EVALUATING LANDSLIDE HAZARDS FOR RESOURCES MANAGEMENT ON THE FISHLAKE NATIONAL FOREST, CENTRAL UTAH

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ABSTRACT

Landslide-related losses on National Forests commonly involve damage to facilities or resources and landsliding that acts as a barrier to resource utilization. Landslide-hazard reduction programs have the potential for significantly reducing losses. The comprehensive landslide-hazard reduction program on the Fishlake National Forest seeks to avoid reactivation of existing landslides or creation of new ones. It aids management decision-making for: 1) land and resource allocation 2) project design, and 3) prioritizing remedial measures. An inventory locating, describing, and mapping existing landslides is basic to aiding all three kinds of decisions. Inventory work found eighty-nine landslides ranging from 1 to 1,239 acres on the southern Wasatch Plateau. Using this landslide data, a quantitative approach assigned relative landslide-susceptibility to unfailed slopes. Knowledge of existing and potential landslides in this area aids land and resource allocation decisions. Avoidance of all existing or potential landslides is not always possible in resource management. There is a 0.34 probability of future landslide movement near the south end of Thousand Lake Mountain. This was determined from tree-ring analysis of past activity within this old landslide deposit. This information guides decisions on project design changes. Physical monitoring established a 10.5 feet per year rate of movement for a Salina Canyon landslide adjacent to the Interstate 70 right-of-way. At this current rate, the landslide will encroach on the right-of-way in 14 years. Observational monitoring occurs along a 2.7 mile road

section in Beaver Canyon. Over a three year period, an average of 20 locations hosted multiple failures each year. The annual intensity indicates the use being made of debris disposal sites. Activity index for indiviual locations indicates failure activity per year. Most locations are subject to a failure every year with a few hosting two failures per year. Prioritizing remedial measures is easily made with this type of data.

INTRODUCTION

Landslides like all natural disasters result in monetary and resource losses (Fleming and Taylor, 1980). For natural resources management, this means both damage to existing facilities or resources and landsliding that acts as a barrier to resource utilization. It is not uncommon for the magnitude of landslide-related losses to go unrecognized. The lower density of people and structures on National Forests compared to urban and suburban areas only tends to enhance this misperception. Fewer attention-getting events occur to illustrate the need for a comprehensive approach to landslide hazard reduction. Too often, efforts are only directed where landslides are proving especially troublesome. This crisis-oriented approach avoids addressing the total range of landslide-related losses being incurred. Significant reduction in losses is possible through efforts aimed at preventing or mitigating damage that may occur (Fleming et al, 1979; Fleming and Taylor, 1980). This can represent a considerable savings over a number of years. For example, an estimated $400,000 was spent by federal, state, and private sources for remedial work on landslides within the Fishlake National Forest in central Utah during the last four years. This amount represents costs for debris removal and landslide stabilization; no dollar values for natural resources damaged or blocked from future development are included. Clearly, a comprehensive program contributing to reduction of landslide losses is desirable from a management standpoint.

LANDSLIDE HAZARD REDUCTION

The Fishlake National Forest encompasses approximately 1.5 million acres in central Utah (Fig. 1). Principal resources managed are water, range land, minerals, recreation use, wildlife habitat and timber. The Forest includes the southern Wasatch Plateau, Pavant Range, Canyon Range, northern Sevier Plateau, Fishlake Plateau, Tushar Mountains, and Thousand Lake Mountain. These landforms include a variety of sedimentary and igneous rock types with thrust faults, normal faults, and broad folds as typical structural features. Elevations range from 1520 m to 3895 m. A number of major, known landslides are found within the Forest boundaries (Shroder, 1971).

A comprehensive landslide-hazard reduction program is being instituted on the Fishlake National Forest. Avoiding reactivation of existing landslides or creation of new ones is the primary goal. It evaluates landslide hazards to aid management decision-making in three major areas: 1) land and resource allocation, 2) project design, and 3) prioritizing mitigation or remedial measures. The inital step in the program is an inventory to locate, describe, and map all existing landslides. This inventory provides the basic data for: 1) assessing landslide-susceptibility, 2) establishing probability of future movement, and 3) determining frequency or rate of sliding. Landslide inventory work uses existing geologic maps, interpretation of large-scale aerial photography, and field evaluation. The inventory is presently complete on the southern Wasatch Plateau, northern Sevier Plateau, and Tushar Mountains. A total of 89, 26, and 213 landslides, respectively, are found within these three areas.

LAND AND RESOURCE ALLOCATION

Land and resource allocation questions involve comparison between alternative courses of action. For example, it is desirable to choose the road route crossing the least amount of landslide-susceptible terrain from among several feasible routes. These decisions require knowledge of existing landslides and relative landslide potential on unfailed slopes. The landslide inventory provides the information on existing landslides. Establishing the relative potential for landsliding on unfailed slopes takes the form of a regional landslide study. Regional landslide-susceptibility studies are commonly based on the relation of local landsliding to a few measurable factors such as bedrock, slope inclination, and slope orientation (Nilsen and Brabb, 1975; Lessing and Erwin, 1977; DeGraff, 1978).

The Fishlake National Forest uses a matrix assessment approach to determine relative landslide-susceptibility for unfailed slopes (DeGraff and Romesburg, 1980). This approach defines discrete susceptibility classes by a quantitative comparison of landslide site conditions to similar site conditions on unfailed areas. Data on existing landslides is one component of this assessment. Mapping in 1979, identified 89 landslides on the southern Wasatch Plateau within the Forest boundaries (Fig. 1).

These landslides ranged from 1 to 1,239 acres in size. A total of 7,878 acres amounting to about 3% of this area is subject to past landslide disturbance. Data collection for each landslide included determining bedrock unit, slope inclination, slope orientation, and area. The total number of landslide areas for each combination of bedrock, inclination, and orientation was divided by the acres within the southern Wasatch Plateau study area having the same set of characteristics. This yields the proportion of that area subject to past landsliding. Combinations of bedrock, inclination, and orientation with high proportions have greater landslide-susceptibility than those with lower proportions. A statistical procedure groups the range of proportions to define the three most susceptible classes of the four classes of relative landslide-susceptibility. The fourth class is the low susceptibility rating. It consists of areas with bedrock, inclination, and orientation combinations with a proportion of zero, reflecting the absence of any associated landsliding. Proportions for combinations with associated landsliding range from .01 to 1.00. Combinations with proportions between .01 and .15 define moderate susceptibility areas. High susceptibility areas have combinations with proportions between .16 and .51. Combinations with proportions between .52 and 1.00 identify severe susceptibility areas. A computer mapping system groups adjacent points with identical susceptibility ratings into map units within the southern Wasatch Plateau. Figure 2 shows a part of that map for an area near White Mountain. Land and resource allocation can now examine alternatives in terms of relative landslide-susceptibility within this part of the Forest.

PROJECT DESIGN

Even with a region landslide-susceptibility evaluation, avoidance of all existing or potential landslides may not be possible. It may be appropriate to modify project design to avoid ot mitigate potential landslide damage. It is necessary to know the likelihood of future landslide movement to decide if modification is justified. Failure to consider this point when converting tree cover to grass cover in the Sheep Creek watershed resulted in widespread reactivation of landslide movement that continues fourteen years after initial project work (DeGraff, 1979). Tree-ring analysis provides a valuable tool in determining probability of future landsliding (Shroder, 1980). Tree tilted by landslide movement respond by adjusting growth patterns to restore the growth tip to a vertical orientation. The trees develop a curved form from tip to base. In confiers, this geotropic response creates a wider ring in the downtilt side of the tree compared to the uptilt side for the same growth year. This eccentric growth is detectable from cross-sections of affected trees. Frequently, reddish-tinged cells called reaction wood are associated with an eccentric growth pattern. Other agents, such as fallen timber and snow shove, can cause eccentric growth. A landslide study must carefully choose sample trees that appear unaffected by these agents.

In 1980, the probability of future landsliding arose for a location on the Forest at the south end of Thousand Lake Mountain (Fig. 1). An apparently fresh ground crack in old landslide deposits was noted. A water collection ditch and an access road to a municipal spring are adjacent to this potentially moving area. To preserve these facilities from the effects of future movement, mitigating measures could be necessary.

The slope adjacent to and downslope from the crack hosts an open stand of Douglas fir. Many of these trees exhibit a curved form oriented downslope. There is no evidence suggesting that any agent other than landsliding is affecting tree form. Sample density was about 1 tree per 0.5 acres for a total of six trees. An increment borer extracted cores oriented through the curve of each tree at breast height and base level. After drying, mounting, and sanding, measurement was made of ring widths for each cross-section. For each annual ring, the percentage of total ring width represented by the uptilt side width was calculated. Percentage values greater than 60 or less than 40 are considered significant eccentricity beyond normal environmental variations. Landslide movement events sufficient to tilt the tree and cause eccentric growth are those that created significant eccentricity in both the breast height and base level cores for the same growth years. Figure 3 shows a composite of all landslide events recorded for an 80-year period from the six trees sampled. Landsliding has a recurrence rate at this location of one landslide every three years. Using the formula:

$$p = \frac{1}{T}$$

where p is the probability of an event and T is the recurrence rate of an event; there is an 0.34 probability of future movement at this location.

This probability does not justify immediate mitigating measures for these low investment facilities. It does indicate a potential problem area for the future.

PRIORITIZING REMEDIAL EFFORTS

Resources management sometimes must deal with existing, active landslides (Fig. 4). The focus for decision-making is expending limited funds for remedial work on only high priority problems. It is not always obvious which landslides deserve a high or low priority. In practical terms, landslides with the greatest immediacy for causing damage and locations with chronic landslide occurrence warrant highest priority. Rate of landslide movement and frequency of slide occurrence data provides a basis for determining priority. Physical and observational monitoring is a primary source of such data. Physical monitoring involves placing simple measuring devices on a landslide (DeGraff and Olson, 1980). The total distance measured for a given period of time yields the rate of landslide movement. Observational monitoring requires careful recording of landslide events. This record includes location, size, cost and time of occurrence information.

A good example of physical monitoring is a 1-acre landslide adjacent to the Interstate 70 right-of-way through Salina Canyon (Fig. 1). Encroachment onto the right-of-way will require coordination with appropriate agencies to ensure no impairment occurs to I-70. Physical monitoring consists of a toe stake monitor. Nine 3-foot metal posts are placed at

7-foot intervals downslope forn the moving toe of this landslide. The distance moved is determined by the number of metal posts remaining each year. Original installation was in 1976. By 1980, movement amounted to 42 feet. This translates to a average movement of 10.5 feet per year. Another 150 feet of movement will bring the landslide into the right-of way. If the present rate is maintained, remedial efforts will be required in 14 years.

Beaver Canyon in the Tushar Mountains provides an excellent illustration of observational monitoring (Fig. 1). A 2.7-mile section of Utah highway 153 is subject of annual landlside activity. Landslide debris removal by the Utah Department of Transportation requires disposal at selected sites on Forest lands. These sites are chosen to minimize sediment entering the Beaver River from accumulated debris. Once sites are filled, surface restoration occurs to prevent future erosion of this material. Table 1 shows a summary of landslide activity for this road section. The activity ration provides a measure showing the extent to which the four present debris disposal sites are being used each year. It is clear that the activity ratio of 1.1 for 1978 indicates multiple failures resulting in high utilization of disposal sites. Activity at individual landslide locations can also be calculated. This involves computing annual land-slide frequency index values. This provides a measure for determining chronic failure locations. Annual frequency index is the total number of failure events divided by the number of years observed at a location. Frequency index values for the past 3 years range form 0.33 to 2.00 with a mean value of 1.00. This shows that most locations are subject to only one failure event each year. The most chronic locations are subject to an average of two failure events each year. Observational monitoring data readily demonstrates the need for remedial measures as well as prioritizing locations.

CONCLUSIONS

The magnitude of landslide losses in resources management is often greater than commonly recognized. A comprehensive approach to landslide-hazard reduction can reduce these losses by aiding management decision-making. Land and resource allocation decisions rely on knowledge of existing and potential landslide areas. Project design decisions need data on the probability of future landslide movment. Decisions on prioritizing remedial work must consider the rate of movement and frequency of landslide occurrence. Techniques for acquiring data to satisfy all three decision-making concerns are currently available. The The Fishlake National Forest illustrates application of a comprehensive landslide-hazard reduction program to resources managment. This continuing effort will reduce future landslide losses and make more effective use of limited funds available for remedial measures.

Table 1. Landslide activity summarized from observational monitoring along U-153 in Beaver Canyon.

Year	Landslide Locations	Failure Events	Activity Ratio*
1978	22	45	1.1
1979	12	12	0.0
1980	26	35	0.4

* Activity ratio is found by dividing total annual failure events, minus total annual landslide locations, by total annual landslide locations. A value of 0.0 indicates that only one failure event per location occurred in that year. Values exceeding 0.0 reflect the frequency of multiple failures at landslide locations.

FIGURE CAPTIONS

Figure 1. Location of the Fishlake National Forest in central Utah. The bold numbers correspond to the following geographic areas within the Forest: 1) Canyon Range, 2) Pavant Range, 3) Tushar Mountains, 4) northern Sevier Plateau, 5) southern Wasatch Plateau, 6) Fishlake Plateau, and 7) Thousand Lake Mountain. The tree-ring analysis area is shown by a filled triangle. The monitored landslide near Interstate 70 is shown by a filled circle. The landslide area along U-153 in Beaver Canyon is shown by a filled square.

Figure 2. A part of the landslide-susceptibility map produced for the southern Wasatch Plateau. This area is southeast of White Mountain near Quitchupah Creek. Susceptibility ratings for map units are: L - low, M - moderate, H - high, and S - severe. The torpographic base is the Acord Lakes 15-minute topographic map.

Figure 3. A time line for the period of 1900 to 1980. Twenty-seven significant landslide movement events occurred on old landslide deposits during this 80-year period. A heavy vertical bar indicates each year with a movement event.

Figure 4. This large rockslide blocked traffic for several days in the Spring of 1978. It is one of many chronic landslide locations along U-153 in Beaver Canyon. The landslide debris was hauled to a nearby disposal site on the Forest.

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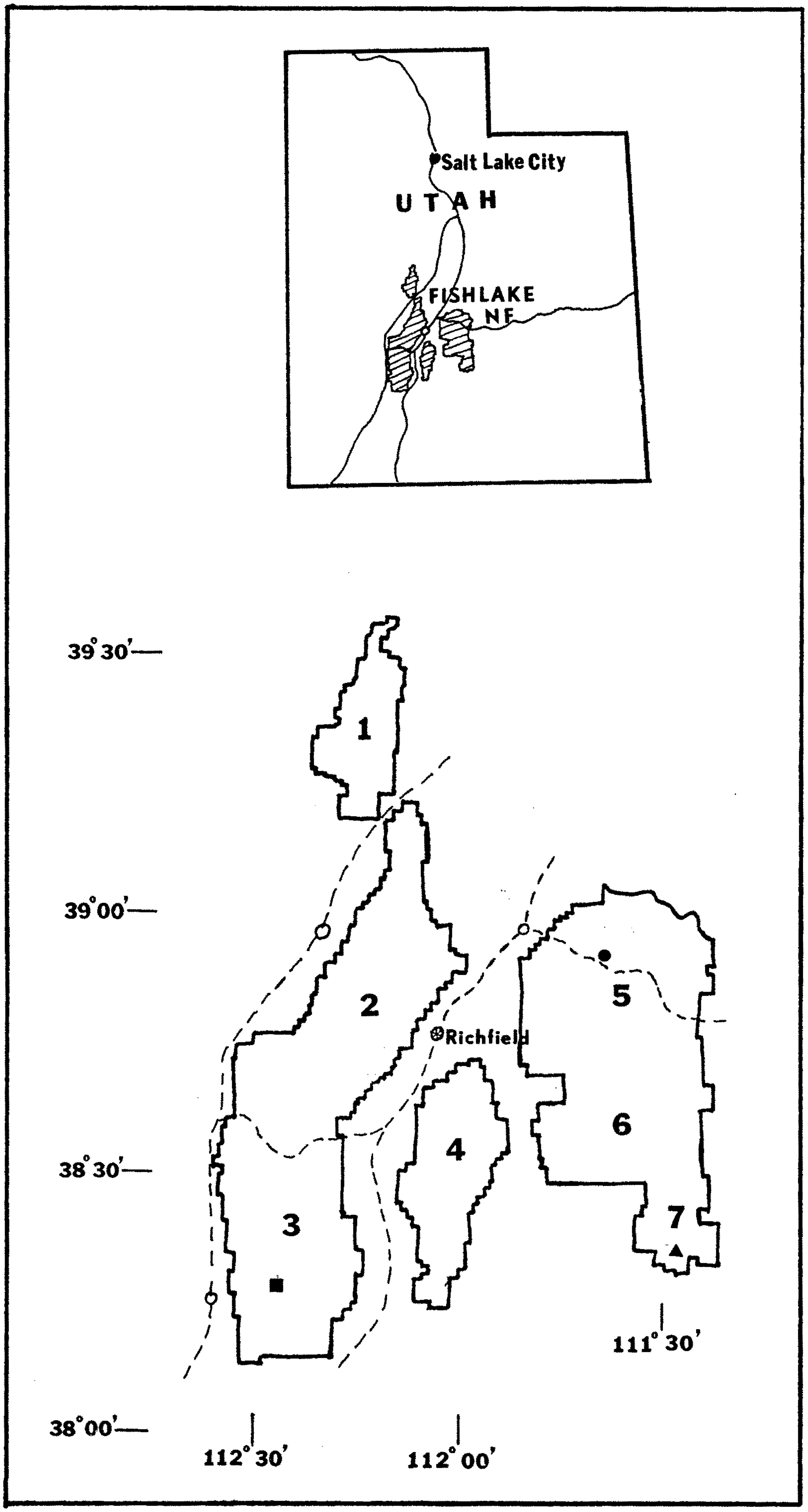
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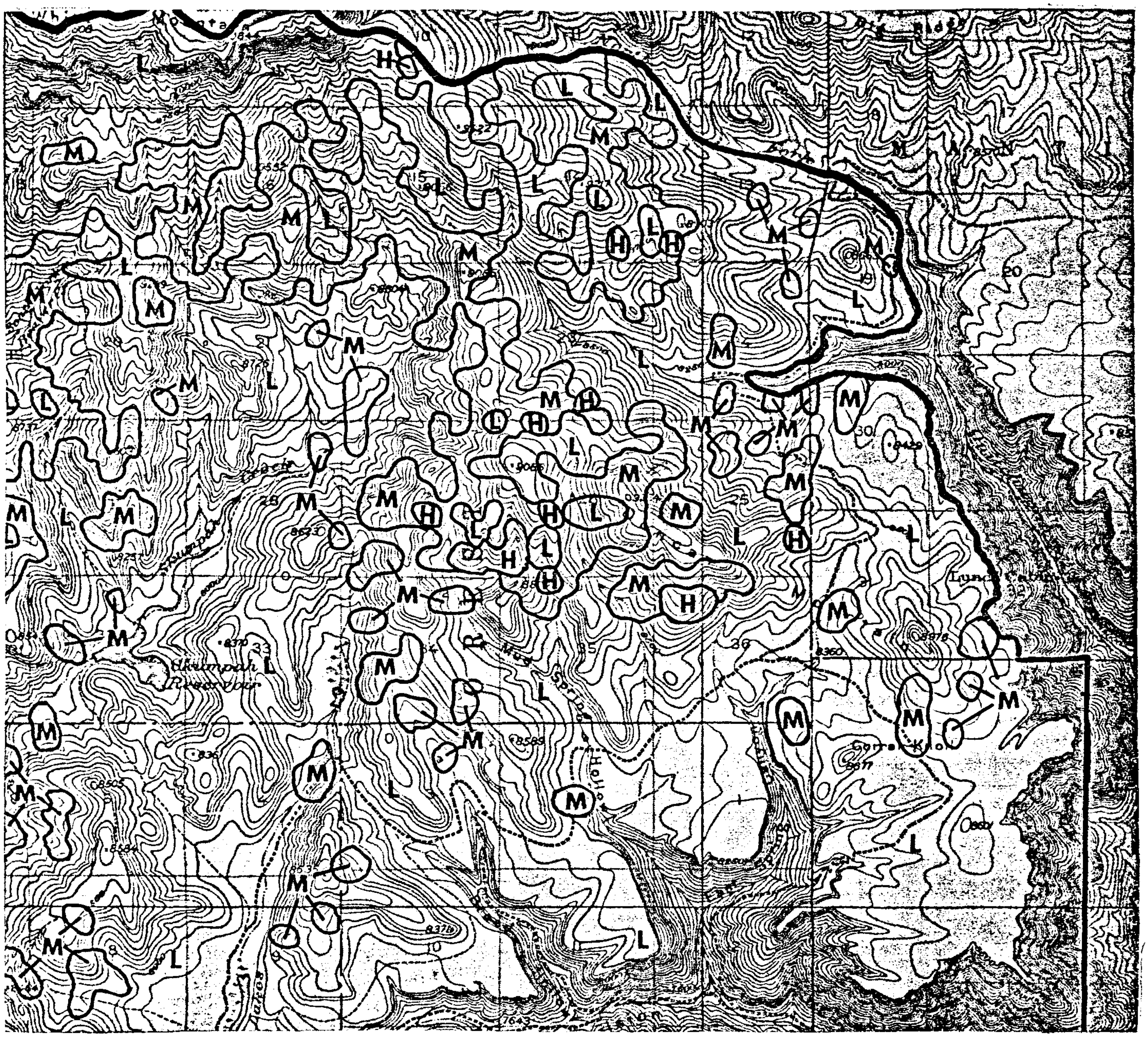

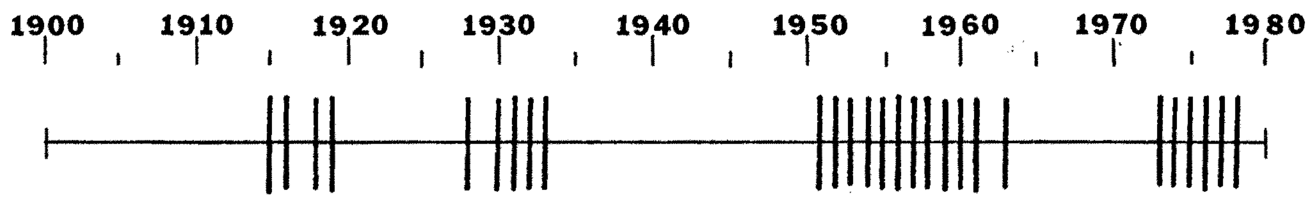
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