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WINDMILL SITES IN MOUNTAINOUS AREAS[1] OF THE UNITED STATES

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Rapidly increasing demands for energy and rising energy prices are resulting in a renewed search for alternate methods of power generation. One promising avenue is harnessing the wind and converting its kinetic energy into mechanical and thence into electrical energy. The windmill, which was long a functional element in the landscape of Europe and North America, may return as a competitive supplier of energy if its design can be made more efficient and if it is appropriately sited.

The very large windmills necessary for power generation would require strong and relatively constant winds for optimal operation, such as exist in high mountain areas. A major constraint on wind power generation is the availability of mountain peaks on which to site windmills. This study, through terrain sampling, estimates the frequency of occurrence of peaks in various mountain regions of the coterminous United States. Although there exists a considerable literature on quantitative terrain analysis, the majority of it pertains to negative elements of topography. In this study attention is focused on the quantification of positive

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elements of the terrain, a research area only modestly developed since Horton's pioneer analysis of drainage networks.[2]

Specific data on frequency of occurrence of mountain summits was unobtainable from published sources; therefore selected map sheets from various mountain regions were sampled. Mountain areas of the United States were defined in terms of Hammond's map of classes of land surface form.[3] Selection of sample sites was confined to those areas mapped as low mountain (D5) and high mountain (D6).[4] Additionally, within Hammond's mountain areas the selected map sheets were chosen to represent various physiographic provinces as defined by Fenneman.[5] In this way the sampling plan might reveal anything geomorphically significant in the summit expectancies of physiographically dissimilar mountain regions. The physiographic provinces represented were the Cascade Range, Sierra Nevada, northern, central and southern Rocky Mountains, Klamath Mountains, and the Blue Ridge Mountains.

Fifteen-minute quadrangle maps were chosen for sampling to maximize the area of coverage and yet maintain a sufficient level of detail. In practically all cases only one map was available from each of the selected regions--a function of the U.S. Geological Survey's 15-minute quadrangle mapping program in sparsely settled mountain regions, coupled with the additional restriction of 80-foot (24.4 meter) contour intervals necessitated by the design criteria for wind power generators (Dr. Arnold Court, personal communication). The eight quadrangle maps eventually selected for study (Figure 1 and Table 1) were typical of the regions they were chosen to represent. The choice of maps was based on a visual examination of the selected area in comparison to its surroundings on larger-scale maps. In each case the selected quadrangle showed no apparent disparity in relief or in pattern from the surrounding areas. Additionally,

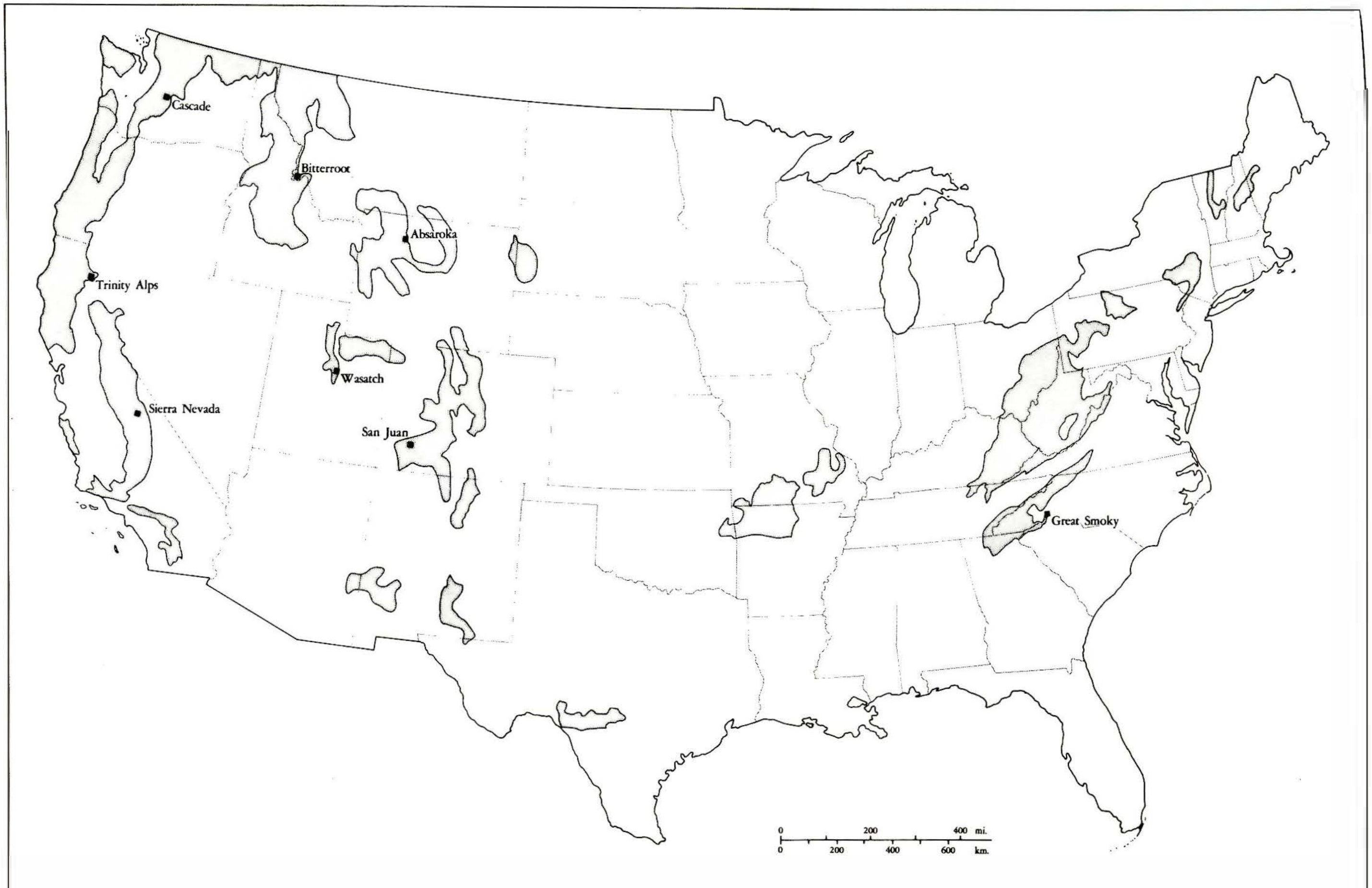

Figure 1. Hills and mountains of conterminous U.S.

Table 1

Names, Locations, Elevations and Areas of 15-minute USGS Quadrangles and Numbers of Closed Contours at 80-foot (24.4 meter) Spacing

· USGS Quadrangle Sheet; Map Designation; Physiographic Province	Year Mapped	Southeast Corner		Maximum Elev. Ft.	Area Sq. Mi.	No. of Peaks	Peaks per Sq. Mile
		Lat. N	Long. W				
MOUNT SI, WA Cascade/Cascade Mtns.	1960	47°30'	121°30'	5,576	200.4	366	1.8
COFFEE CREEK, CA Trinity Alps/Klamath Mtns.	1955	41°00'	122°45'	7,853	224.5	318	1.4
SHUTEYE PEAK, CA Sierra Nevada/Sierra Nevada	1953	37°15'	119°15'	9,165	236.5	642	2.7
MARION, NC Great Smoky/Blue Ridge Mtns.	1962	35°30'	82°00'	5,160	241.7	869	3.6
PAINTED ROCKS LAKE, MT/ID Bitteroot/Northern Rocky Mtns.	1960	45°30'	114°15'	7,822	208.1	383	1.8
IRISH ROCK, WY Absaroka/Central Rocky Mtns.	1957	44°00'	109°15'	12,319	213.3	563	2.6
SANTAQUIN PEAK, UT Wasatch/Central Rocky Mtns.	1952	39°45'	111°30'	10,685	228.8	473	2.1
TELLURIDE, CO San Juan/Southern Rocky Mtns.	1955	37°45'	107°45'	14,246	234.8	519	2.2

each was located well within its physiographic province. It should also be kept in mind that, as with most geomorphic regions, there is only gross topographic similarity from place to place. Any particular section of a region will be unique and thus somewhat different from its surroundings.

Using a one-mile-square grid system, the number of summits in each square mile was tallied. Mountain summits, defined as a topographic high having at least one 800-foot contour, were counted only once (i.e., a summit falling on a grid line was assigned to the square in which its greatest proportion lay). The planimetric area for each map sheet was derived, the total number of summits for each sheet was tabulated, and the mean number of summits per square mile was calculated (Table 1). The number of grid squares having the same number of summits per square was counted, and the percentage of occurrence for each integer number of summits was computed. The resulting data were then plotted as cumulative frequency curves (Figure 2).

The total area of the selected maps is 4,577 km^2 (1,788 mi^2) (Table 1). Planimetry of sheets 83-84 of the National Atlas of the United States reveals that hills and mountains in the coterminous United States comprise approximately 839,680 km^2. The eight topographic maps employed in this preliminary investigation constitute a selection of about 0.5 percent of the D5 and D6 classes of land surface form in the coterminous United States.

The cumulative frequency curves for each of the eight 15-minute quadrangles indicate the cumulative probability of finding a given number of fewer peaks per square mile. Since the chosen quadrangles were selected from a larger mapped area the cumulative probabilities shown in Figure 2 could be taken as an indication of the specific physiographic provinces sampled.

The strong similarity in cumulative probabilities for those quadrangles in the Laramide Rockies (Bitterroot,

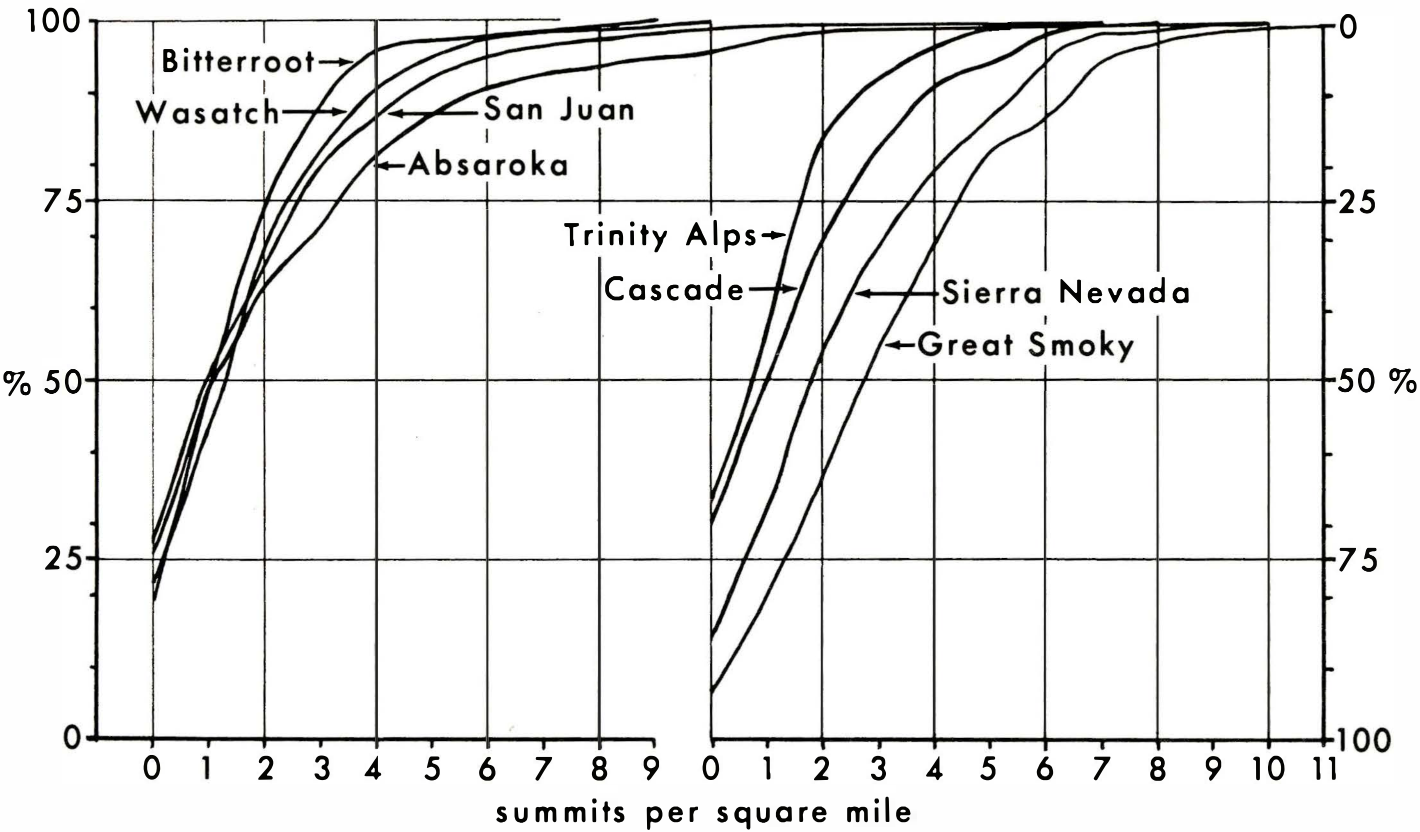

Figure 2. Frequency of number of square miles having no more than (left scale) or more than (right scale) indicated number of summits (25 meter relief) in various mountain areas of conterminous United States.

Wasatch, San Juan, is very noticeable in Figure 2 in spite of dissimilar geologic structures represented by each sample. The probability of finding one or fewer peaks per square mile in the Rocky Mountains ranges from 40 percent in the Wasatch to 50 percent in the San Juan. The median number of peaks per square mile in the Rocky Mountains ranges from 1 to 1.5 and the mean number of peaks varies from 1.8 to 2.6 per square mile.

Also shown in Figure 2 is the greater range of probabilities for the second group of curves which includes the Trinity Alps, Sierra Nevada, Cascades, and Great Smoky Mountains. The probability of finding one or fewer peaks per square mile in this group ranges from 20 percent in the Great Smoky Mountains to 56 percent in the Trinity Alps. The frequency of square miles with no summits ranges from 6.5 percent in the Great Smoky Mountains to 33 percent in the Trinity Alps. In this second graph, the curves for the Trinity Alps and Cascade Mountains are similar to those of the preceding group of curves. The mean number of peaks per square mile in the Trinity Alps is 1.4 while for the Cascades the value is 1.8. The median values range from 0.8 (Trinity Alps) to 1.0 (Cascades). The Cascades and Trinity Alps have similar peak expectancies to the first group curves (Laramide Rockies). The curves for the Sierra Nevada and Great Smoky Mountains, on the other hand, appear to indicate somewhat different summit probabilities. The values for mean and median number of peaks per square mile are greater than, or above the range of, the previous six. In the Sierra Nevada, the mean and median are 2.7 and 1.75 respectively, while in the Great Smoky Mountains they are 3.6 and 2.75 respectively. The graphs for the Sierra Nevada and Great Smoky Mountains, when compared with the previous six graphs, indicate a greater number of peaks per square mile and a smaller probability of finding a square mile in which there would be no peaks (7-15 percent versus 20-34 percent).

Based upon this selection of maps and the derived cumulative probabilities, it appears that the areas of greatest summit densities are found in the Sierra Nevada and Great Smoky Mountains. A lower frequency of occurrence is found in the Laramide Rockies, Cascades, and Klamath Mountains. Since contemporary geomorphic theories dealing with landscape development are built on open system models, the similar summit frequencies in the geologically diverse Laramide Rockies may be an indication of approaching equifinality in an open system landscape (i.e., similar end results from different initial conditions). The diverse lithologies and erosional histories in these areas have produced landscapes possessing similar degrees of dissection. The geomorphic reasons for the disparity in the values of peak expectancies for the Great Smoky Mountains and Sierra Nevada when compared to the other six mountain regions are uncertain at this time, as special erosional histories, duration of erosion, or specific lithologies are not exclusive to either group of curves.

The eight quadrangle maps form a selection 0.5 percent of the hills and mountains of the coterminous United States. The fairly close agreement in cumulative frequency curves permits some general conclusions to be drawn. As an example, on the average, the probability is about one chance in four that a square mile chosen at random in the mountain areas of the United States will have no summit. On the other hand, the probability is one chance in two that a randomly selected square mile will have at least one summit.

The percent surface area of mountainous terrain for the coterminous United States can be used to arrive at an estimate of the total number of mountain summits to be expected in Hammond's class D5 and D6. These summit expectancy figures can provide initial, tentative planning estimates for potential numbers of wind power generators in mountainous areas. For final planning purposes, however, this data generating technique would need to be greatly expanded and its results modified to reflect actual wind conditions in areas of available and accessible generating sites. These data should ultimately prove useful to electrical utilities seeking scale economies in the harnessing and distribution of wind energy.

NOTES

[1]This problem was investigated at the suggestion of Professor Arnold Court, and was supported in part by Contract AT(04-3)-1075 between the Energy Research and Development Administration and the Lockheed Aircraft Corporation. Critical reading of this paper by Dr. Warren Bland is greatly appreciated.

[2]Robert E. Horton, "Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology," *Geological Society of America Bulletin,* Vol. 56 (1945), pp. 275-370.

[3]Map Sheets 82-83, *National Atlas of the United States* (U. S. Government Printing Office), derived from: Edwin H. Hammond, "Classes of Land Surface Form of the United States," Map Supplement 4, *Annals of the Association of American Geographers,* Vol. 54 (1964).

[4]The D5 category applies to low mountains whose local relief is between 300 and 900 meters with less than 20 percent of the area in gentle slope (less than 8 percent). Category D6 defines high mountains with local relief greater than 900 meters having less than 20 percent of the area in gentle slope.

[5]Nevin M. Fenneman, "Physiographic Divisions of the United States," *Annals of the Association of American Geographers,* Vol. 18 (1928), pp. 261-353.