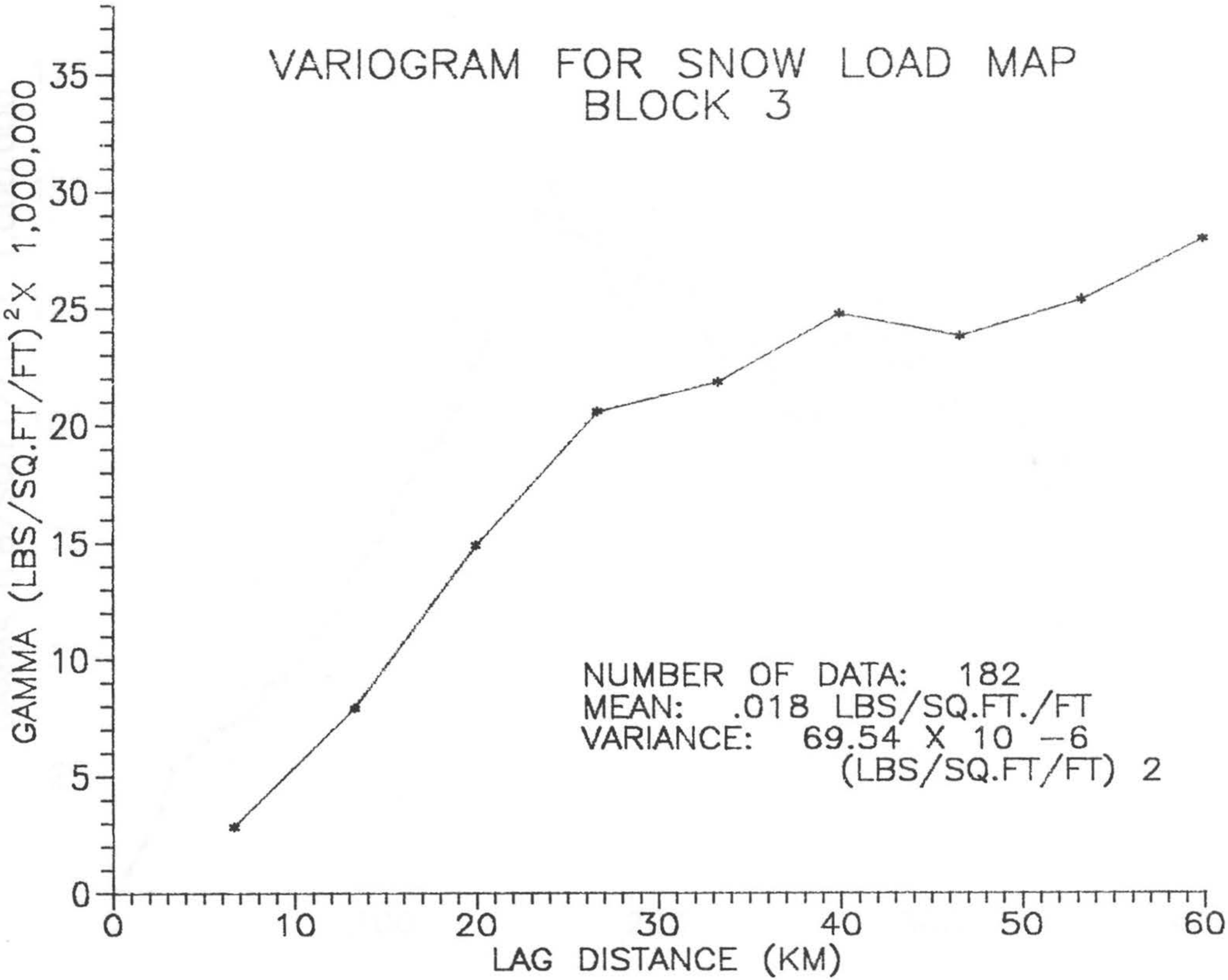
VARIOGRAMS FOR SNOW LOAD MAP

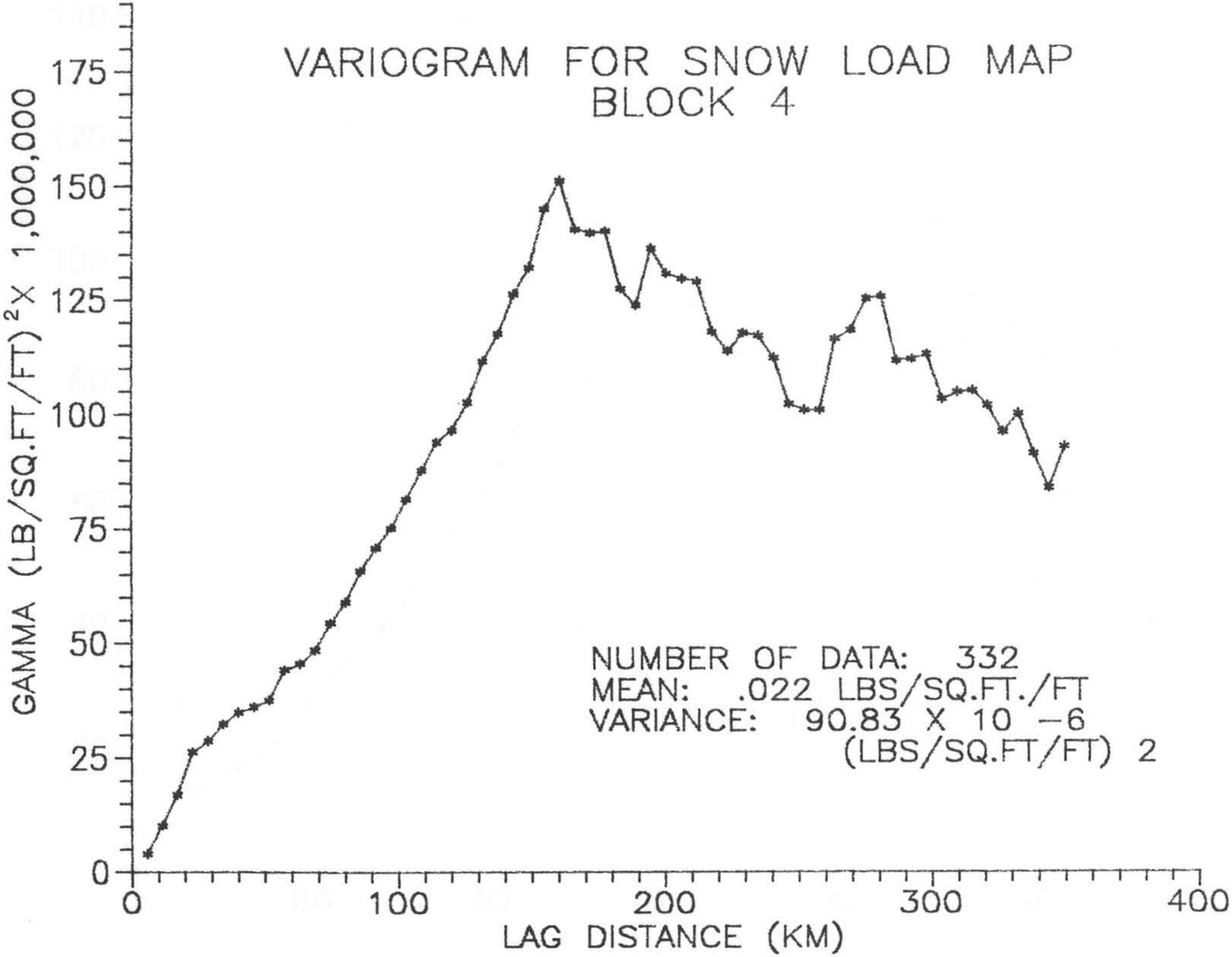


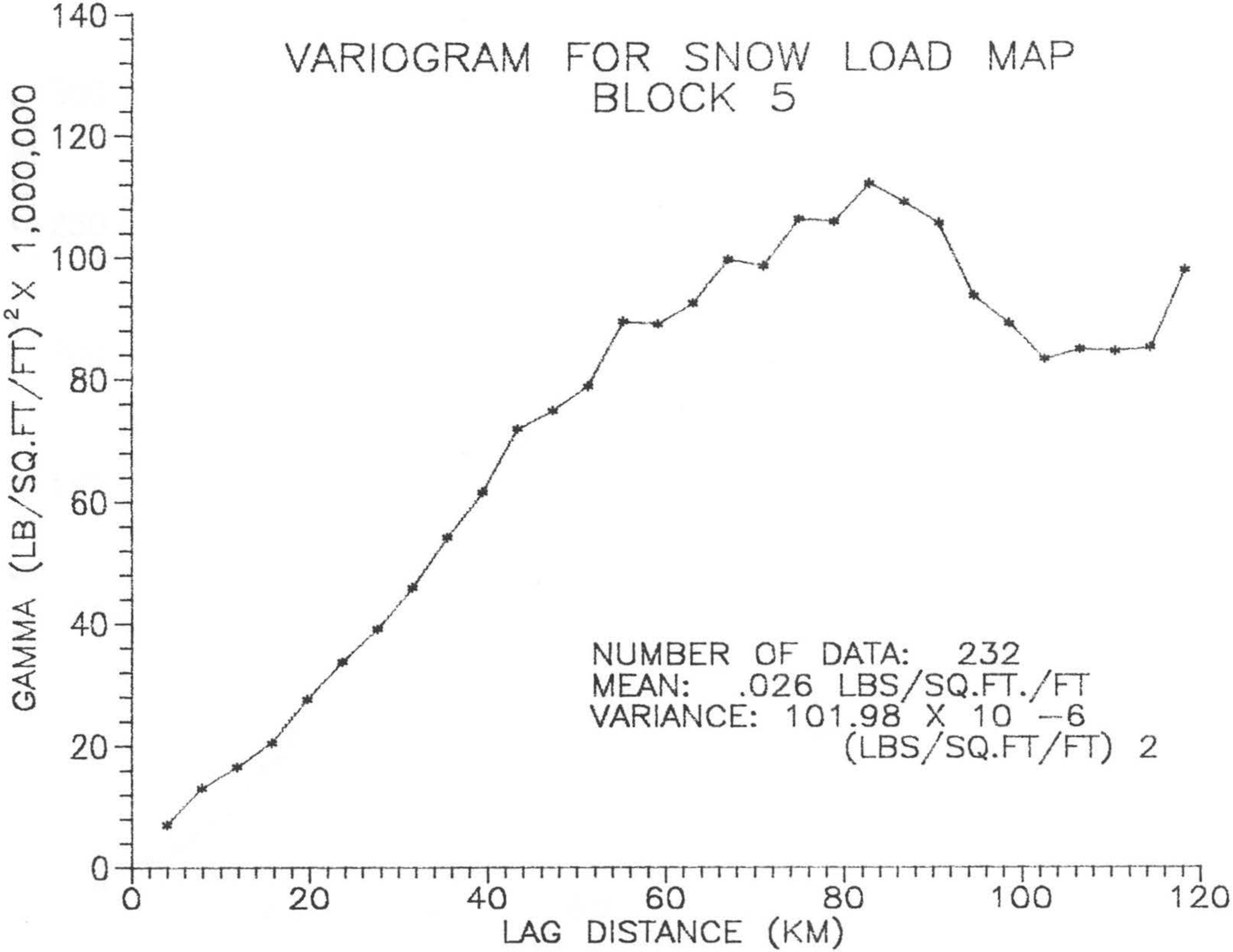
VARIOGRAM FOR SNOW LOAD MAP
BLOCK 1
GAMMA (LB/SQ.FT/FT)^2 X 1,000,000
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
LAG DISTANCE (KM)
NUMBER OF DATA: 239
MEAN: .012 LBS/SQ.FT./FT
VARIANCE: 29.79 X 10 -6
(LBS/SQ.FT/FT) 2

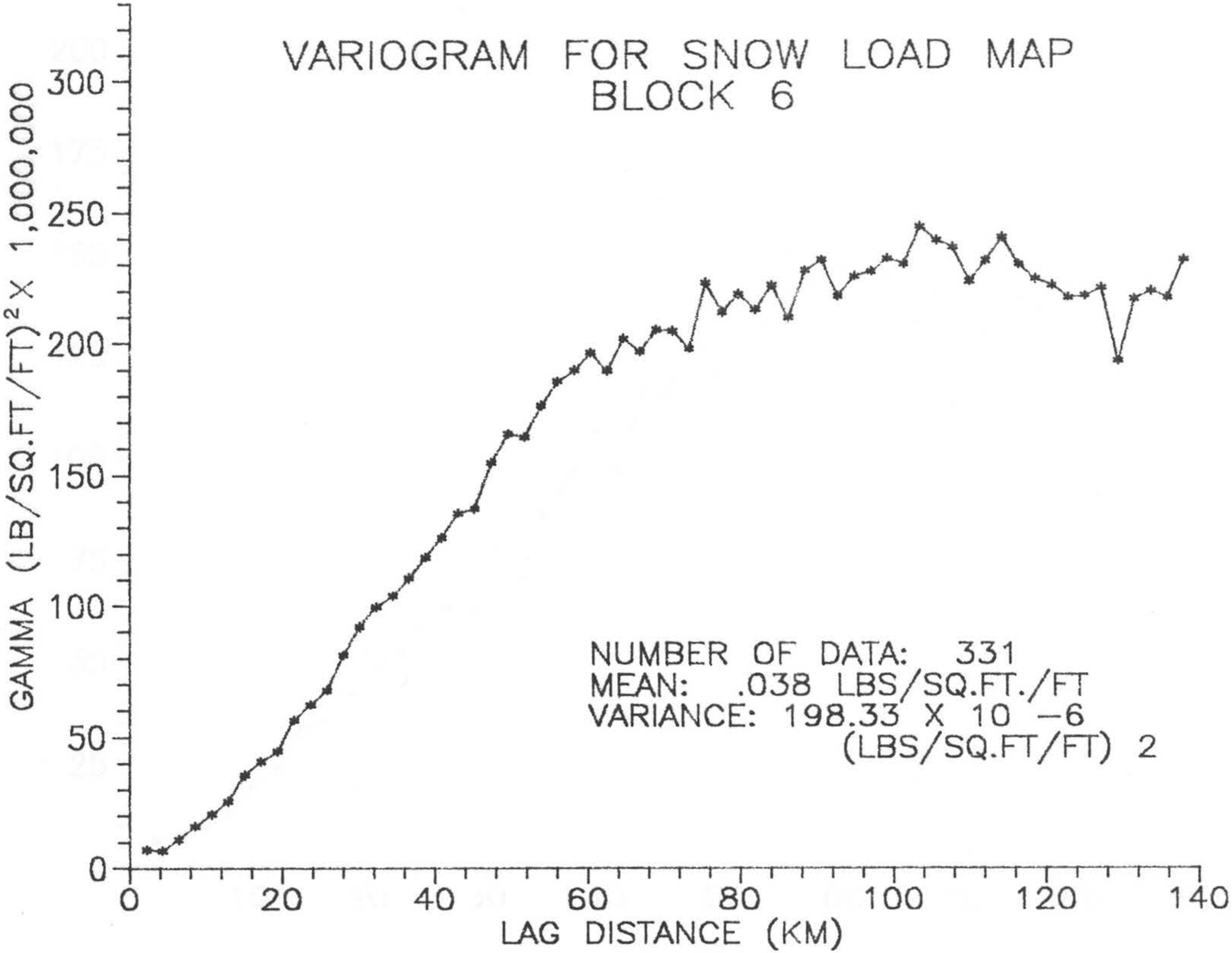


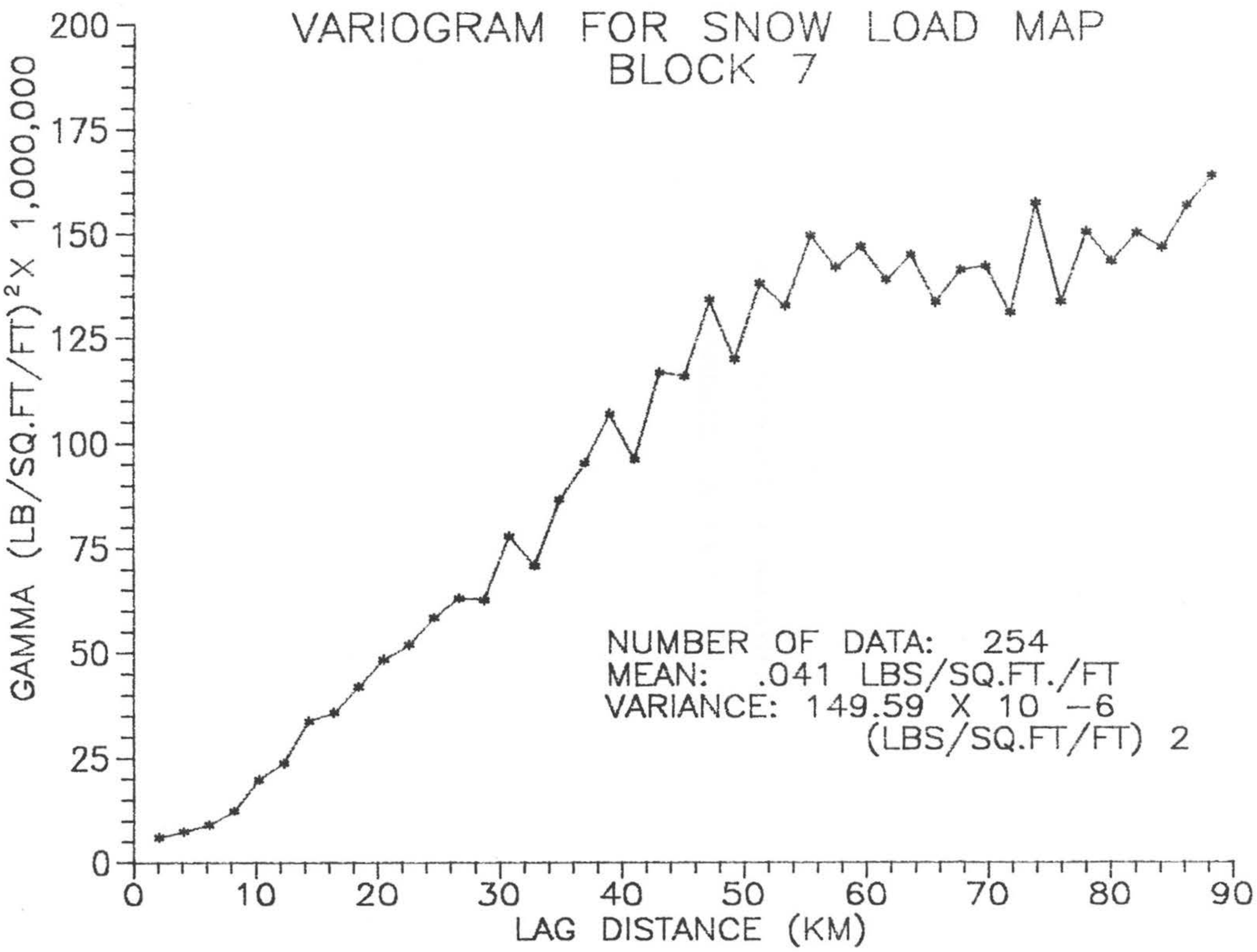
VARIOGRAM FOR SNOW LOAD MAP
BLOCK 2
GAMMA (LBS/SQ.FT/FT)² X 1,000,000
0
10
20
30
40
50
60
LAG DISTANCE (KM)
0
20
40
60
80
100
120
140
NUMBER OF DATA: 199
MEAN: .014 LBS/SQ.FT./FT
VARIANCE: 50.62 X 10 -6
(LBS/SQ.FT/FT) 2


VARIOGRAM FOR SNOW LOAD MAP
BLOCK 3
GAMMA (LBS/SQ.FT/FT)^2 X 1,000,000
LAG DISTANCE (KM)
NUMBER OF DATA: 182
MEAN: .018 LBS/SQ.FT./FT
VARIANCE: 69.54 X 10 −6
(LBS/SQ.FT/FT) 2
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60


VARIOGRAM FOR SNOW LOAD MAP
BLOCK 4
GAMMA (LB/SQ.FT/FT)^{2}X 1,000,000
0
25
50
75
100
125
150
175
0
100
200
300
400
LAG DISTANCE (KM)
NUMBER OF DATA: 332
MEAN: .022 LBS/SQ.FT./FT
VARIANCE: 90.83 X 10 −6
(LBS/SQ.FT/FT) 2


VARIOGRAM FOR SNOW LOAD MAP
BLOCK 5
GAMMA (LB/SQ.FT/FT)² X 1,000,000
LAG DISTANCE (KM)
NUMBER OF DATA: 232
MEAN: .026 LBS/SQ.FT./FT
VARIANCE: 101.98 X 10 −6
(LBS/SQ.FT/FT) 2
0
20
40
60
80
100
120
140

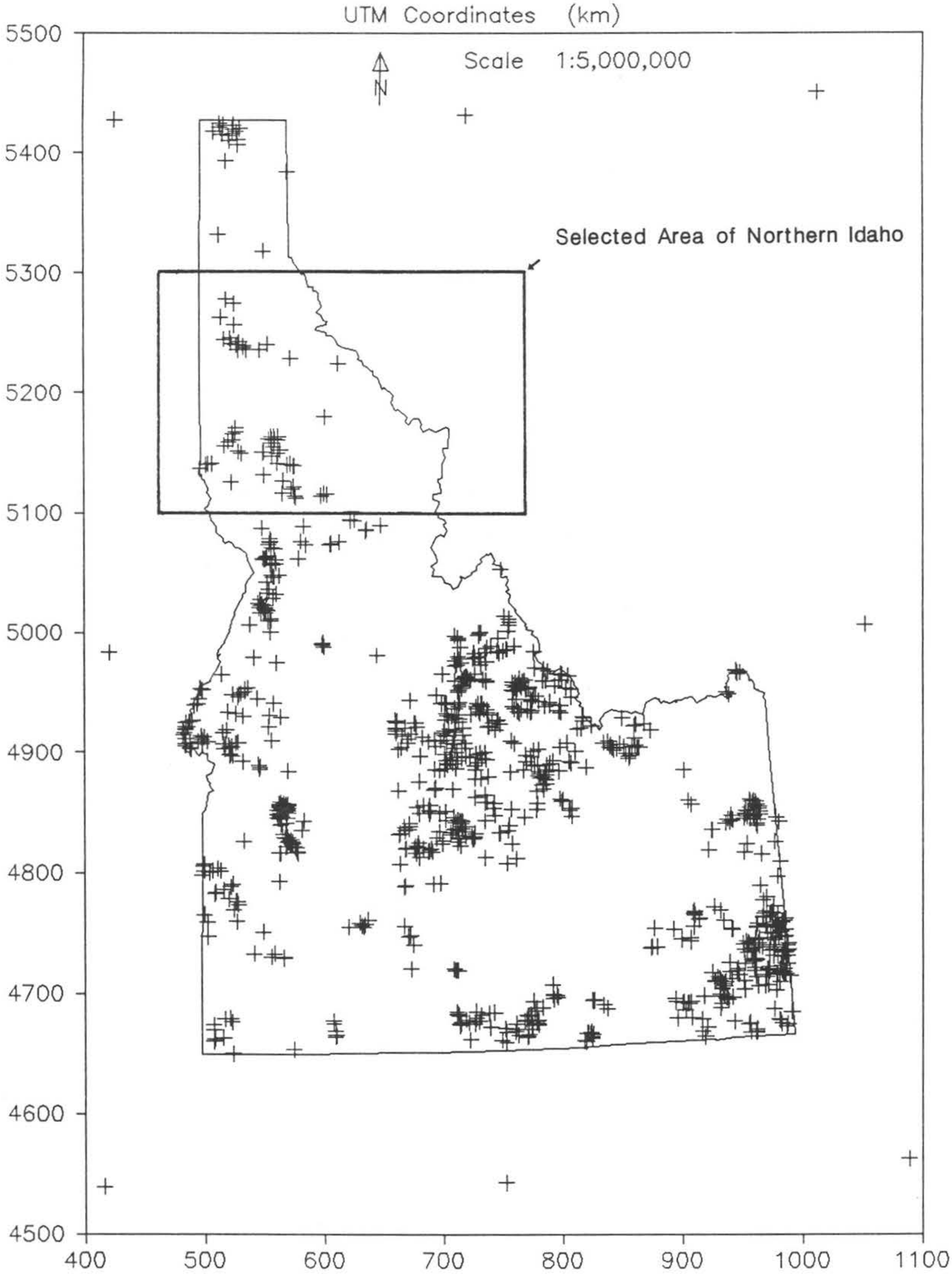

VARIOGRAM FOR SNOW LOAD MAP
BLOCK 6
GAMMA (LB/SQ.FT/FT)² X 1,000,000
LAG DISTANCE (KM)
NUMBER OF DATA: 331
MEAN: .038 LBS/SQ.FT./FT
VARIANCE: 198.33 X 10 −6
(LBS/SQ.FT/FT) 2
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140



VARIOGRAM FOR SNOW LOAD MAP
BLOCK 7
GAMMA (LB/SQ.FT/FT)² X 1,000,000
0
25
50
75
100
125
150
175
200
0
10
20
30
40
50
60
70
80
90
LAG DISTANCE (KM)
NUMBER OF DATA: 254
MEAN: .041 LBS/SQ.FT./FT
VARIANCE: 149.59 X 10 -6
(LBS/SQ.FT/FT) 2

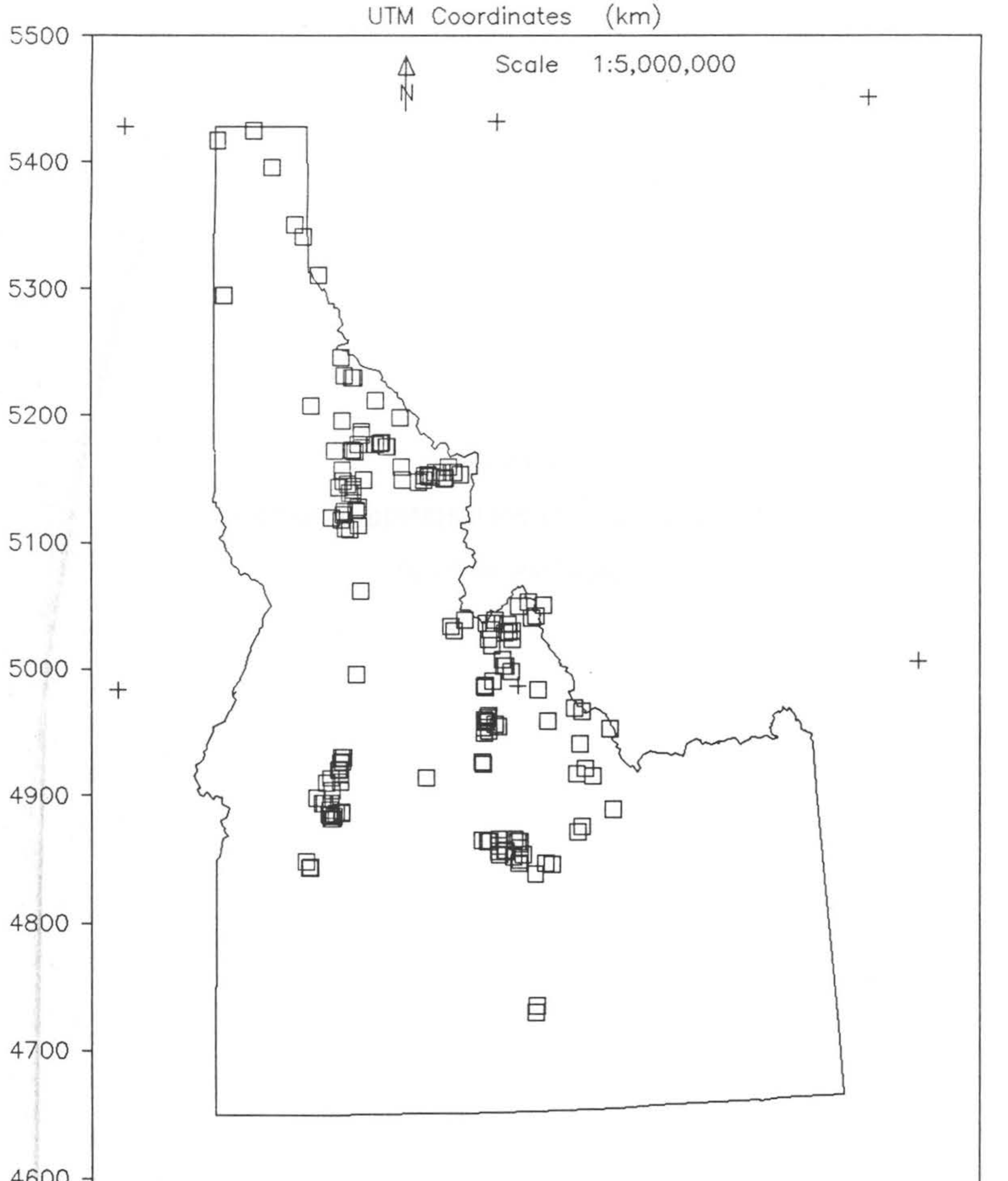
APPENDIX F-1

GEOGRAPHIC DISTRIBUTION OF UNCLASSIFIED LANDSLIDES IN IDAHO


UTM Coordinates (km)
Scale 1:5,000,000
N
Selected Area of Northern Idaho
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
400
500
600
700
800
900
1000
1100

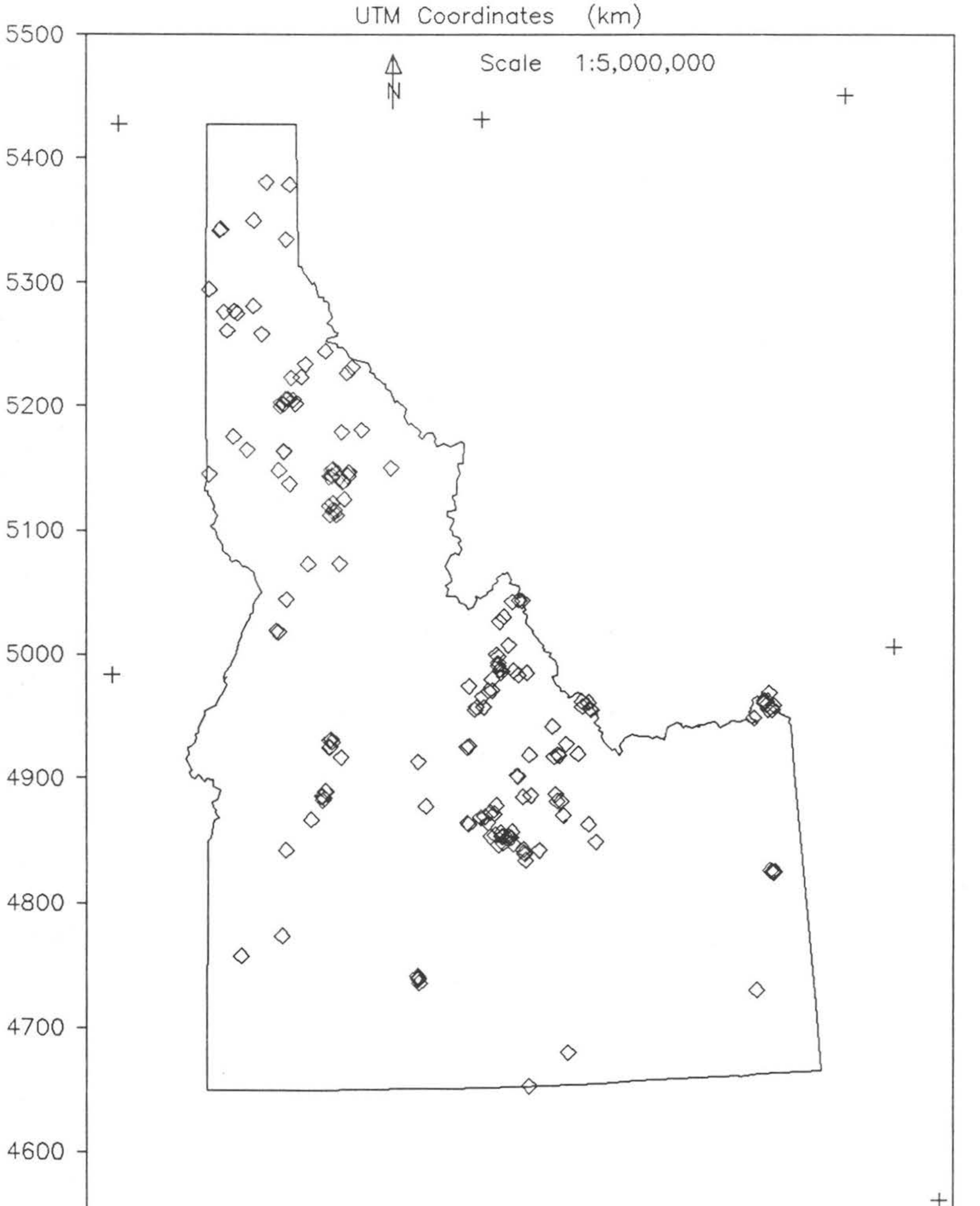
APPENDIX F-2

GEOGRAPHIC DISTRIBUTION OF IDAHO LANDSLIDES IN DEBRIS MATERIAL


UTM Coordinates (km)
Scale 1:5,000,000
N
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
400
500
600
700
800
900
1000
1100

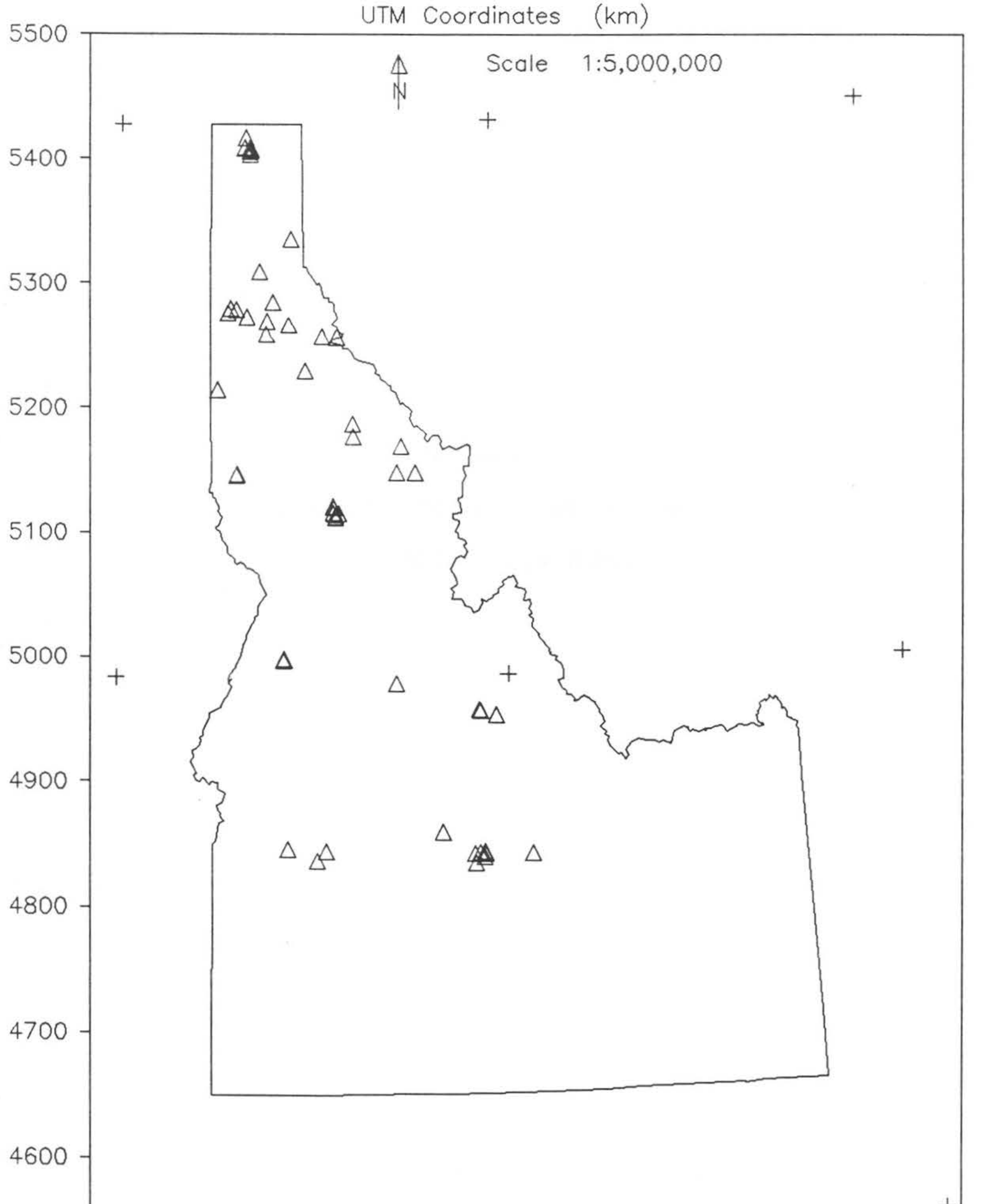
APPENDIX F-3

GEOGRAPHIC DISTRIBUTION OF IDAHO LANDSLIDES IN EARTH MATERIAL


UTM Coordinates (km)
Scale 1:5,000,000
N
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
400
500
600
700
800
900
1000
1100

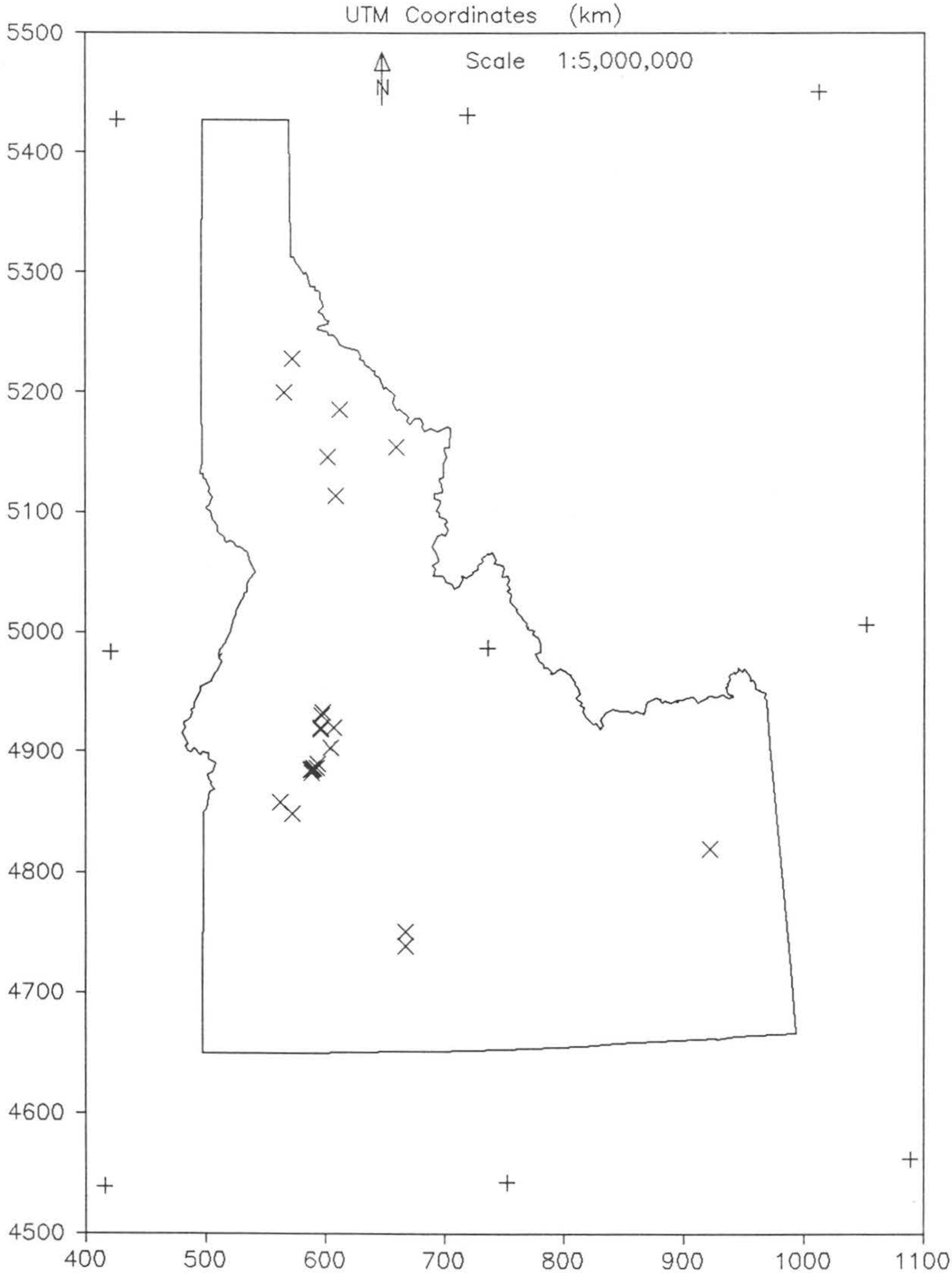
APPENDIX F-4

GEOGRAPHIC DISTRIBUTION OF IDAHO LANDSLIDES IN ROCK MATERIAL


UTM Coordinates (km)
Scale 1:5,000,000
N
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
400
500
600
700
800
900
1000
1100

APPENDIX F-5

GEOGRAPHIC DISTRIBUTION OF COMPLEX LANDSLIDES IN IDAHO


UTM Coordinates (km)
Scale 1:5,000,000
N
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
400
500
600
700
800
900
1000
1100

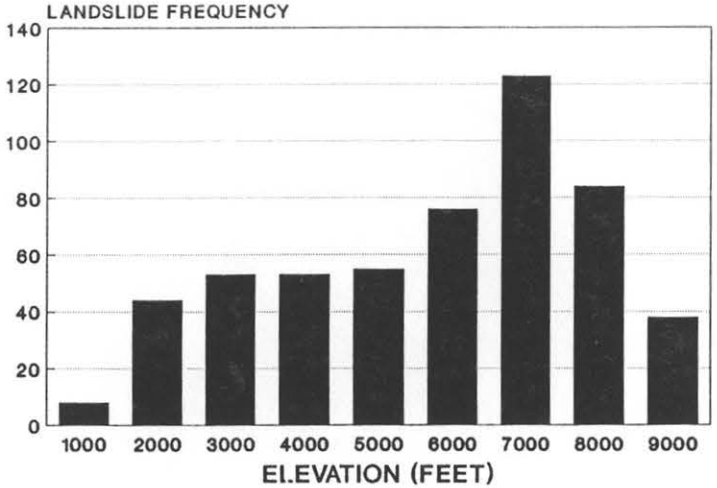
APPENDIX G

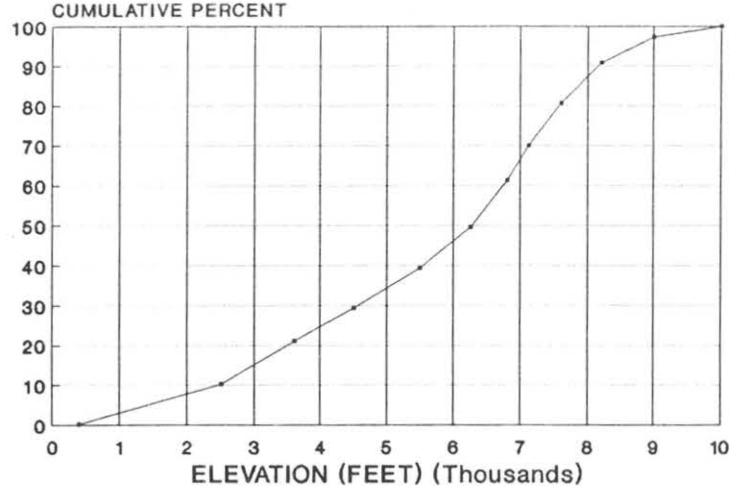
NUMBER OF LANDSLIDES ASSOCIATED WITH MAPPED LANDSLIDE MATERIALS

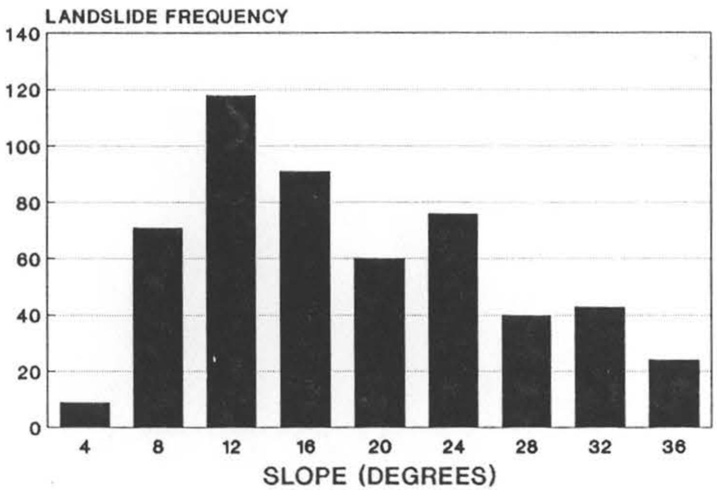
MAPPED Earth-material		NUMBER OF LANDSLIDES				
	MATERIAL GROUP:	1	2	3	4	5
AND	= andesite	49				
ALLU	= alluvium					38
ARG	= argillite				12	
BA	= basalt	143				
BIGN	= biotite gneiss			1		
BR	= breccia (tuff)	4				
COLV	= colluvium					13
CONG	= conglomerate				21	
DACI	= dacite	33				
DIO	= diorite		7			
DOLO	= dolomite				9	
GDIO	= granodiorite		79			
GNEI	= gneiss			45		
GRAV	= gravel					21
GRNT	= granite		33			
GWKE	= graywake				2	
INTR	= intrusives undifferentiated		7			
LMST	= limestone				84	
MSED	= metasediments undifferentiated			6		
MVOL	= metavolcanics undifferentiated			13		
PHYL	= phyllite				15	
QTZD	= quartz diorite		6			
QTZM	= quartz monzonite		158			
QTZT	= quartzite				119	
RHYL	= rhyolite	35				
SAND	= sand					1
SED	= sediments undifferentiated				38	
SHL	= shale				63	
SHST	= schist			91		
SLAT	= slate			17		
SLT	= silt					6
SLST	= siltstone				30	
SSTN	= sandstone				42	
TILL	= glacial till and debris					41
TUFF	= volcanic tuff and ash	247				
LANDSLIDE MATERIAL GROUP TOTALS:		511	290	173	435	120

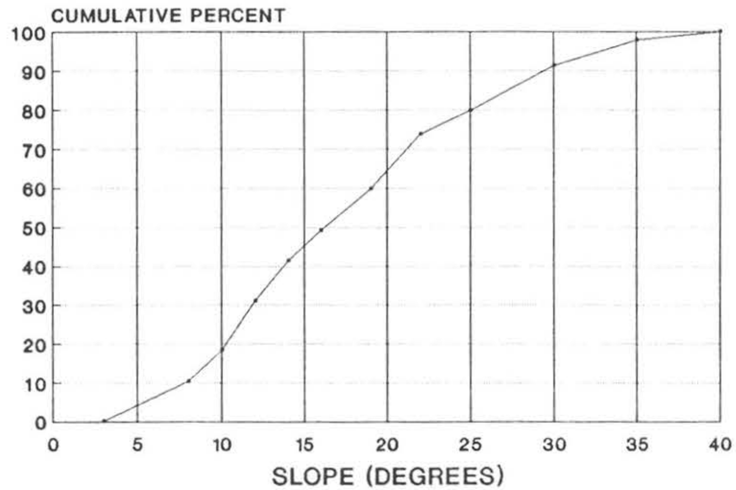
APPENDIX H-1

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE FOR IDAHO LANDSLIDES ASSOCIATED WITH IGNEOUS EXTRUSIVE ROCK


LANDSLIDE FREQUENCY
140
120
100
80
60
40
20
0
1000 2000 3000 4000 5000 6000 7000 8000 9000
ELEVATION (FEET)

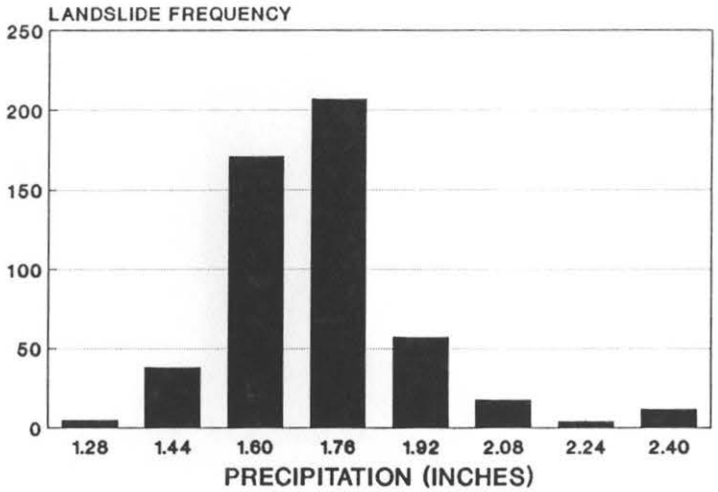

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10
ELEVATION (FEET) (Thousands)

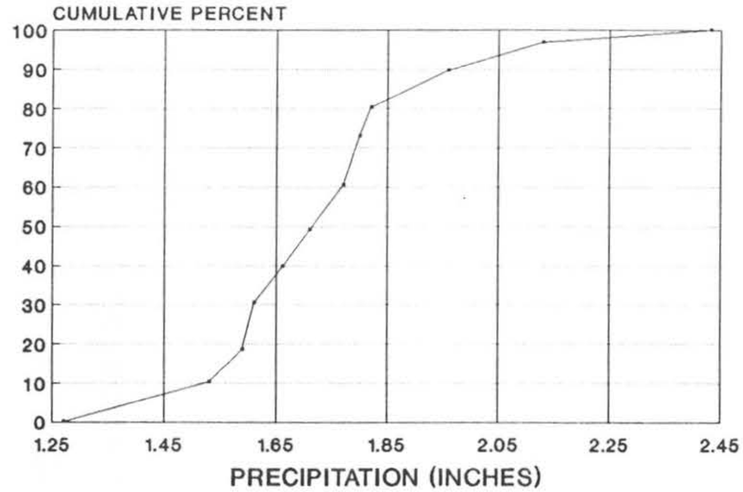

LANDSLIDE FREQUENCY
140
120
100
80
60
40
20
0
4 8 12 16 20 24 28 32 36
SLOPE (DEGREES)

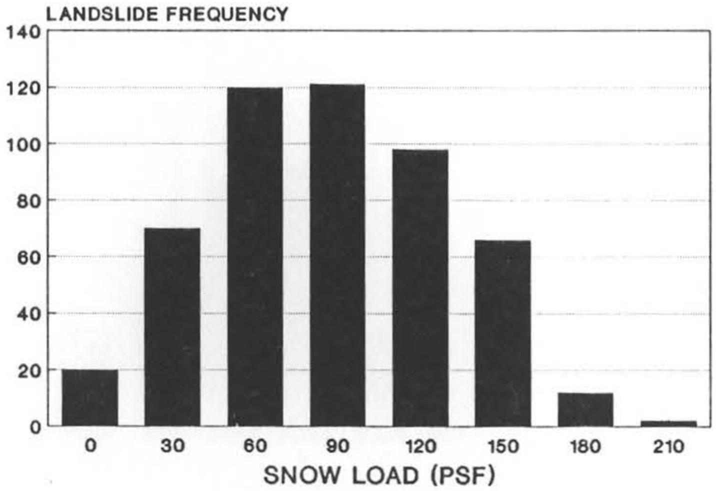

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40
SLOPE (DEGREES)

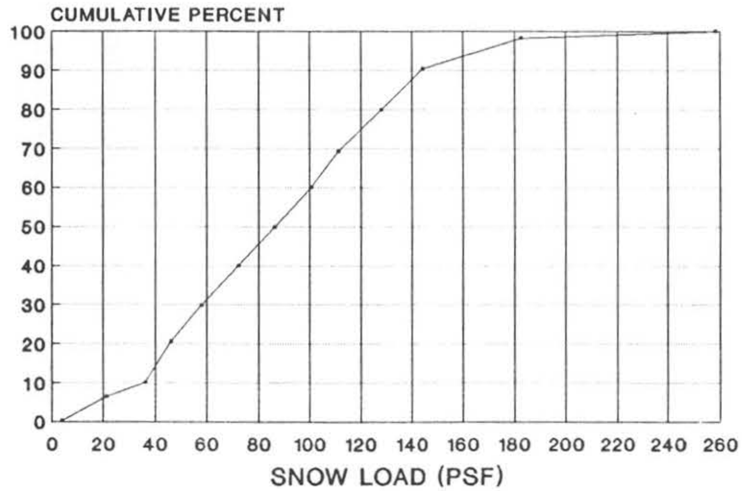
APPENDIX H-2

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD FOR IDAHO LANDSLIDES ASSOCIATED WITH IGNEOUS EXTRUSIVE ROCK


LANDSLIDE FREQUENCY
250
200
150
100
50
0
1.28
1.44
1.60
1.76
1.92
2.08
2.24
2.40
PRECIPITATION (INCHES)

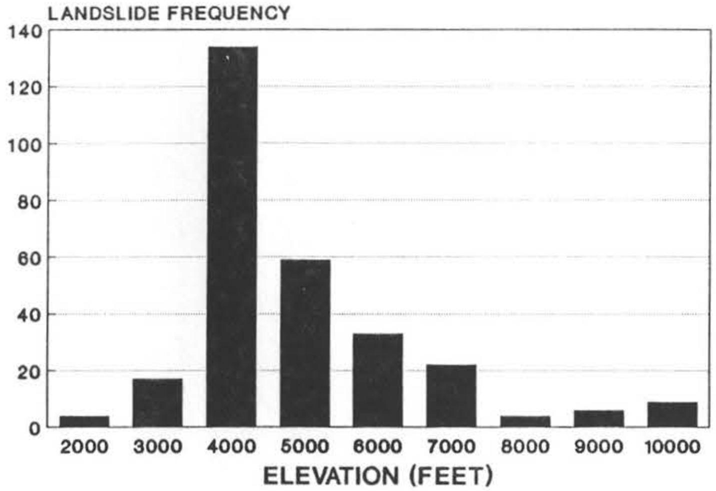

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.25
1.45
1.65
1.85
2.05
2.25
2.45
PRECIPITATION (INCHES)

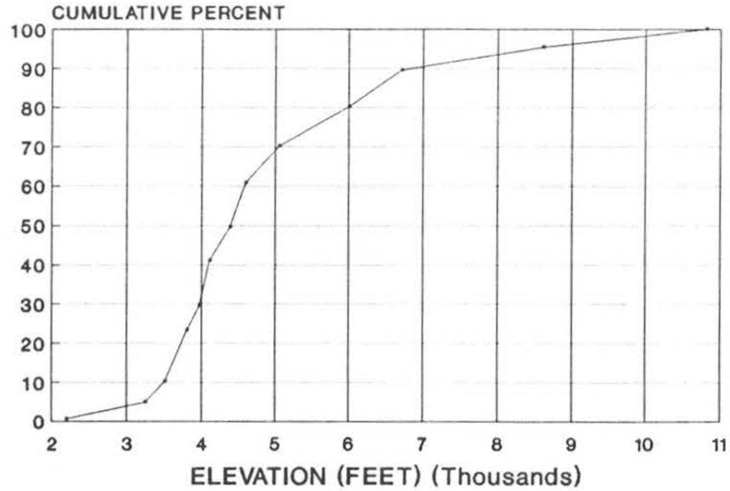

LANDSLIDE FREQUENCY
140
120
100
80
60
40
20
0
0
30
60
90
120
150
180
210
SNOW LOAD (PSF)

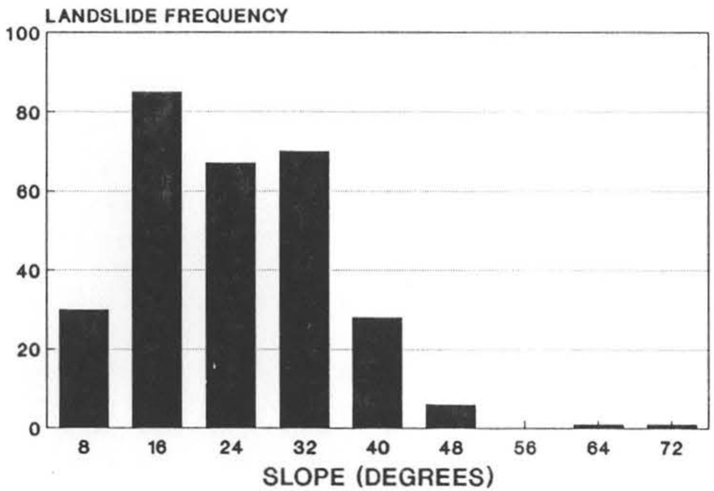

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
SNOW LOAD (PSF)

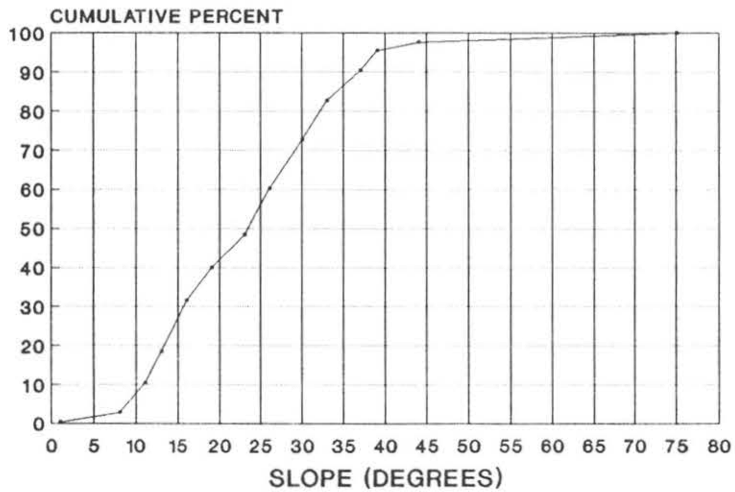
APPENDIX H-3

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE FOR IDAHO LANDSLIDES ASSOCIATED WITH IGNEOUS INTRUSIVE ROCK


LANDSLIDE FREQUENCY
140
120
100
80
60
40
20
0
2000 3000 4000 5000 6000 7000 8000 9000 10000
ELEVATION (FEET)

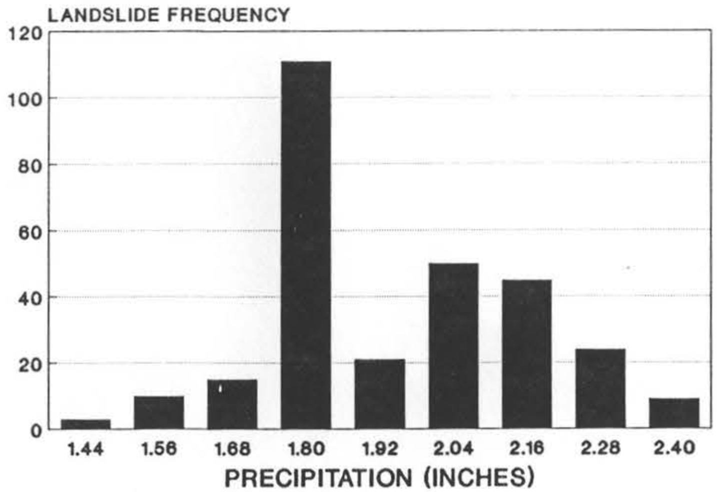

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
2 3 4 5 6 7 8 9 10 11
ELEVATION (FEET) (Thousands)

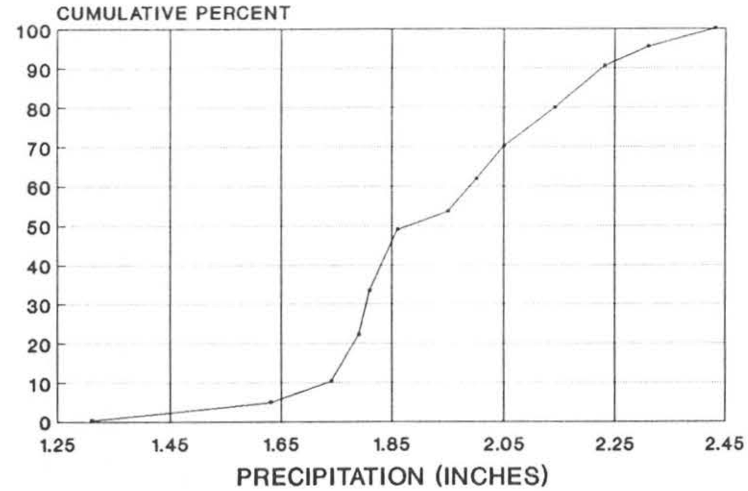

LANDSLIDE FREQUENCY
100
80
60
40
20
0
8 16 24 32 40 48 56 64 72
SLOPE (DEGREES)

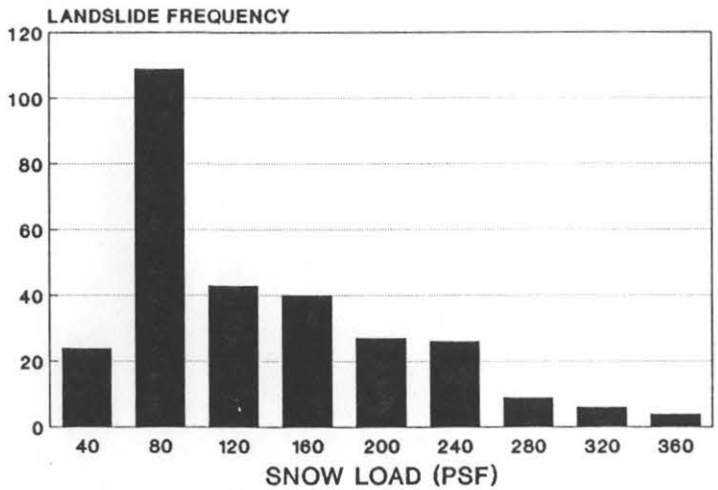

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
SLOPE (DEGREES)

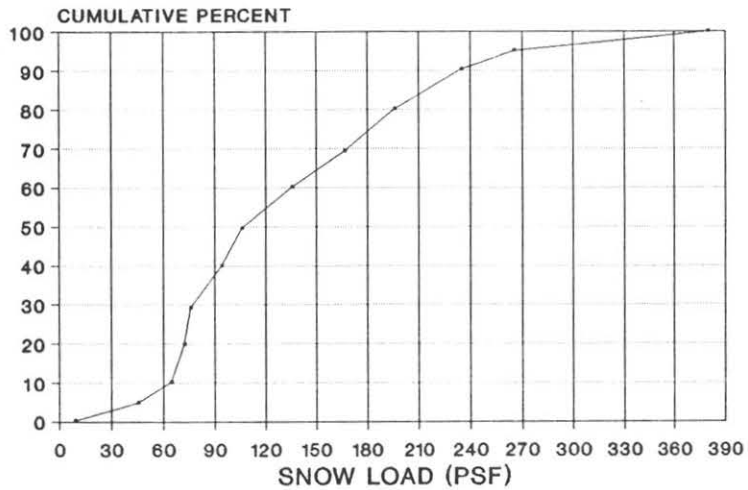
APPENDIX H-4

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD FOR IDAHO LANDSLIDES ASSOCIATED WITH IGNEOUS INTRUSIVE ROCK


LANDSLIDE FREQUENCY
120
100
80
60
40
20
0
1.44 1.56 1.68 1.80 1.92 2.04 2.16 2.28 2.40
PRECIPITATION (INCHES)

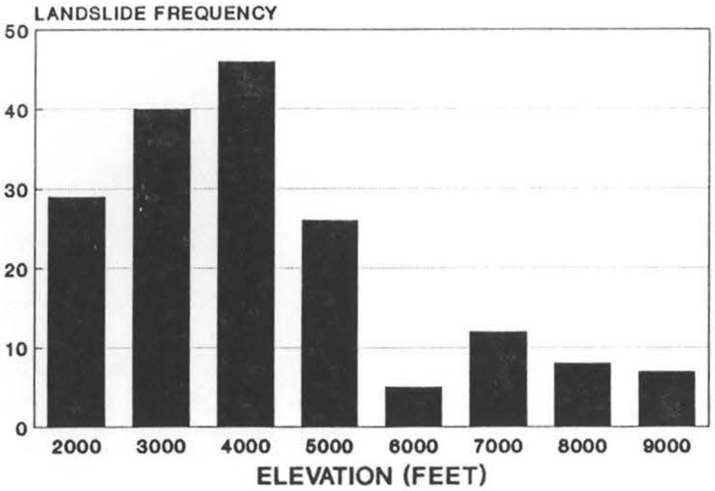

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.25 1.45 1.65 1.85 2.05 2.25 2.45
PRECIPITATION (INCHES)

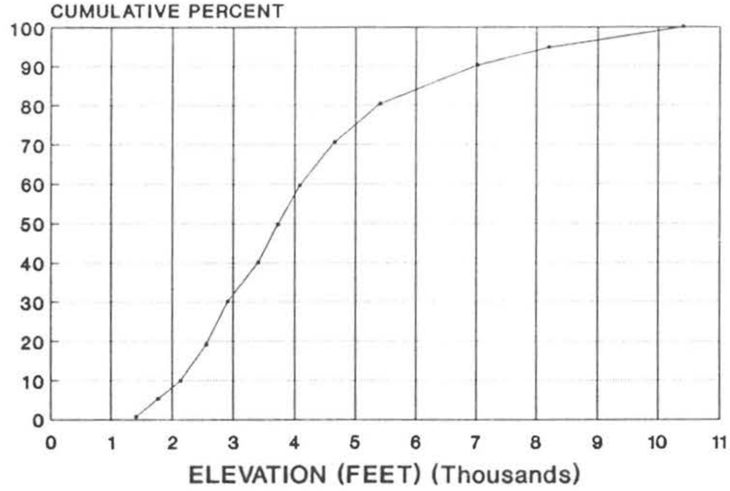

LANDSLIDE FREQUENCY
120
100
80
60
40
20
0
40 80 120 160 200 240 280 320 360
SNOW LOAD (PSF)

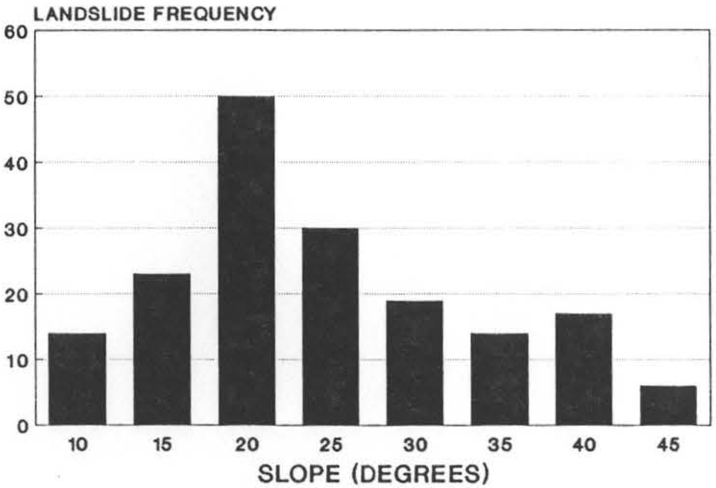

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 30 60 90 120 150 180 210 240 270 300 330 360 390
SNOW LOAD (PSF)

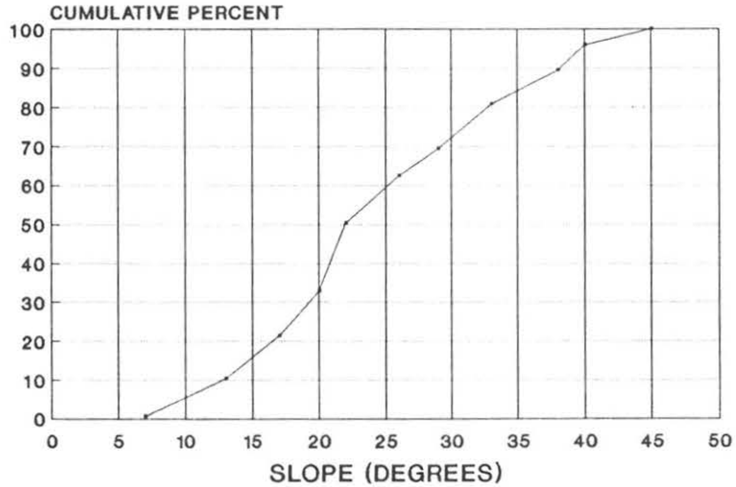
APPENDIX H-5

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE FOR IDAHO LANDSLIDES ASSOCIATED WITH METAMORPHIC ROCK


LANDSLIDE FREQUENCY
0
10
20
30
40
50
2000
3000
4000
5000
6000
7000
8000
9000
ELEVATION (FEET)

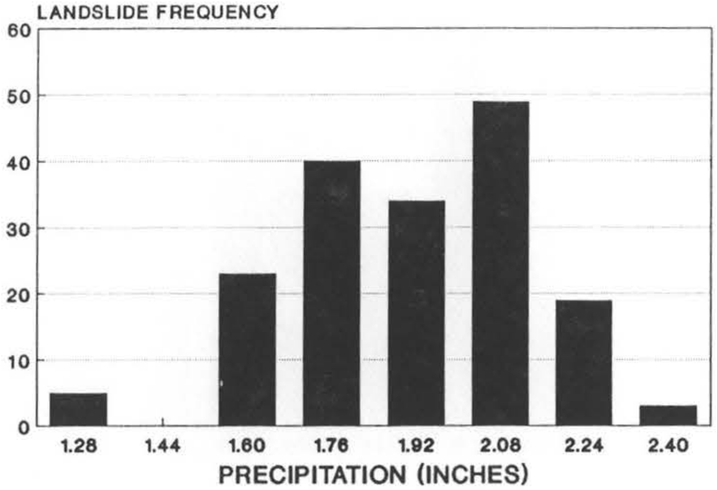

CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
5
6
7
8
9
10
11
ELEVATION (FEET) (Thousands)

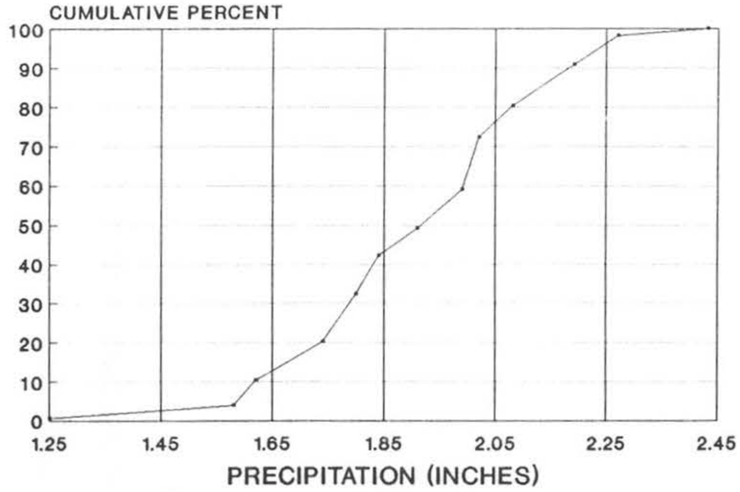

LANDSLIDE FREQUENCY
0
10
20
30
40
50
60
10
15
20
25
30
35
40
45
SLOPE (DEGREES)

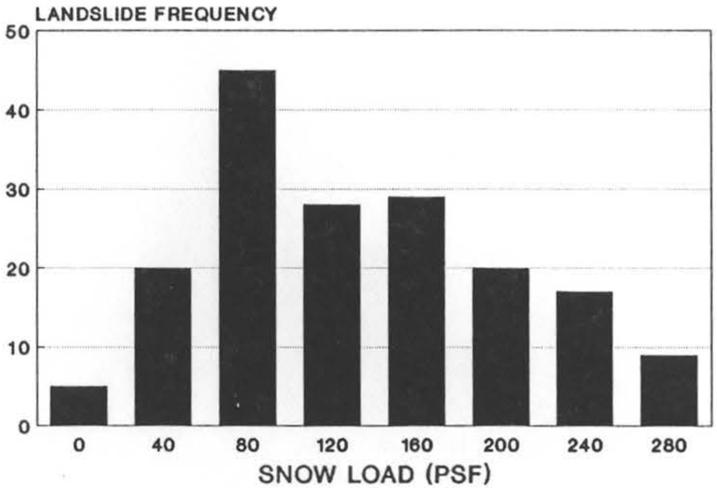

CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
50
SLOPE (DEGREES)

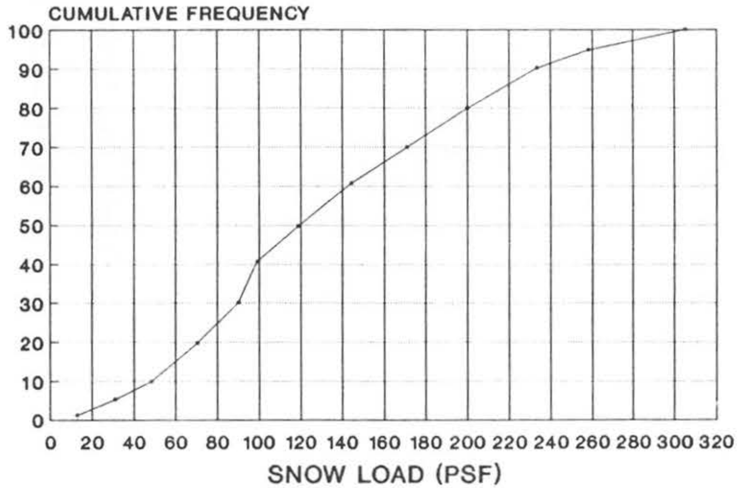
APPENDIX H-6

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD FOR IDAHO LANDSLIDES ASSOCIATED WITH METAMORPHIC ROCK


LANDSLIDE FREQUENCY
60
50
40
30
20
10
0
1.28
1.44
1.60
1.76
1.92
2.08
2.24
2.40
PRECIPITATION (INCHES)


CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.25
1.45
1.65
1.85
2.05
2.25
2.45
PRECIPITATION (INCHES)


LANDSLIDE FREQUENCY
50
40
30
20
10
0
0
40
80
120
160
200
240
280
SNOW LOAD (PSF)

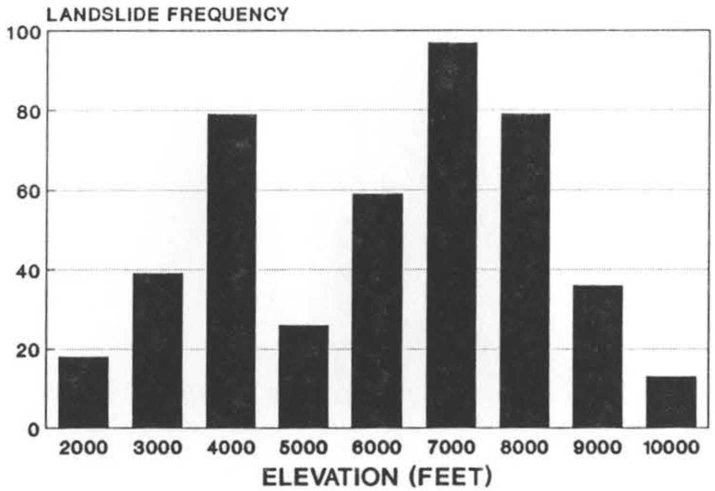

CUMULATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
SNOW LOAD (PSF)

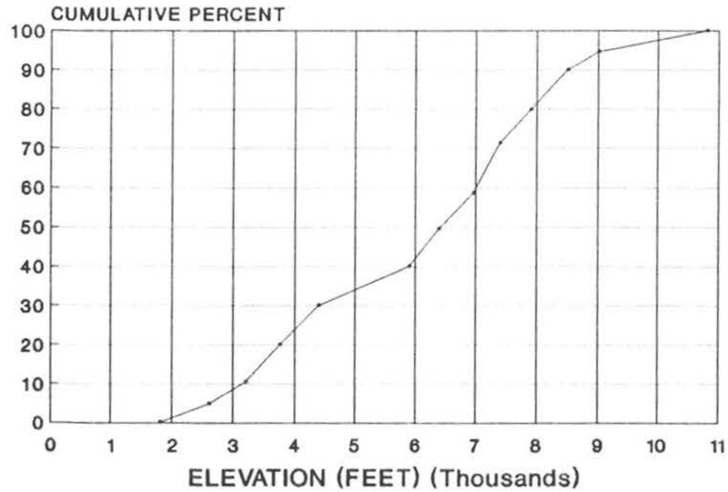
APPENDIX H-7

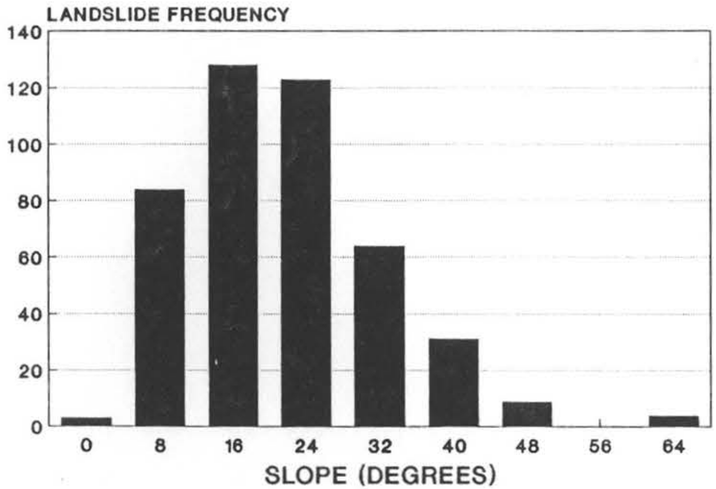
DISTRIBUTION OF ELEVATION AND SLOPE ANGLE

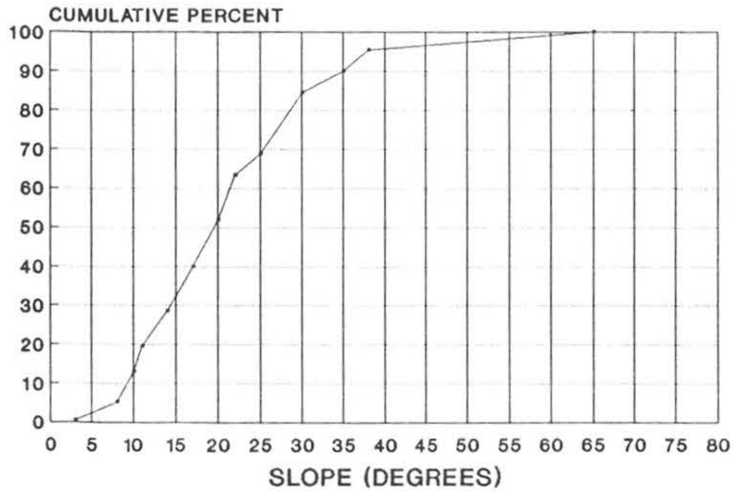
FOR IDAHO LANDSLIDES ASSOCIATED

WITH SEDIMENTARY ROCK


LANDSLIDE FREQUENCY
100
80
60
40
20
0
2000 3000 4000 5000 6000 7000 8000 9000 10000
ELEVATION (FEET)

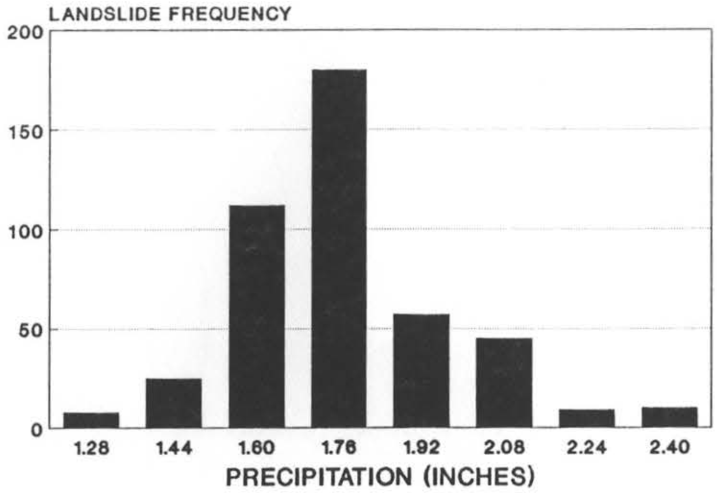

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11
ELEVATION (FEET) (Thousands)

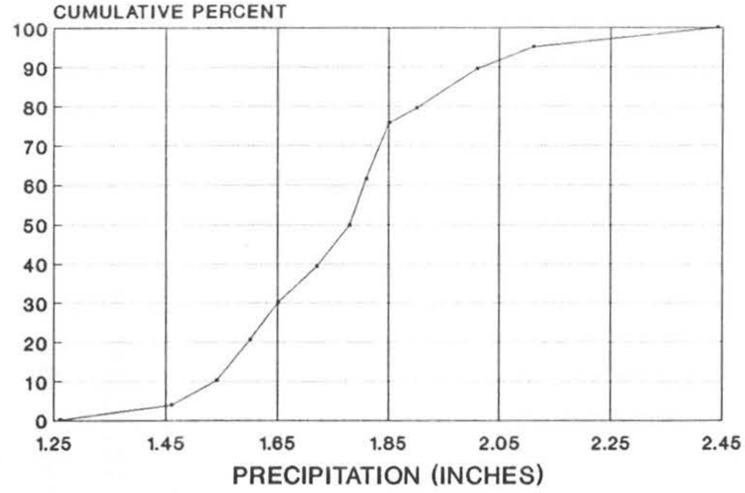

LANDSLIDE FREQUENCY
140
120
100
80
60
40
20
0
0 8 16 24 32 40 48 56 64
SLOPE (DEGREES)

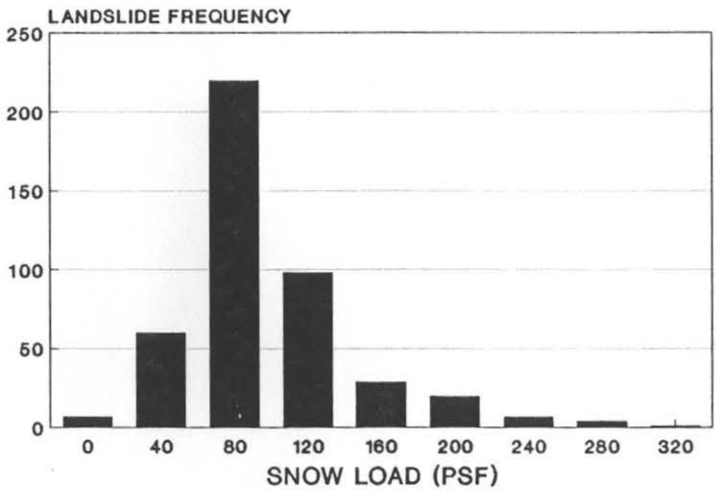

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
SLOPE (DEGREES)

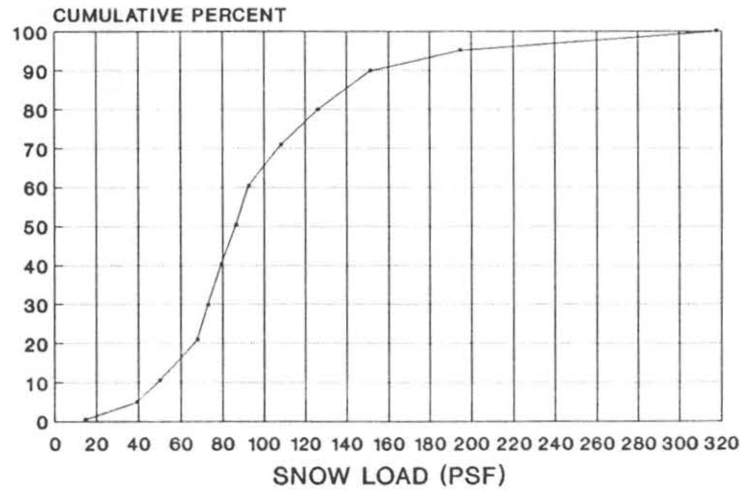
APPENDIX H-8

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD FOR IDAHO LANDSLIDES ASSOCIATED WITH SEDIMENTARY ROCK


LANDSLIDE FREQUENCY
200
150
100
50
0
1.28
1.44
1.60
1.76
1.92
2.08
2.24
2.40
PRECIPITATION (INCHES)

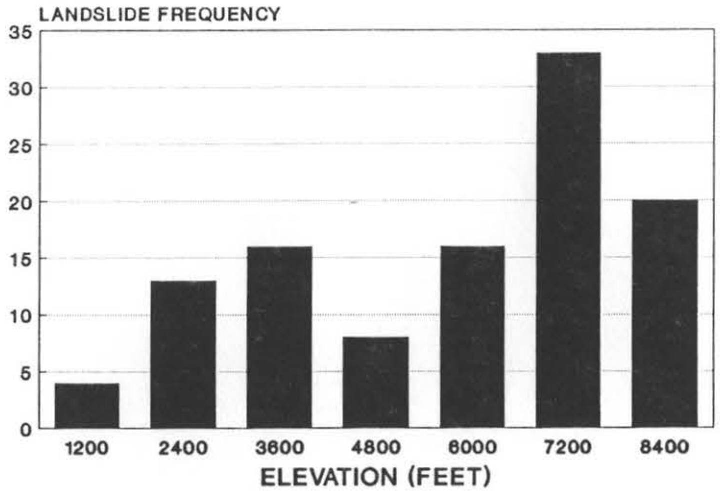

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.25
1.45
1.65
1.85
2.05
2.25
2.45
PRECIPITATION (INCHES)

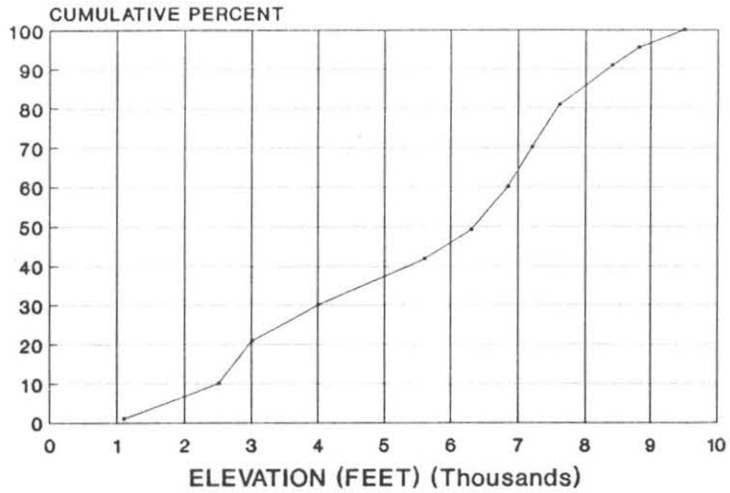

LANDSLIDE FREQUENCY
250
200
150
100
50
0
0
40
80
120
160
200
240
280
320
SNOW LOAD (PSF)

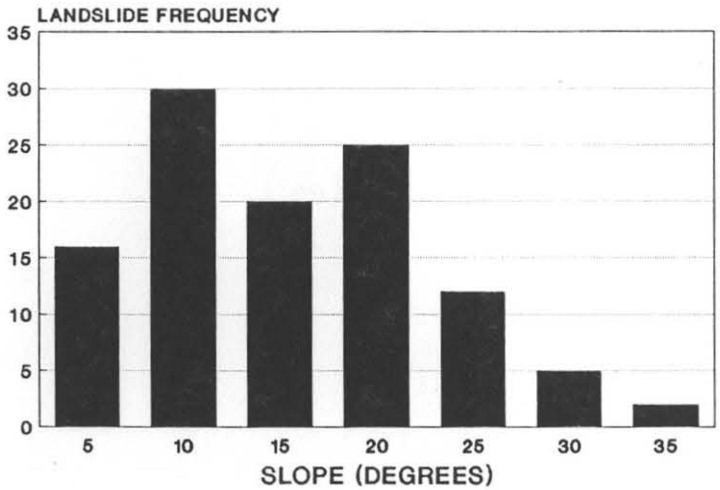

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
SNOW LOAD (PSF)

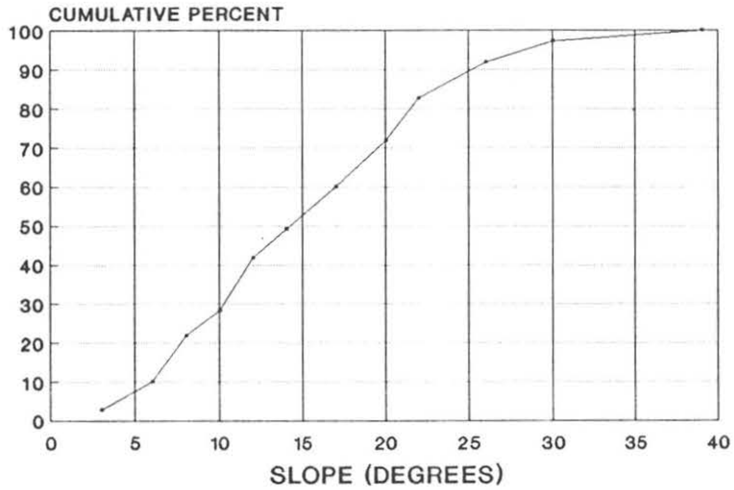
APPENDIX H-9

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE
FOR IDAHO LANDSLIDES ASSOCIATED
WITH SURFICIAL DEPOSITS


LANDSLIDE FREQUENCY
35
30
25
20
15
10
5
0
1200
2400
3600
4800
6000
7200
8400
ELEVATION (FEET)

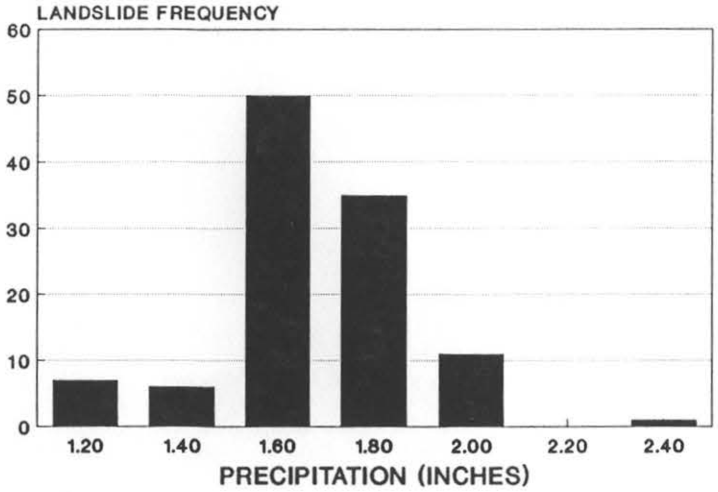

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
ELEVATION (FEET) (Thousands)

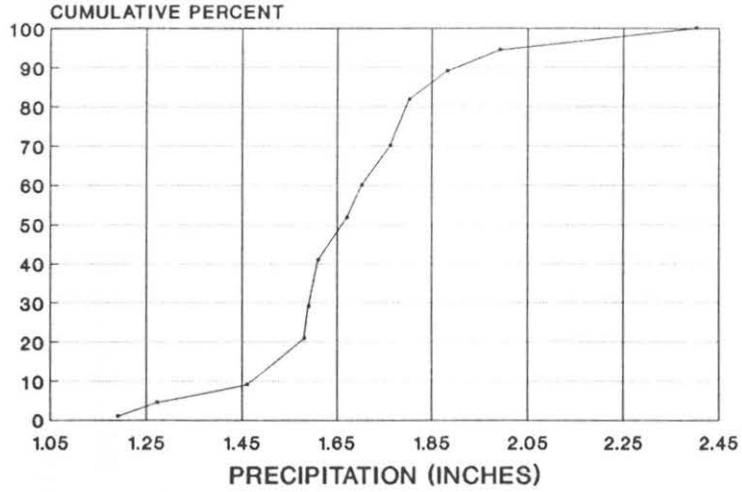

LANDSLIDE FREQUENCY
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
SLOPE (DEGREES)

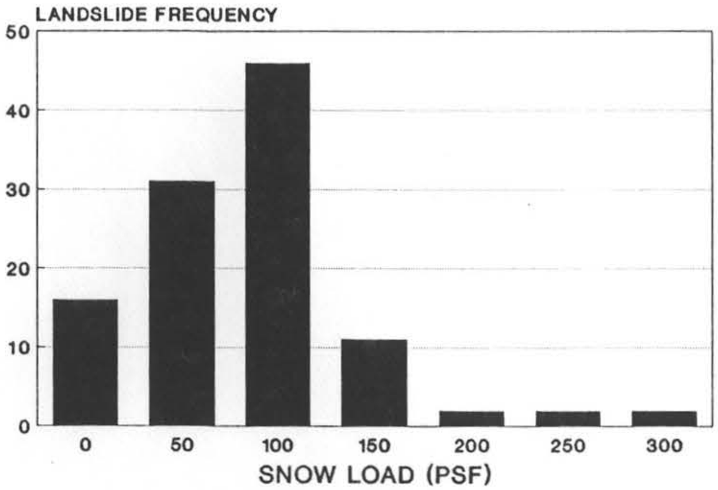

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
SLOPE (DEGREES)

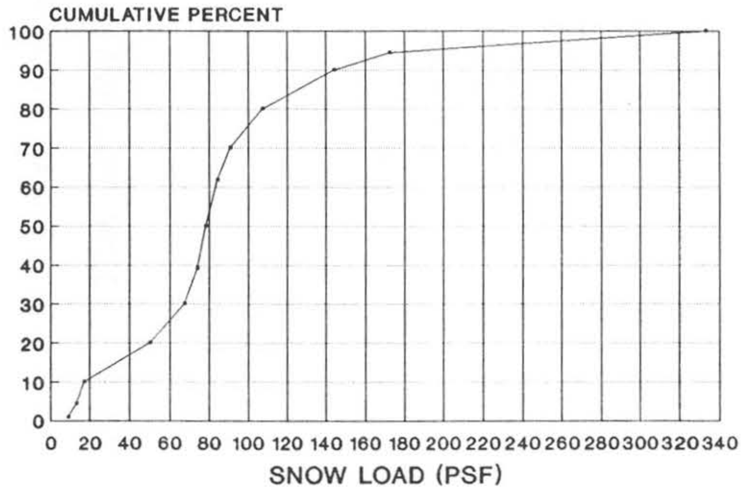
APPENDIX H-10

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD FOR IDAHO LANDSLIDES ASSOCIATED WITH SURFICIAL DEPOSITS


LANDSLIDE FREQUENCY
60
50
40
30
20
10
0
1.20
1.40
1.60
1.80
2.00
2.20
2.40
PRECIPITATION (INCHES)

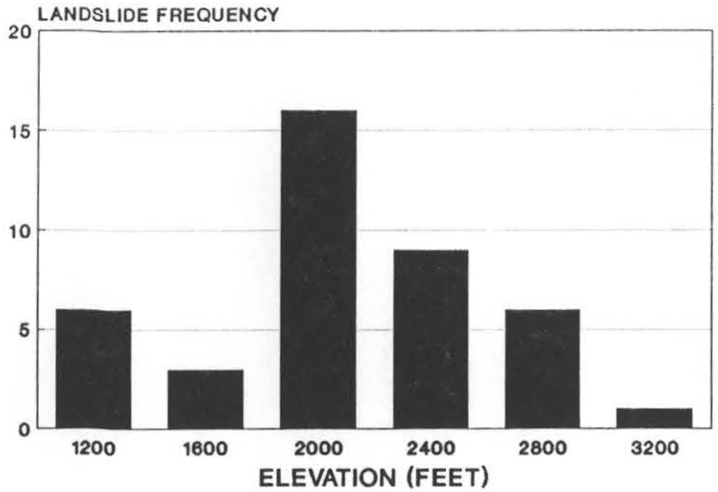

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.05
1.25
1.45
1.65
1.85
2.05
2.25
2.45
PRECIPITATION (INCHES)

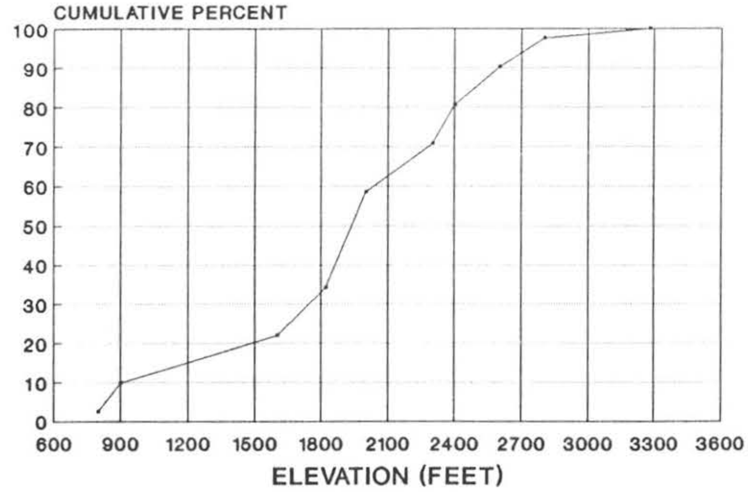

LANDSLIDE FREQUENCY
50
40
30
20
10
0
0
50
100
150
200
250
300
SNOW LOAD (PSF)

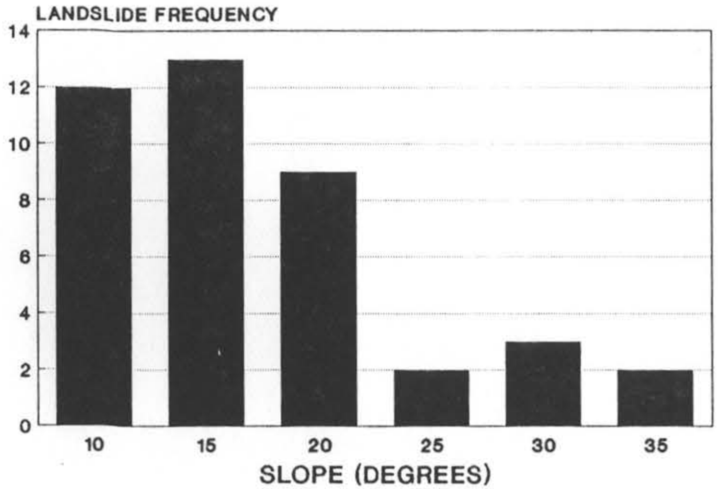

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
SNOW LOAD (PSF)

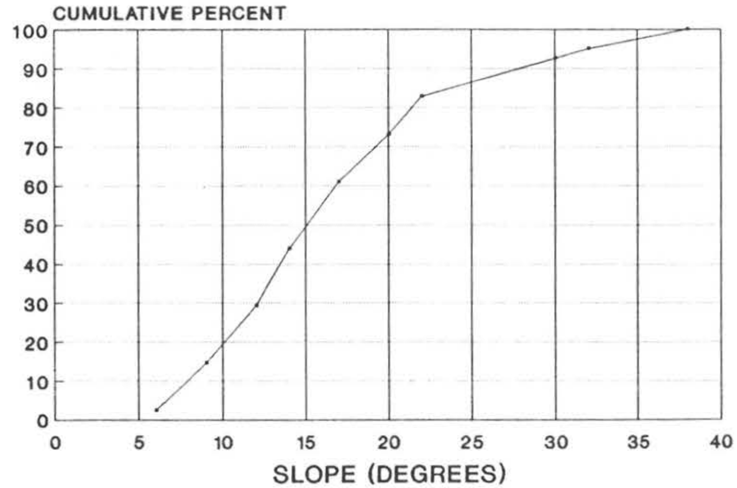
APPENDIX I-1

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH IGNEOUS EXTRUSIVE ROCK


LANDSLIDE FREQUENCY
20
15
10
5
0
1200
1600
2000
2400
2800
3200
ELEVATION (FEET)

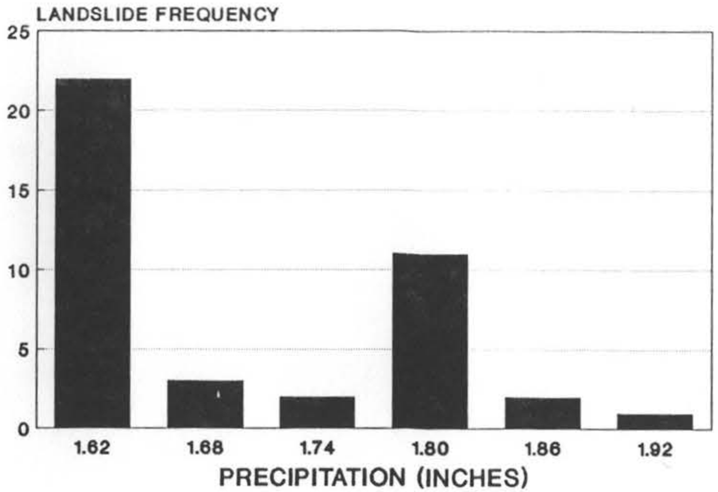

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
ELEVATION (FEET)

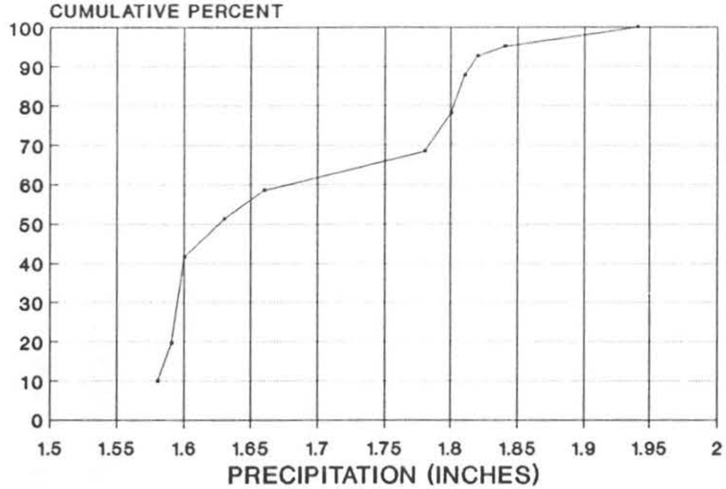

LANDSLIDE FREQUENCY
14
12
10
8
6
4
2
0
10
15
20
25
30
35
SLOPE (DEGREES)

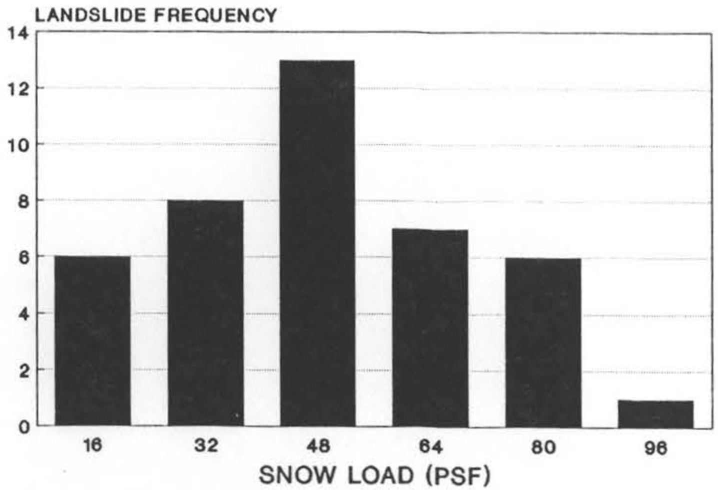

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
SLOPE (DEGREES)

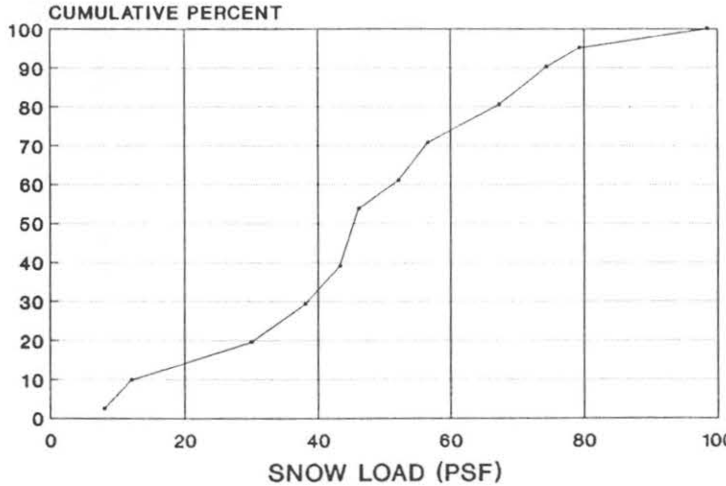
APPENDIX I-2

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH IGNEOUS EXTRUSIVE ROCK


LANDSLIDE FREQUENCY
25
20
15
10
5
0
1.62
1.68
1.74
1.80
1.86
1.92
PRECIPITATION (INCHES)

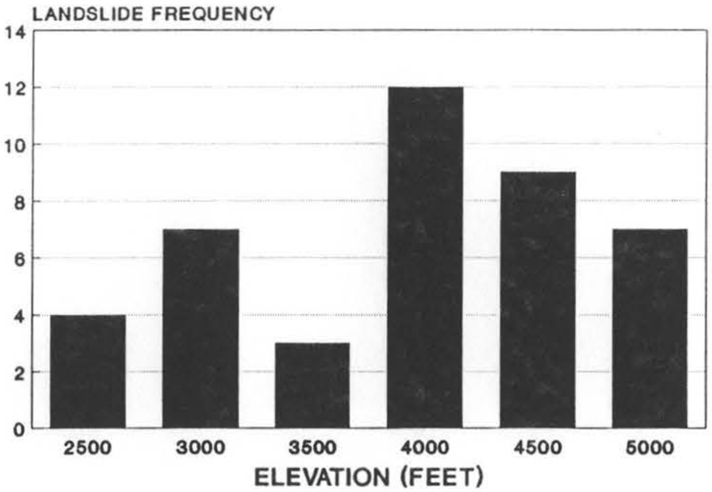

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.5
1.55
1.6
1.65
1.7
1.75
1.8
1.85
1.9
1.95
2
PRECIPITATION (INCHES)

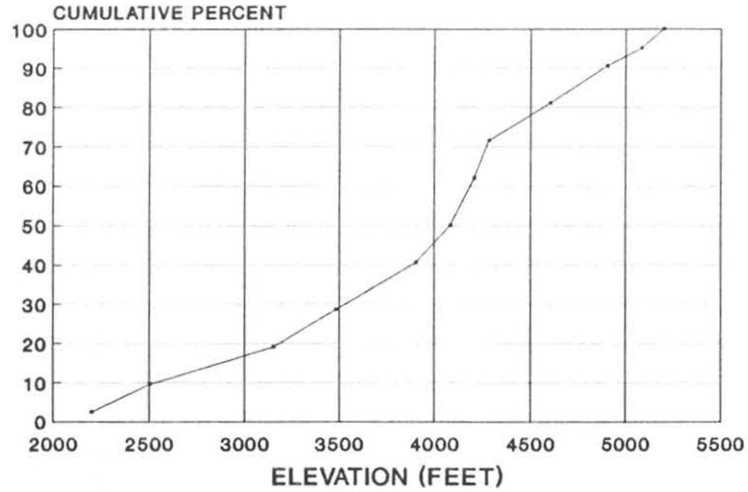

LANDSLIDE FREQUENCY
14
12
10
8
6
4
2
0
16
32
48
64
80
96
SNOW LOAD (PSF)

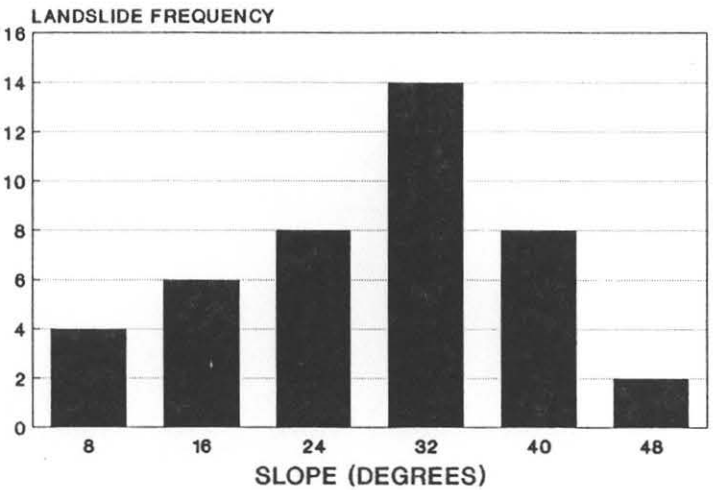

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
SNOW LOAD (PSF)

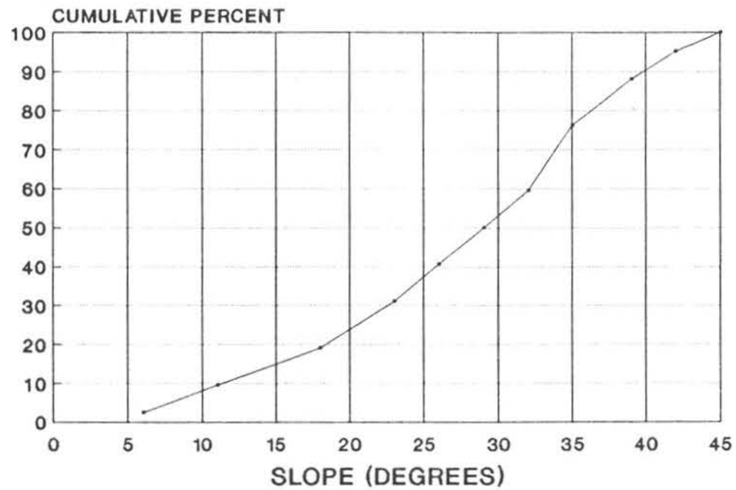
APPENDIX I-3

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH IGNEOUS INTRUSIVE ROCK


LANDSLIDE FREQUENCY
0
2
4
6
8
10
12
14
2500
3000
3500
4000
4500
5000
ELEVATION (FEET)

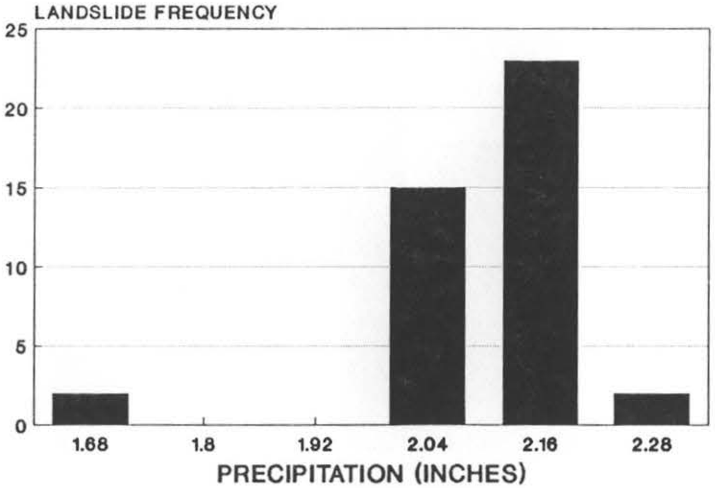

CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
2000
2500
3000
3500
4000
4500
5000
5500
ELEVATION (FEET)

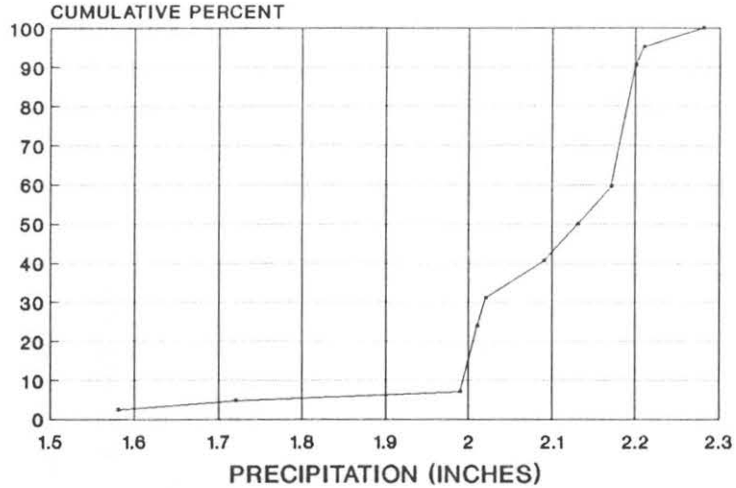

LANDSLIDE FREQUENCY
0
2
4
6
8
10
12
14
16
8
16
24
32
40
48
SLOPE (DEGREES)

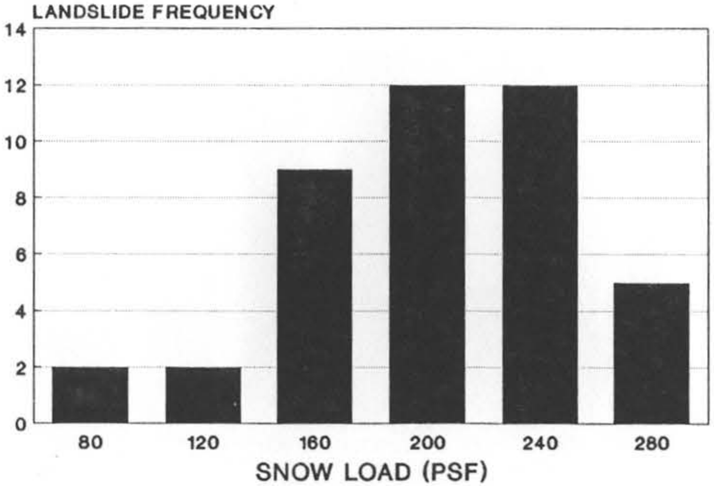

CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
SLOPE (DEGREES)

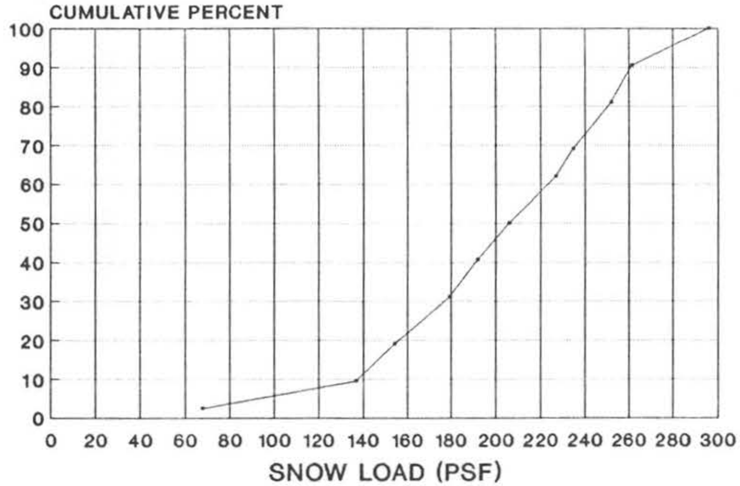
APPENDIX I-4

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH IGNEOUS INTRUSIVE ROCK


LANDSLIDE FREQUENCY
25
20
15
10
5
0
1.68
1.8
1.92
2.04
2.16
2.28
PRECIPITATION (INCHES)

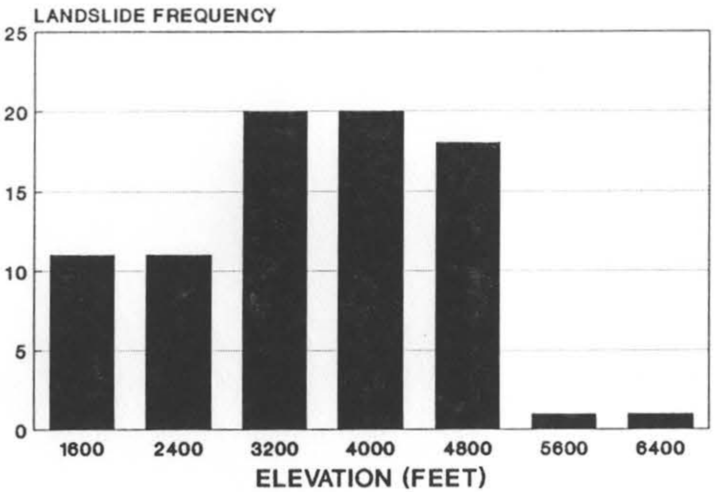

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
PRECIPITATION (INCHES)

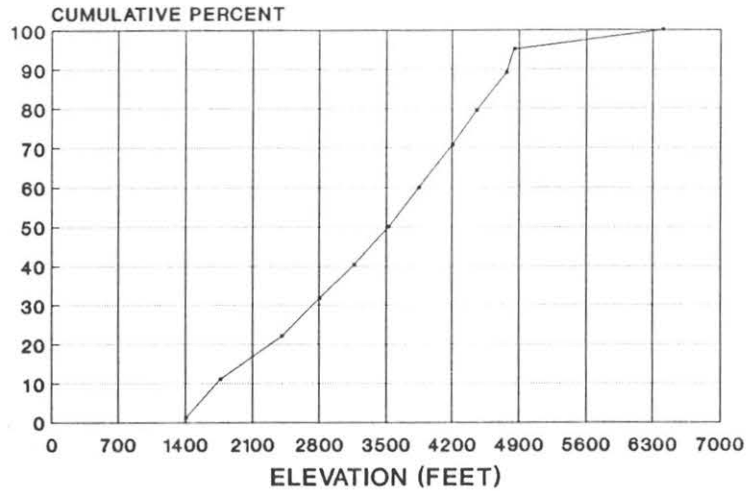

LANDSLIDE FREQUENCY
14
12
10
8
6
4
2
0
80
120
160
200
240
280
SNOW LOAD (PSF)

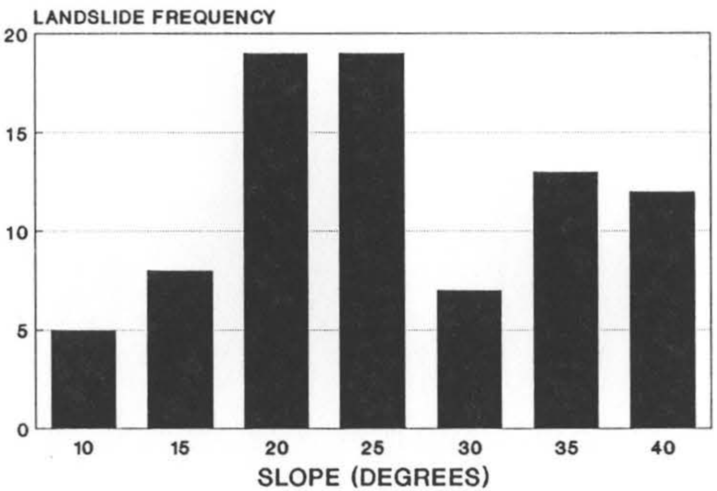

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
SNOW LOAD (PSF)

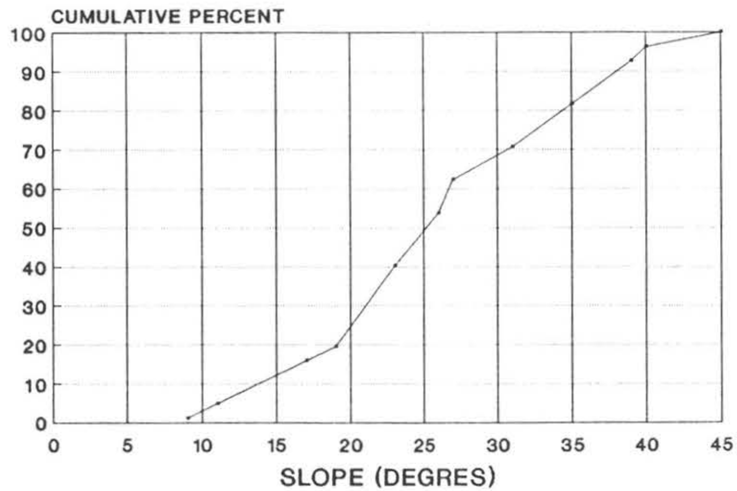
APPENDIX I-5

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH METAMORPHIC ROCK


LANDSLIDE FREQUENCY
25
20
15
10
5
0
1600
2400
3200
4000
4800
5600
6400
ELEVATION (FEET)

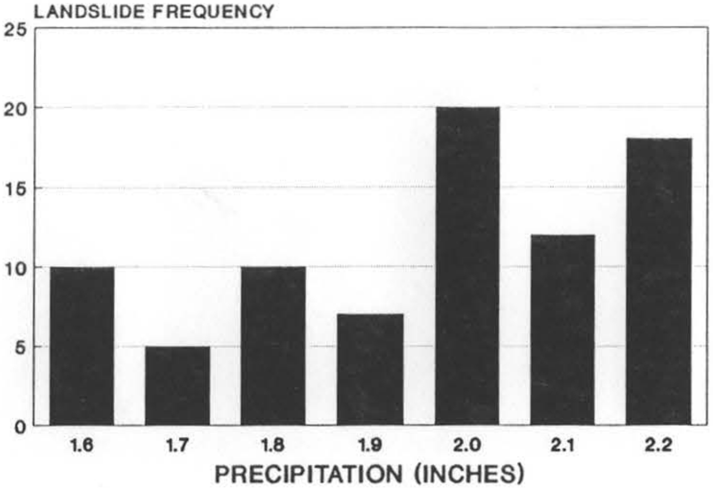

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
700
1400
2100
2800
3500
4200
4900
5600
6300
7000
ELEVATION (FEET)

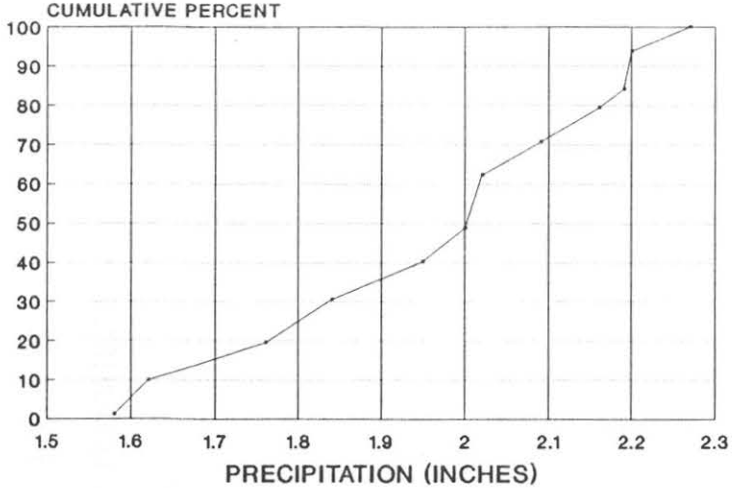

LANDSLIDE FREQUENCY
20
15
10
5
0
10
15
20
25
30
35
40
SLOPE (DEGREES)

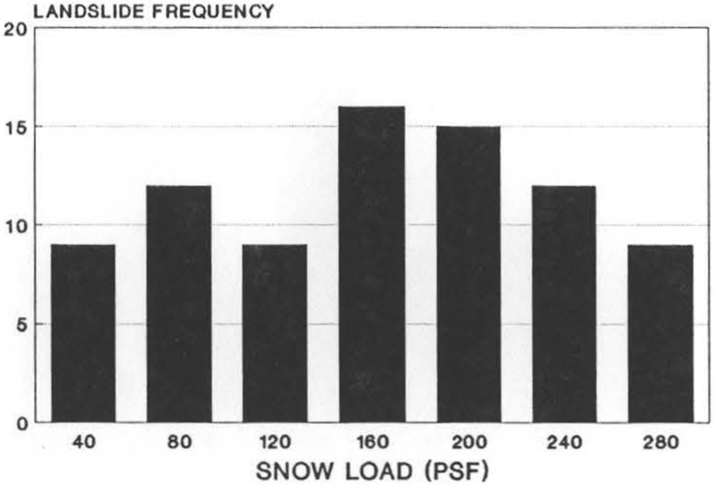

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
SLOPE (DEGRES)

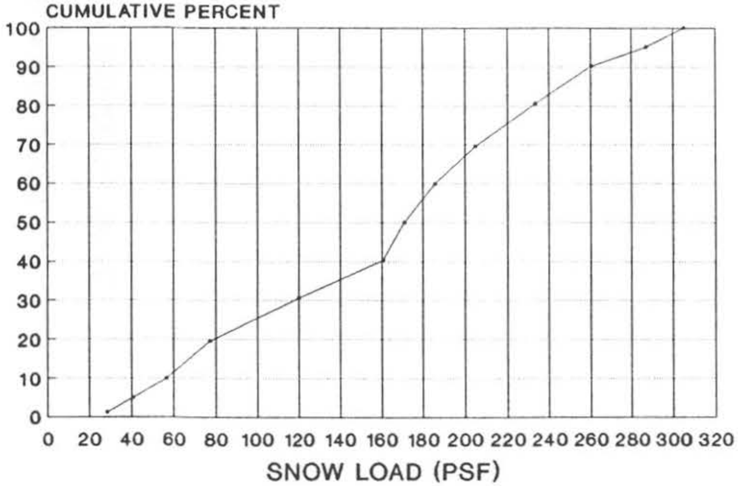
APPENDIX I-6

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD
IN A SELECT REGION OF NORTH IDAHO
FOR LANDSLIDES ASSOCIATED WITH
METAMORPHIC ROCK


LANDSLIDE FREQUENCY
25
20
15
10
5
0
1.6
1.7
1.8
1.9
2.0
2.1
2.2
PRECIPITATION (INCHES)

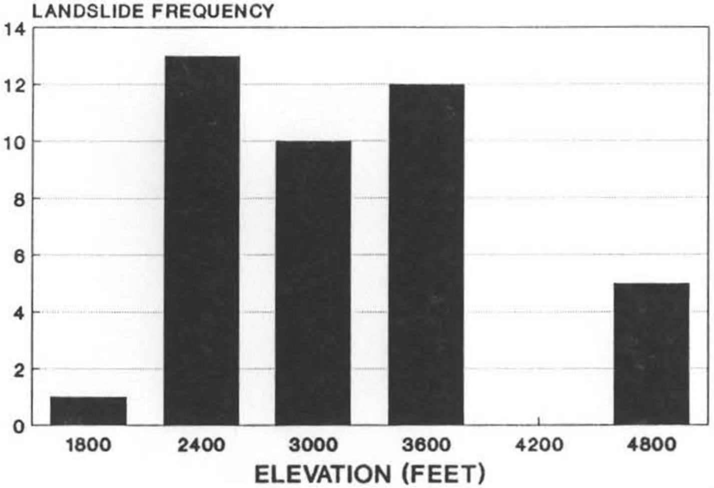

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
PRECIPITATION (INCHES)

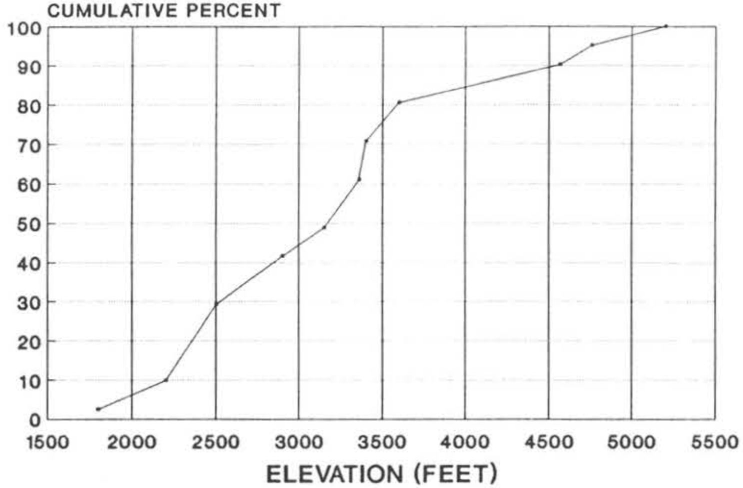

LANDSLIDE FREQUENCY
20
15
10
5
0
40
80
120
160
200
240
280
SNOW LOAD (PSF)

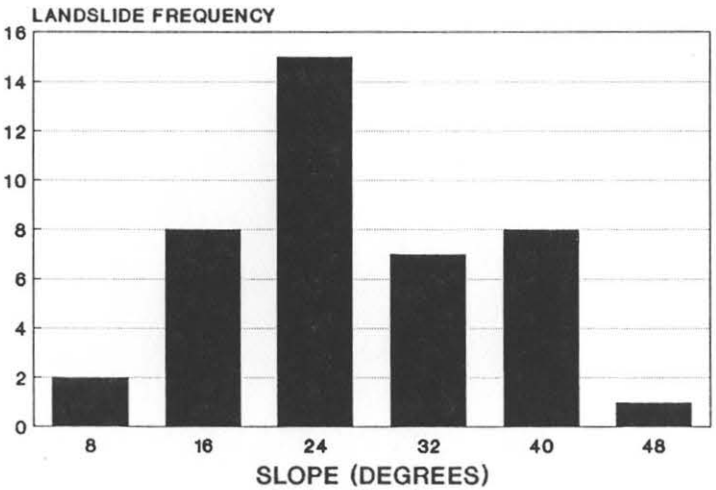

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
SNOW LOAD (PSF)

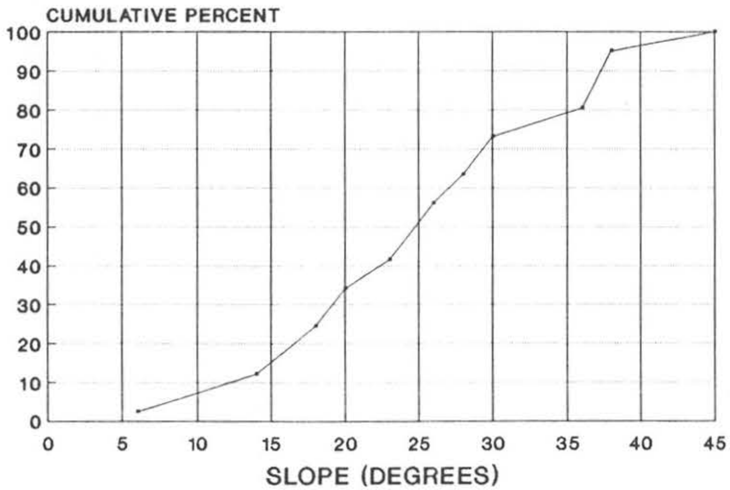
APPENDIX I-7

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH SEDIMENTARY ROCK


LANDSLIDE FREQUENCY
0
2
4
6
8
10
12
14
1800
2400
3000
3600
4200
4800
ELEVATION (FEET)

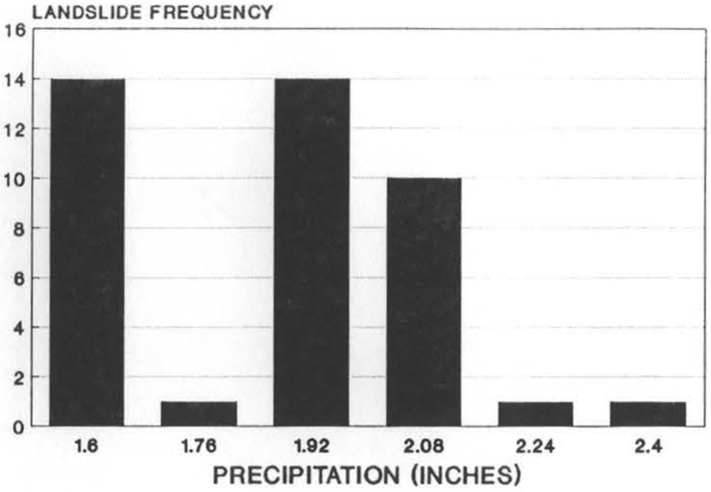

CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
1500
2000
2500
3000
3500
4000
4500
5000
5500
ELEVATION (FEET)

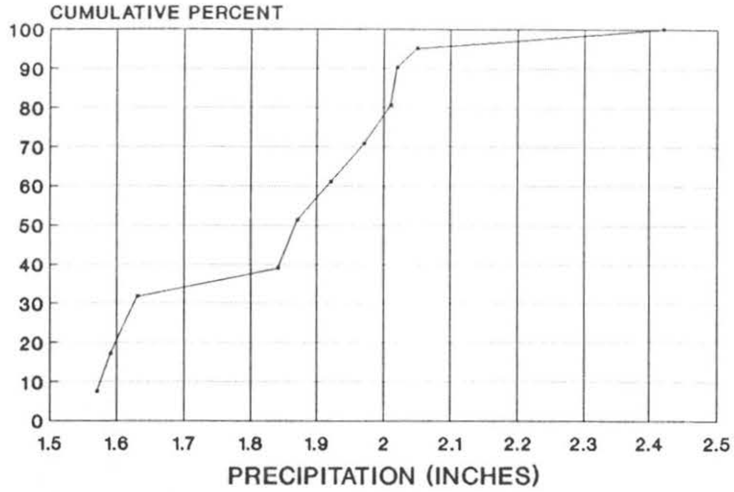

LANDSLIDE FREQUENCY
0
2
4
6
8
10
12
14
16
8
16
24
32
40
48
SLOPE (DEGREES)

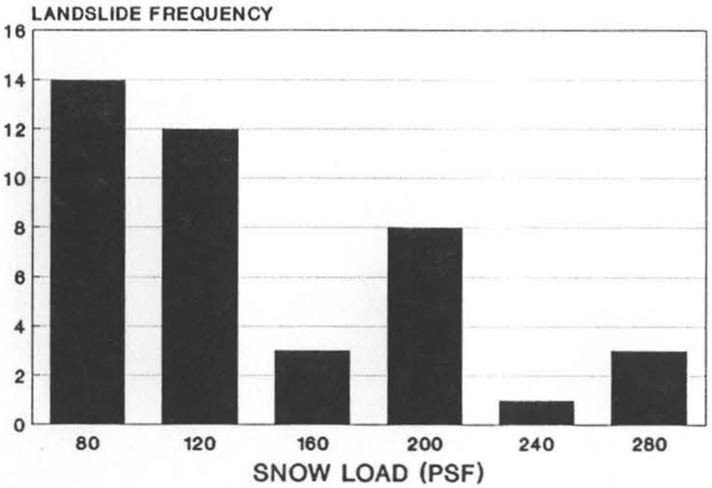

CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
SLOPE (DEGREES)

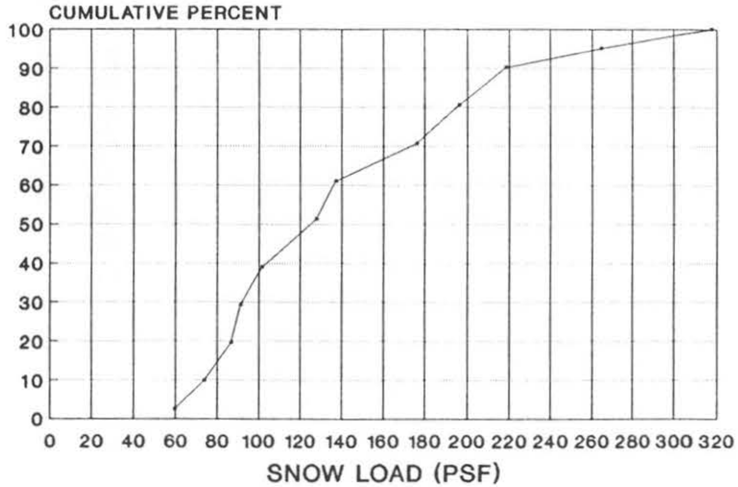
APPENDIX I-8

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH SEDIMENTARY ROCK


LANDSLIDE FREQUENCY
16
14
12
10
8
6
4
2
0
1.6
1.76
1.92
2.08
2.24
2.4
PRECIPITATION (INCHES)

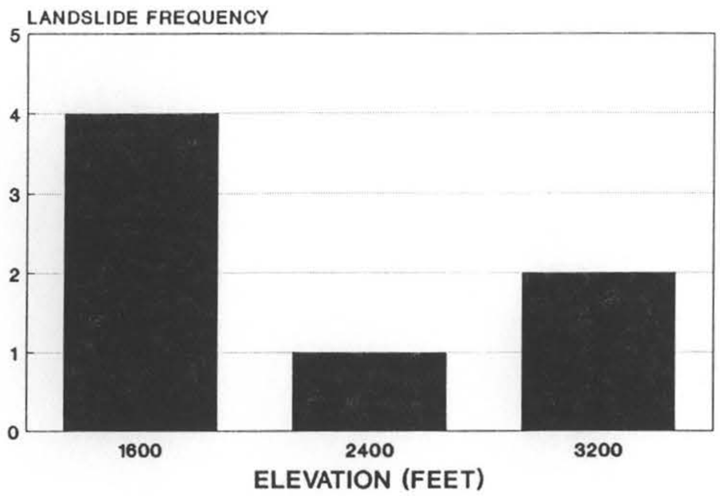

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
PRECIPITATION (INCHES)

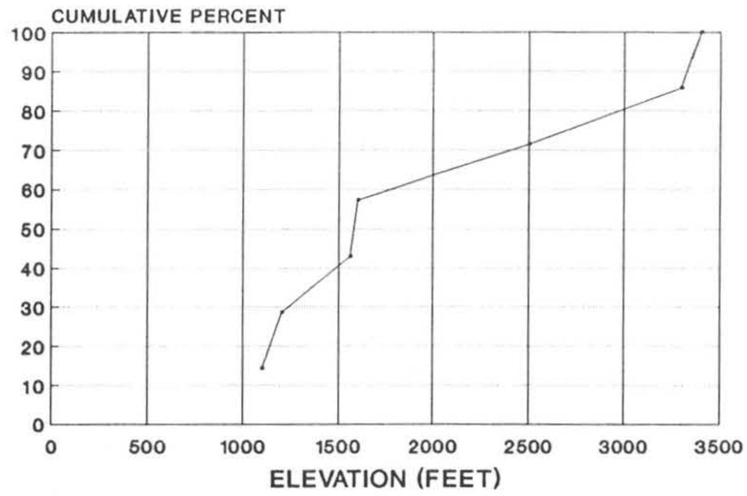

LANDSLIDE FREQUENCY
16
14
12
10
8
6
4
2
0
80
120
160
200
240
280
SNOW LOAD (PSF)

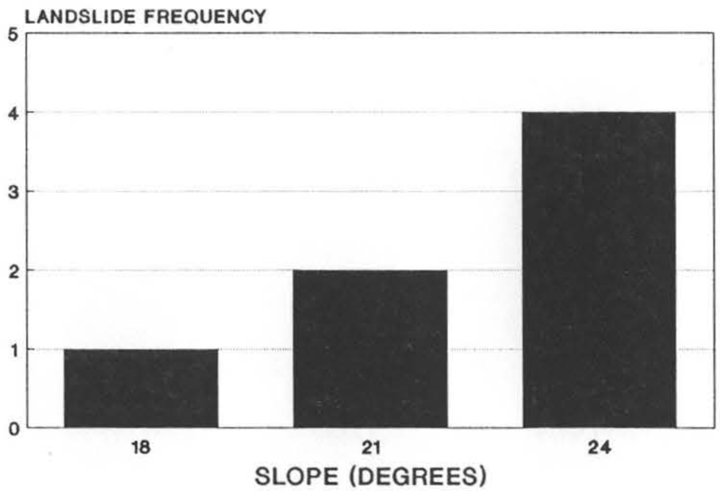

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
SNOW LOAD (PSF)

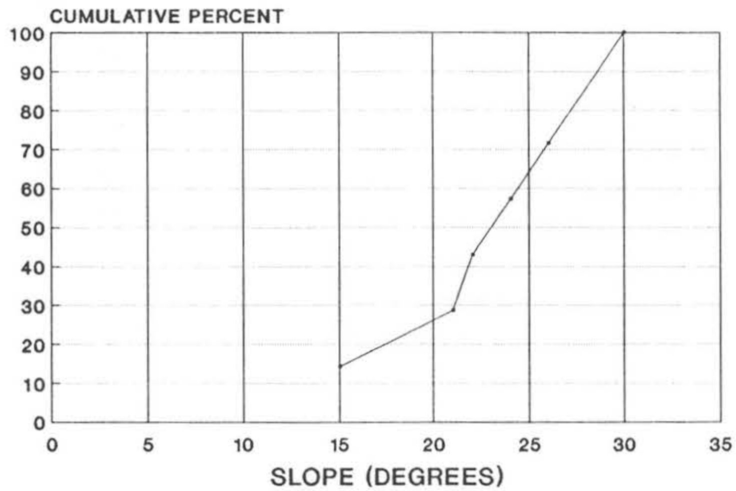
APPENDIX I-9

DISTRIBUTION OF ELEVATION AND SLOPE ANGLE IN A SELECT REGION OF NORTH IDAHO FOR LANDSLIDES ASSOCIATED WITH SURFICIAL DEPOSITS


LANDSLIDE FREQUENCY
5
4
3
2
1
0
1600
2400
3200
ELEVATION (FEET)

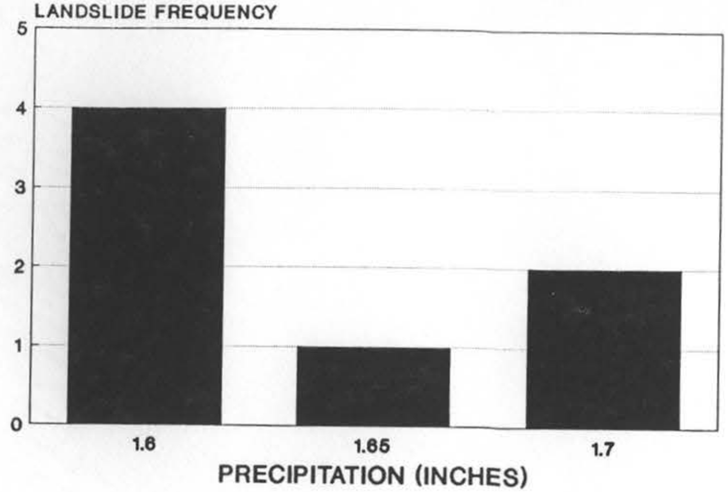

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
3000
3500
ELEVATION (FEET)

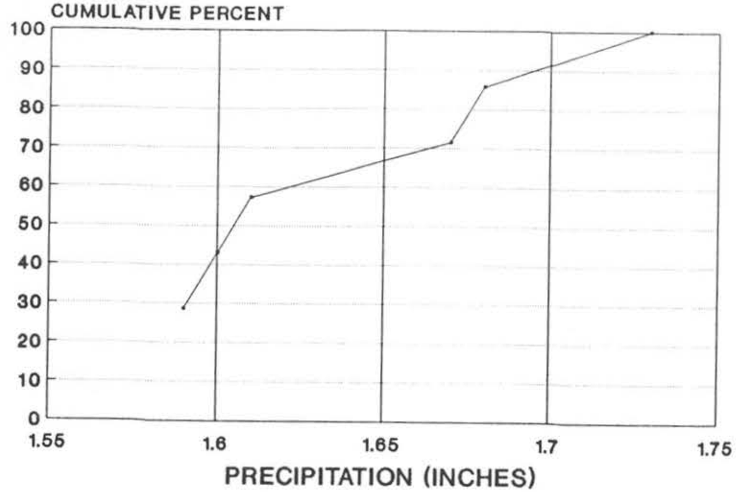

LANDSLIDE FREQUENCY
5
4
3
2
1
0
18
21
24
SLOPE (DEGREES)

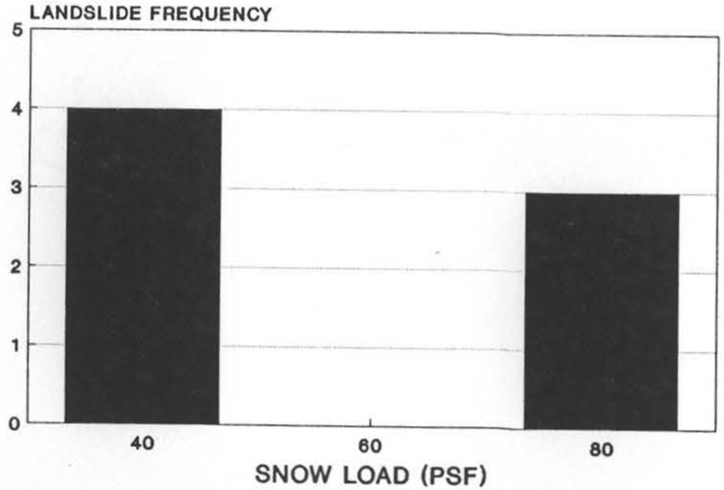

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
SLOPE (DEGREES)

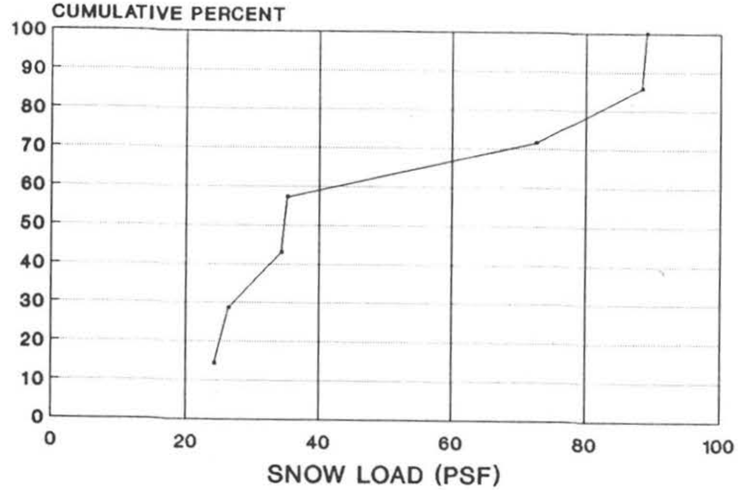
APPENDIX I-10

DISTRIBUTION OF PRECIPITATION AND SNOW LOAD
IN A SELECT REGION OF NORTH IDAHO
FOR LANDSLIDES ASSOCIATED WITH
SURFICIAL DEPOSITS


LANDSLIDE FREQUENCY
5
4
3
2
1
0
1.6
1.65
1.7
PRECIPITATION (INCHES)


CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
1.55
1.6
1.65
1.7
1.75
PRECIPITATION (INCHES)


LANDSLIDE FREQUENCY
5
4
3
2
1
0
40
60
80
SNOW LOAD (PSF)


CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
SNOW LOAD (PSF)