MILITARY EVALUATION OF GEOGRAPHIC AREAS, REPORTS ON ACTIVITIES TO APRIL 1963

AD 450-616

MISCELLANEOUS PAPER NO. 3-610

December 1963

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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PREFACE

This report consists of 22 papers which were presented at a meeting of the Board of Consultants for the project "Military Evaluation of Geographic Areas" (MEGA), Project No. 1-T-0-25001-A-131, held at the U. S. Army Engineer Waterways Experiment Station (WES) on 17-18 April 1963. The presentations were intended to describe the major research activities of the MEGA project, to discuss the present status of the research, to define the most important problems faced in each activity, and to propose a research program in general terms for the future.

The Board of Consultants of the MEGA project consists of Prof. Joseph A. Russell, Department of Geography, University of Illinois; Dr. Kenneth B. Woods, Chairman, Department of Civil Engineering, Purdue University; Dr. Norman W. Radforth, Department of Botany, McMaster University, Hamilton, Ontario; Dr. A. W. Küchler, Department of Geography, University of Kansas; and Dr. Harold G. Wilm, Commissioner, Conservation Department, State of New York. Dr. Wilm was unable to attend the meeting reported herein because of illness.

The authors of the various papers are identified in the text. WES personnel who contributed papers were: Messrs. Joseph R. Compton, Warren E. Grabau, Adam A. Rula, Richard G. Ahlvin, Edward E. Garrett, Richard R. Friesz, Marvin P. Meyer, Eugene E. Addor, Marcos A. Zappi, John H. Shamburger, Bob O. Benn, William K. Dornbusch, Jr., and Jerald D. Broughton. Contractor personnel who contributed papers were: Dr. Richard Stone, Department of Geology, University of Southern California; Dr. Pierre Dansereau, New York Botanical Garden; Drs. Peter Krenkel and Peter Hoadley, Department of Civil Engineering, Vanderbilt University; Dr. Howard L. Mills, Department of Botany, Marshall University; and Dr. Fred Norris,

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Department of Botany, and Dr. R. E. McLaughlin, Department of Geology, University of Tennessee.

At the conclusion of the meeting, Mr. Robert Jackson of Army Materiel Command, the agency sponsoring the MEGA project, made the following statement:

> On the basis of presentations made at this meeting, it is evident that the work under the project is responsive to the guidance which has been provided by AMC. It is a matter of considerable satisfaction to note both the demands for the capabilities in quantifying environmental effects and the responses which have been made an integral part of this project work. The prime examples of this are to be found in Project OTTER and the preliminary aspects of Project MERS, and in the Vicksburg Exercises I, II, and III.
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> For the sake of emphasis, it is pointed out again that this project aims at providing a classification and description system which can be applied universally to military situations, i.e., infantry, armor, logistics, aviation, etc. It was gratifying to note from several of the presentations that due consideration has been given to terrain features that exert their effects on the entire spectrum of the military situation.
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> Considering the complexities of nature, it is believed that the factor family concept constitutes the best technical approach for attaining project objectives even though it is recognized that new knowledge may require adjustments in the future.

All phases of the MEGA project were under the direct supervision of Messrs. Joseph R. Compton, Embankment and Foundation Branch, and Warren E. Grabau, Area Evaluation Section, WES, and under the general supervision of Messrs. W. J. Turnbull and W. G. Shockley, Soils Division, WES.

During the conduct of the phases of the project reported herein, Col. Alex G. Sutton, Jr., was Director of the Waterways Experiment Station, and Mr. J. B. Tiffany was Technical Director.

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MILITARY EVALUATION OF GEOGRAPHIC AREAS
REPORTS ON ACTIVITIES TO APRIL 1963

BACKGROUND AND HISTORY

by

Joseph R. Compton[1]

It has been 10 years since the project "Military Evaluation of Geographic Areas" (MEGA) was assigned to the Corps of Engineers by the then OA Chief of Staff, G-4, having been conceived by Dr. Paul Siple who had a desk and a secretary in the Pentagon. He and his secretary comprised the Environmental Section under the Research and Development (R&D) Division. Now the project, no longer a babe in arms and having been subjected to all the usual and some unusual childhood diseases, is grown up under new parents--it is supported by Army Research Office under the watchful eyes of Dr. Leonard Wilson and Mr. Merrill Kreipke, with Mr. Robert Philippe and Mr. Robert Jackson of the Environmental Sciences Division of the Army Materiel Command (AMC) directly monitoring WES's upbringing of MEGA. At the Waterways Experiment Station (WES), the project is under the direct supervision of Mr. Warren E. Grabau, Chief of the Area Evaluation Section, Soils Division. The project derives considerable support from the Geology Branch, also of the Soils Division.

The overall objective of the project can be briefly expressed as the development of methods and techniques for determining and evaluating the effects of environment (particularly terrain and climate) on military operations anywhere in the world. The principal problems to be solved are expressed by these questions:

- a. What are the militarily important environmental stresses and effects?
- b. How can these stresses and effects be measured and classified?
- c. How can the measurement and classification techniques which are developed be evaluated and utilized?

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1 Chief, Embankment and Foundation Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Almost two years have elapsed since the last meeting of the Board of Consultants. Since then, many refinements and extensions have been made. Also, there has occurred a notable shift in emphasis on areas of study (for example, to tropical areas) and in work phases (toward application phases and data-collection phases). And again also, there has occurred a great expansion of the MEGA program, which since 1961 has been operating at a funding level approximately twice that previously enjoyed.

In the past, one of the work phases which received considerable emphasis was the determination of environmental stresses and effects. For many years specific work was directed toward this end through the study of military records by the George Washington University Historical Records project, through the study of maneuvers and equipment testing reports by the University of South Carolina, and through other similar means of obtaining such information. At present not much effort is being put in this direction because it is felt that most of these data are rather limited in value, chiefly because of their very general nature and because of the absence of clear-cut cause-effect relations in the records. Rather, the current efforts in this direction are primarily in the direct generation of such data by observations of the interplay of carefully measured terrain attributes and the measured reactions of equipment and men.

For the present the agenda subjects are grouped under three major headings:

- a. Terrain research: the development of suitable terrain classification systems.
- b. Application studies: the application of these classification systems to specific areas to evaluate military performance and capabilities.
- c. Data collection: the sampling of terrain conditions in many environments to test systems and to define the ranges of variations to be expected in terrain characteristics.

CONCEPT AND STATUS OF TERRAIN RESEARCH

by

Warren E. Grabau[1]

In general terms, the Military Evaluation of Geographic Areas (MEGA) project has been given four principal objectives:

- a. To develop techniques for describing geographic areas which will identify in quantitative terms those properties of the environment, particularly those relating to terrain, which will affect military materiel, personnel, and operational procedures;
- b. To establish correlations between terrain factors and the probable performance of military materiel, personnel, or operations;
- c. To analyze geographic areas throughout the world, compare them with Army and/or Department of Defense test sites, and establish the degree of similarity or analogy; and
- d. To develop improved portrayal systems for the transmission of terrain intelligence to both military planners and tacticians.

It is evident that these four objectives are interrelated. For example, the ability to establish the degree of analogy of two noncontiguous areas is obviously dependent upon the ability to describe both areas in common terms. Thus, the first objective of the MEGA project must be effectively solved before the third can be explored with hope of success.

Similarly, the establishment of correlations between terrain factors and performance is entirely dependent upon internally consistent measurement of both the effect-producing agent and the thing being affected. In this context, internally consistent measurement implies the existence of a universally applicable descriptive system, or set of systems. At this point, it is apropos to define what is meant by a universally applicable descriptive system. Such a system is one which always uses the same term to define the same condition, no matter what other attributes are associated with it.

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[1] Chief, Area Evaluation Section, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

While this definition seems quite reasonable and proper, it has proven to be astonishingly difficult to apply. The reasons for this are several, but the most important seems to be that the most widely used descriptive or classification systems are based on multiple criteria. For example, most individuals assume what is meant by the standard physiographic term "plain," but when an attempt is made to apply the term rigorously, the idea becomes amazingly elusive. "Plain" seems to mean relatively flat ground, yet most physiographers unhesitatingly include the Vicksburg area within the Gulf Coastal Plain, even though an examination of the area will reveal very little flat ground. On the other hand, some areas normally classified as hills are much less rugged than the Vicksburg area. Obviously, the word "plain" in the physiographic sense does not necessarily imply an area of relatively flat ground, nor does the term "hill" necessarily imply rugged ground. Exactly what the terms do mean is very hard to establish.

Faced with this problem, the MEGA project was directed toward a search for a means of description which was based entirely on measurements, so that the terms of the descriptive system could be positively defined. A system based entirely on measurements would automatically be universally applicable. The rationale which emerged from this search is called the "factor family concept." It is not proposed to deal exhaustively with the origins or evolution of this concept; only the concept itself will be described.

The factor family concept owes its genesis to two major considerations. First, a universally applicable descriptive system was needed so that noncontiguous areas could be reliably compared. Second, a method was needed for quantitatively estimating the performance of materiel and men in any environmental context. Since it is obviously impossible to achieve a quantitative answer if part of the formula is qualitative, it follows that terrain must be described and classified in such fashion that the relation between environmental conditions and military activities can be stated in analytical terms. Obviously a prediction of effect implies that the causative agent, or agents, can be recognized.

The trouble with this notion is simple but devastating; nature operates with all of her attributes simultaneously, and therefore the effects that are normally recognized and measured are actually responses to several things acting in concert. For example, it is known that the slope which a vehicle must climb is not the only factor affecting its speed. The characteristics of the soil must also be taken into account. To be even more precise, the roughness of the surface must also be considered.

On the other hand, different combinations of terrain factors may produce the same total effect on an activity. It is well known that a vehicle traveling in a straight line can pass across a softer soil than would be practicable if the vehicle were forced to maneuver. Thus, a combination of large trees on relatively firm soil might produce immobilization as readily as soft soil acting alone.

There are so many independent attributes that any system which purports to describe all of them simultaneously becomes inordinately complex. There is, however, one thing which suggests that an expedient might be found; there is a tendency for attributes to fall into related families. Furthermore, in a general way these families tend to produce a characteristic type of effect on military materiel or activities. For example, the effects produced by the topography--that is, the shape of the surface--are in general different in kind than those produced by bodies of water. While there are many exceptions to this, nevertheless there remains the suggestion that a division of the environment into classes of related attributes would be both reasonable and fruitful. This notion is the "factor family concept."

The factor families identified by this scheme do not precisely follow the patterns of the traditional scientific disciplines, though they are obviously related to them. For instance, geology and geography are concerned with the morphology of the landscape, primarily as an indicator of history or development. The military analyst is interested in morphology only insofar as variations in the shape of the landscape surface affect military materiel or activities.

The distinction is sufficient to justify the use of a special terminology. Attributes of the environment that affect military activities in general are called "environmental factors." The families of such factors with which the MEGA project has thus far dealt are as follows:

a. Surface geometry. This family is concerned only with the physical shape of the surface of the earth and not at all with how the shape got that way, or of what it is composed. Actually, nature operates with a complete range of sizes: a continuum, from molecular irregularities in the surfaces of rocks to continental irregularities in the crust of the planet. It has been found convenient to break this immense range up into two subfamilies, even though nature makes no real distinction between them. The subfamilies are:

(1) Surface macrogeometry, which is that surface which can be adequately defined by a contour interval of 5 ft. Thus, if a surface feature can be closely defined by two 5-ft contour lines, it is a macrogeometry feature. An investigation of methods for quantitatively describing such surfaces has been conducted by the Vanderbilt University.

(2) Surface microgeometry, on the other hand, is a surface such that its irregularities or attributes of shape cannot be adequately defined with a contour interval of 5 ft. That is, a feature which can be concealed between two 5-ft contour lines is a microgeometry feature. Investigations of descriptive and analytical methods of dealing with such surfaces are being carried out by the University of Southern California (Stone; "Quantitative Expression of Microgeometry," pp 9-14).

b. The second major factor family is surface composition. This family is concerned with the physical characteristics of the materials of which the surface is composed. This includes not only the materials normally considered as soils and rocks, but such things as ice and snow as well. The sand dune in the Sonoran Desert and the ice of Antarctica are simply variations of surface materials. Interestingly enough, both materials can assume the same shape. That is, shape is independent of materials. Research into the description and classification of soils is being conducted by the Army Mobility Research Center (AMRC) of the Waterways Experiment Station (Meyer; "Surface Composition--Research in Soil and Snow Trafficability," pp 15-32). It should be emphasized that the general field of soils is the special province of the AMRC; the Area Evaluation Section (AES) does not directly engage in research in this area, but simply uses the results of the AMRC studies.

c. Hydrologic geometry is the third factor family. It is concerned with the shape, size, and distribution of water bodies of all kinds. Since these shapes vary markedly with time, the temporal variance is also a matter of concern. Of course, there are dynamic considerations as well; current velocity and wave action are cases in point. To date, the AES has made only very tentative probings toward a meaningful description and classification system for this factor family. One unfortunate thing about this factor family is that water normally imposes its most severe effects at the water-land interface. For example, the approach and exit configurations of the bank where vehicles either enter or leave the water, coupled with the position of the water surface with respect to that configuration, appear to be more critical to cross-country movement than the presence of water per se. This poses a question: Is this simply an extreme example of two factor families acting in concert, or do the interface phenomena constitute a separate factor family? It is hoped that this question can be answered in the very near future.

d. Vegetation is the fourth factor family. With this family, as with all other families, the emphasis is on the physical situation only. That is, it is the geometry of the vegetation structure as a whole, including such factors as stem size, spacing, height, branching habit, and many others, and not the taxonomy of the plants that is significant (Addor; "Vegetation Description for Military Purposes," pp 98-129).

e. A fifth factor family is concerned with animal life. It is apparent that this factor family is often significant; anyone who has brushed an ant nest off a tree and into the cab of a vehicle in the tropics is aware that animals can be both exciting and significant. However, the MEGA project has not yet attempted to deal with this problem.

f. The sixth major factor family is weather and climate. The MEGA project has done no research in this field, though it is recognized that this family is vital. It has been the policy of AES to attempt to use the results of the research of other organizations, such as the Research and Engineering Center at Natick, which can bring far greater resources to bear on this problem. Cooperation with these organizations will continue in the future.

It is apparent that the individual factors in these families almost invariably reduce to geometric considerations when examined in the light of their effects on military activities or materiel; however, there are exceptions. The chemical deterioration resulting from bacterial or fungal growth on materials is a good example. Nevertheless, geometry looms as one of the, if not the most, significant attributes. As it turns out, this is a very good thing because it makes possible, at least theoretically, the use of entirely qualitative--and therefore reasonably objective--descriptive systems. Efforts in this area are concentrated on developing quantitative descriptive systems for each factor family. These systems are intended to be detailed enough to permit the estimation with reasonable accuracy of the effects of the factors or factor families on most military materiel or activities. In this sense, precision implies not only the kind of effect, but how much.

It is probably apparent that cultural features have been omitted from the array of factor families. This is deliberate calculation and not oversight. The reason for this apparent omission is that all pertinent factors and characteristics of the landscape, whether man-made or natural, are already included. As the problem has been studied, it has become increasingly apparent that the inclusion of a special factor family for cultural features is a needless redundancy. For example, consider a paved highway. A vehicle rolling along the paved surfaces senses and reacts to the smoothness and hardness, and not to the fact that it was man-made. The Bonneville salt flats are smoother, flatter, and nearly as hard. There are areas in the Sahara where the native sandstone is as flat, and as smooth, and at least as hard. This being the case, a paved highway becomes only a remarkably linear expression of a special type of surface material and is dealt with as such.

Similarly, the distinction between rivers and canals, or lakes and reservoirs, becomes vague to the point of meaninglessness when a large sample of waterways is collected. Recent adventures in Thailand taught this with a vengeance. The important concern is not how it was made, but what it is shaped like; how wide is it, how deep, how high and steep are the banks.

Vegetation is also rife with problems if a separate factor family is erected for cultural features. Is a managed forest a cultural feature, or a natural one? This problem was never decided, and it was finally concluded that it really does not matter. The important things are the size and spacing of the tree trunks, and so on.

In view of these considerations, cultural features have been eliminated as a factor family. They are not ignored; it is felt that they have been incorporated in a more meaningful way than has been possible heretofore.

→ Interesting historical development, as now, 19[illegible], MOUT is of extreme importance.

QUANTITATIVE EXPRESSION OF MICROGEOMETRY

by

Richard O. Stone[1]

Microrelief, microgeometry, surface roughness, and microterrains are terms that have recently been brought into prominence by military geologists, terrain analysts, marine geologists, land locomotion specialists, soil scientists, and even lunar geologists. What is microrelief? Has it been accurately mapped? What is its general nature? Can it be expressed quantitatively? These are the questions that will be examined today and for which answers are being sought.

The term "microrelief" is not new to the geologic vocabulary. The noted geologist LeConte in 1877 used the term "microrelief" for the first time in describing "hog wallows" of the San Joaquin Valley of California. He used the term to denote "small, thickly set mounds 8 to in. higher than the adjoining depressions." Stevenson and Terry in 1957 in a report on sea-floor topography stated that microrelief consists of mounds, ridges, depressions, or undulations. They place a lower limit of 3 ft on microrelief with no upper limit defined, yet in the report they refer to gullies 20 to 30 ft deep and mounds and ridges that project 10 to 40 ft and in places 80 ft above the surrounding sea floor. Dwornik (1959) applied the term to surface relief less than 1 in. in height and was concerned only with irregularities in a 7-ft plot. In his work on the geology of the lunar base, Green (1962) defined microrelief as between 1 mu and 1.7 m, where 1 mu satisfies the conditions of a zero g factor. In terrain mapping in desert regions by Van Lopik and Kolb of the Waterways Experiment Station (1959), the authors referred to microrelief as the relief generated by the 10-ft contour interval.

It is obvious that the word microrelief, which has been used widely and perhaps a bit loosely, has eminently different connotations for various investigators and for different scientific disciplines. Inasmuch

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as this study of microgeometry is to augment existing terrain mapping by personnel of the Waterways Experiment Station, the upper limit of microrelief is taken to be 10 ft. Military organizations consider surface roughness of less than 3 in. to be no problem to movement, either afoot or for vehicles. Therefore, the term microrelief, as used in this work, is defined as those small-scale relief features exhibiting relief greater than 3 in. and not more than 10 ft.

A microrelief research program was undertaken in order to attempt to integrate it into the existing macroterrain mapping systems used at the Waterways Experiment Station. In the macroterrain mapping, those features not detectable on contour maps with a 10-ft contour interval were ignored. But it has been learned, sometimes in a difficult manner, that the small-scale features are the ones that may present the most serious difficulties to military operations, particularly from the standpoint of trafficability. The expressed purpose of the research is to map microrelief features in the field accurately and thus to determine their nature, and to erect a classification system expressed in terms as quantitative as possible.

The writer wishes to acknowledge the assistance and guidance of Dr. James Dugundji of the Mathematics Department of the University of Southern California who has been instrumental in developing the mathematics of microterrain analysis, and to Mr. A. L. Gilmore of the Computer Center of the Waterways Experiment Station at Vicksburg who has processed all of the terrain data through a computer program.

Data collection constituted the first phase of the study. Field mapping of microrelief features in the deserts and semiarid portions of Southern California was undertaken using the plane table and stadia board and the spirit level and graduated rod methods. Twenty-five selected microgeometry types were mapped, including miniature badlands, wadi courses, fault scarps, the lava flow environment, salt crusts on playas, turret dunes, floodplain mounds, incised desert pavement areas, Pleistocene lake terraces, seif dunes, and a marine terrace and storm bench. The scale of mapping varied with the type of feature with which the surveyors were concerned. In most cases a horizontal scale of 1 in. equals 10 ft was applied, but in a few instances scales of 1 in. equals 20 ft and 1 in. to 4 ft were used. In the field studies a series of points was surveyed and from these data a large-scale topographic map prepared. Once a finished office map was made, it was contoured using contour intervals of 2 ft, 1 ft, and, in one case, 3 in.

Data collection by the survey method is successful as far as providing insight on the nature of microrelief, but it is a time-consuming and costly method. For future data collection it is possible that profilometers or profilographs can be used, or perhaps a cart method using a light beam, similar to ones which have been utilized in determining the nature of runway roughness in airfield studies. Another potential method would be that used by North American Aviation which has mapped the lava surfaces of the Pisgah Crater of the Mojave Desert from large-scale aerial photographs. This organization was able to obtain highly detailed topographic information of plots 1000 ft on a side. Horizontal scales of 1 in. equals 30 ft were used and the plots were contoured with a 25-cm interval.

Study of the topographic maps prepared of the listed microrelief features has lead to several conclusions, namely: (a) microrelief features of 3 to 5 ft of relief, or less, are dominant, (b) they are most commonly of small areal extent, measurable at hundreds or thousands of feet on a side, (c) microrelief is classifiable, and (d) microrelief is highly variable in nature. Although some of these conclusions are not earth shattering, they are based on the visible results of field data.

The crucial portion of the study is the quantitative approach, a knotty and involved problem. A variety of approaches were attempted or investigated including expressing the geometry of the small-scale landforms with a series of number or degree ranges, a graphical study, various contour line interpolation or extrapolation systems, the use of power spectra analysis which has been successfully applied to runway roughness studies by such workers as Houbolt and Grimes, and the use of Chebyschev polynomials which was utilized in hydrogeometry studies by a research group at Drexel Institute. For a variety of reasons, largely of a mathematical nature, it was decided that the application most useful to the terrain roughness problem was the Fourier Analysis. A series of terrain profiles derived from the prepared topographic maps was made. These were subjected to a Fourier Analysis. A simplified statement of this analysis is that any complex curve consists of a combination of sine and cosine curves of varying wavelength and period. If a sufficient number of harmonics are computed by the Fourier method, the complete structure and nature of any curve can be determined. The first step then was to calculate the first 16 harmonics of each of the terrain profiles using high-speed computers. The process was simplified by making the curves symmetrical with respect to the y axis, [f(x) equal to the f(-x)] , and hence all sine values in the Fourier transform are dropped, making it necessary to compute only the cosine values.

Originally it was attempted to exactly reproduce the original terrain curves mathematically but, although entirely possible, in complex curves it is necessary to determine an inordinately large number of harmonics--an expensive, time-consuming, and complex process. Furthermore, it was soon obvious that curve irregularity or roughness has many independent component parts. Roughness is thus treated as a vector quantity rather than a single number. This consideration is comparable to the conclusion of Thurstone who, in his work on Intelligence Quotients, ascertained that it is impossible to express IQ accurately or meaningfully with a single number, but rather it must be done with eight vector components. In the microgeometry study, the high frequency harmonics of the terrain profiles are the ones that cause roughness. These harmonics are extracted from the original curve, the curve as such is quickly discarded, and the only consideration is the high frequency components.

What then are the vectors of microrelief? It is proposed that there are six components which must be considered: (a) smoothness, (b) peak height variability, (c) regularity, or similarity of one portion of the curve to other portions, (d) width of significant peaks, (e) height of the most significant peak, and (f) jaggedness. With these vector components, both the reason a terrain is rough and a mathematical expression of the roughness can be ascertained. Further, this treatment will permit comparison of profiles in many different respects, with isolation of the particular aspect of roughness most important to a given consideration (e.g. troop movements) being possible.

Smoothness (K) is a measure of the regularity of the curve. The greater its value, the smoother the curve. This is derived by means of an average square correlation, a type of approximation held in highest esteem by workers in approximation theory. In practice it is a measure of how much the high frequency curve shifted over tau (τ) units differs from itself.

Peak height variability (V) is a measure of variation in peak height. When V is large, the peaks are at different heights; if V is small, the peaks are uniformly not very high. The degradation in delta tau ($\Delta\tau$) is computed at correlation time T , where T is the point past which there is little correlation.

The third vector of roughness is the regularity (T/K), or similarity of one portion of the curve to other portions. The correlation time T of the curve is the amount the curve must be shifted over before the normalized square correlation function descends to its average value. The curve is mathematically "slid along" and compared to itself. From this calculation the "cell length" (a concept of recurring importance in the Vicksburg studies) can be determined. Cell length of a terrain curve is defined as the portion in which the significant basic features are displayed and which indicate the variability of the curve, i.e. the portions required to get similar features, T/K . The larger T/K , the more irregular the curve.

Width of the most pronounced irregularity (2T) or width of the most significant "hump" is another vector component of importance. As the curve is slid along, correlation tapers off when a significant peak in the curve is being passed.

The height of the most significant peak (a_s,s), which is a measure of amplitude roughness, is another factor in the geometry computation. Maximal peak indication is determined with the rapidity of amplitude variation. The largest Fourier coefficient is a_s (amplitude) and s is the frequency.

The final factor is the jaggedness of the curve. A jagged curve infers that the slope varies very rapidly and irregularly, and has relatively wide sweeps. Jaggedness ($a_s s^2$,s) is a measure of the rate of change of the curve where a_s is the largest amplitude, s is the frequency, and s^2 is how fast the slope is changing.

Maximal peak indication and jaggedness are lexicographically ordered in order to compare profile groups from a given terrain plot or from different plots. It is also recognized that smoothness, variability, and the width of the most pronounced irregularity are interrelated, but this interrelation makes it possible to determine which vector is the most significant for a given curve as well as which is the best measure of roughness.

Three fundamental questions regarding the work arise. First, what is the current status of the work? For all curves, a_s and s values of 16 Fourier coefficients have been obtained. The six microgeometry parameters of the profiles are currently being processed and will be received shortly. For two sets of profiles, the roughness parameters have been hand-calculated and show interpretable variations and are highly promising. In addition, a series of idealized curves has been submitted for analysis and is being processed. Second, is the work too complex, too intricate, too sophisticated? Perhaps, but this is an inevitable result of expressing the complexities of variable microrelief surfaces in a mathematical form. A simple number is not possible for expressing the nature of roughness, but from the basic work a number sequence can be developed which can be reasonably applied to the quantitative expression. Third, does this research work represent an end product? No. Considerable work and study, and maybe even changing of course remain. It does represent, however, a step forward, albeit a hesitant one, in the bewildering and complex world of small-scale landscapes and their quantitative expression.

SURFACE COMPOSITION
RESEARCH IN SOIL AND SNOW TRAFFICABILITY

by

M. P. Meyer[1]

The surface composition factor family is important because it imposes profound effects on several important military activities, including all kinds of construction activities and the off-road mobility of vehicles. Only selected portions of the effects on the latter activity will be discussed in this paper. Thus, this paper deals with a limited aspect of only one of the factor families of concern to the MEGA project.

Let us consider surface composition as the medium on which vehicles operate. If the surface is not firm enough to support a given vehicle, the vehicle obviously will not be able to confront other terrain factors or obstacles which it must negotiate. Soil strength, then, is basic, in the sense that an excess of soil strength, over and above the minimum required by the vehicle for mere self-propulsion, is required to provide the excess traction the vehicle must develop in order to go faster, or to overcome other terrain obstacles.

Extensive efforts have been directed by several Army laboratories toward determining the effects of surface composition on the mobility of vehicles; the discussion of research and development work in soil and snow trafficability which follows concerns that being conducted by the Trafficability Section, Army Mobility Research Center (AMRC), Soils Division, located at the Waterways Experiment Station (WES). The objective of research in trafficability at WES is to determine relations between the performance of vehicles and the soils (or other medium, such as snow) upon which they perform, in simple terms, using simple instrumentation where feasible. The products of this research are meant to be, for the most part, tools for use by military commanders in the field today. It is hoped that vehicle-soil relations uncovered in trafficability studies will also complement the more

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fundamental mobility studies, which are intended ultimately to aid the vehicle designers.

In the particular sense in which the word is employed herein, trafficability means the ability of a level or sloping surface material--soil, snow, muskeg, or what-have-you--to support the traffic of a vehicle. It refers mainly to the condition or strength of the surface material, and not to obstacles, such as forests, ditches, boulders, streams, etc., which may be equally important in deterring the progress of a vehicle.

When assigned the trafficability project, engineers at WES knowledgeable in soil mechanics recognized the extreme complexity of the vehicle-soil problem and viewed with some skepticism the likelihood of its early solution in purely theoretical terms. This pessimistic viewpoint has been justified, because a comprehensive, fully acceptable theory of vehicle mobility still is not available, even though theoretical aspects of the problem have not been neglected. At any rate, early in the course of the project it was decided to tackle the problem by the accumulation of systematic data on representative vehicles and soils, developing empirical relations between soils and vehicles, and then extrapolating those relations to other vehicles and soils when and if extrapolation appeared to be justified. Consequently, the WES laboratory for research in trafficability has been the earth itself and the principal test apparatus has been the ordinary production-model vehicle.

Trafficability studies are commonly divided into two phases, contact and noncontact. Contact studies are aimed at developing tools and techniques for on-the-spot determination of trafficability. Noncontact studies seek to determine means of estimating trafficability from remote sources. The latter includes airphoto interpretation studies, as well as investigations of means of predicting changes in trafficability as a function of time and weather.

Contact Studies

Cone penetrometer

In early testing it was quickly established that there was a correlation between the consistency or strength of a fine-grained soil and the ability of a vehicle to perform on it. The instrument selected to measure an index of soil strength was the cone penetrometer (fig. 1). This instrument is a simple probe calibrated to indicate the force required to push it into a soil. The cone at the end is a right-circular cone of 30 deg, usually with an end area of 0.5 sq in. The proving ring is calibrated in pounds of force on the handle per square inch of cone end area. Only one man is needed to operate this instrument, and it is possible for him to act as his own recorder. Usually, however, a second man does the recording. Readings are made at arbitrary vertical increments; thus, it is feasible to measure a profile of the strength of the medium.

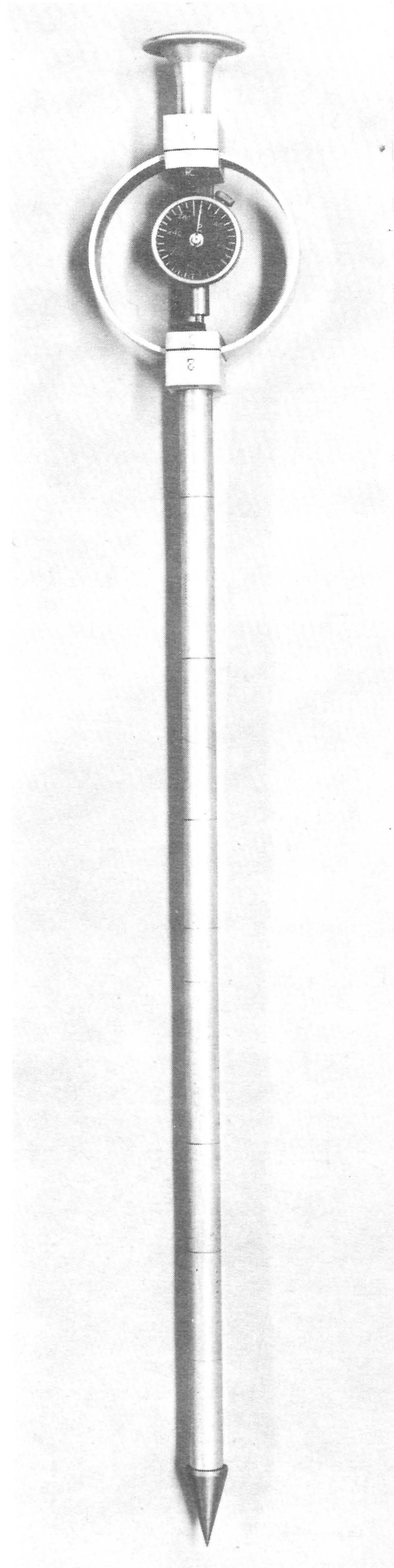

Fig. 1. Cone penetrometer

Cone index profiles

Fig. 2 illustrates some typical cone index (CI) profiles. Although these profiles show a range in soil strength as measured by the cone penetrometer, it cannot be assumed that the strongest soil will provide the best going conditions. Some soils fail progressively under repeated loadings, and in such soils the initial strength values are not valid indicators of trafficability conditions. For example, in fig. 2, profile 1, the heavy curved line with solid data points represents a typical clean sand. The characteristics of sand strength profiles are low surface CI readings and rapid increase of CI with depth. Level clean sands usually provide sufficient bearing and traction capacity to permit travel of all conventional wheeled and tracked vehicles; at high tire pressure, however, the movement of conventional wheeled vehicles may become very difficult mainly due to low traction capacity.

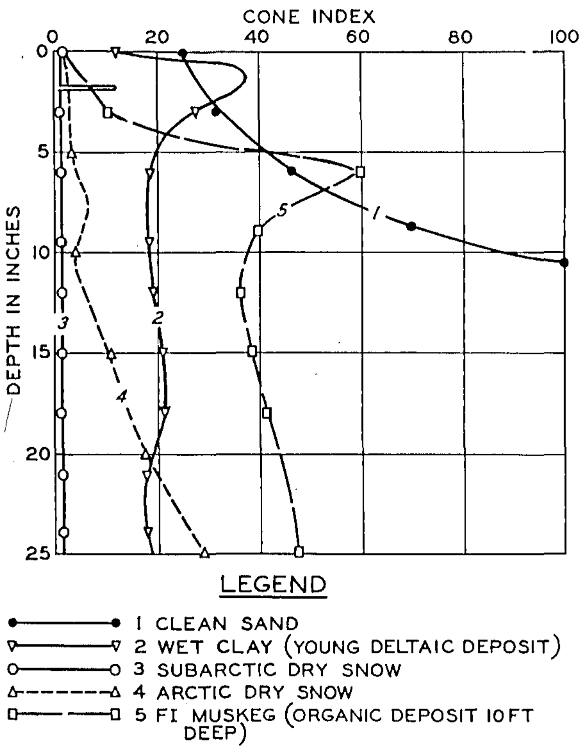

Fig. 2. Cone index profiles

The efficiency of movement can be improved significantly by reducing the tire pressure. Profile 2 in fig. 2 represents a wet clay in a deltaic deposit. Note that the surface layer of this soil is firmer than the underlying material, probably because of drying by evapotranspiration. In order to travel on this soil, vehicles would require cone indexes of less than 20. Profiles 3 and 4 in fig. 2 represent dry snows, 3 a subarctic snow and 4 an arctic snow. Note that the CI's are less than 10 in the upper foot, yet the trafficability conditions are surprisingly good and quite distinct from those of soils with similar CI values. On subarctic snows all tracked and large-diameter-wheel vehicles can travel with no difficulty; however, conventional-wheel vehicles are immobilized if the snow depth equals or exceeds about one-fourth the diameter of the wheel. Even at shallow depths, traction devices, such as chains, would still be required. In contrast to arctic snows, subarctic snows almost always remain very soft.

On arctic snows, "go" conditions prevail for all tracked vehicles and for wheeled vehicles with large diameter wheels which exhibit less than 10-psi ground pressures. Conventional-wheel vehicles are not able to travel on arctic snows. Profile 5 represents muskeg. Note that the surface layer is weak, although the strength increases rapidly to a depth of about 6 in.; the strength then decreases to a depth of 12 in., and increases gradually thereafter. The high CI at 6 in. is caused by compression of the surface vegetal mat prior to its being pierced by the penetrometer. Travel on these soils is limited to tracked vehicles with less than about 4-psi ground pressure. Wheeled vehicles would definitely become immobilized. Light tracked vehicles usually can be supported by the surface mat.

Vehicle testing

The first testing to correlate vehicle performance and cone index were conducted in prepared test lanes using prototype vehicles and fine-grained soils. Cone indexes were measured in the vehicle's path before, during, and after traffic. The vehicle was run back and forth in the same path until it became immobilized or until it was evident that it could go indefinitely. Following specific instructions from the Office, Chief of Engineers, "go" conditions were arbitrarily defined as those which would permit a vehicle to make 50 passes or more, and "no-go" conditions were those which would not permit as many as 50 passes. Analysis of the data proved that it was possible to distinguish go from no-go conditions on the basis of cone index, but the separation was not always definitive. Fig. 3 illustrates the results of the early tests. The soil used was a blend of desert sand and heavy clay. The ordinate is plasticity index, selected only because it was intuitively felt that it had some significance. The closed circles represent tests in which immobilizations occurred before

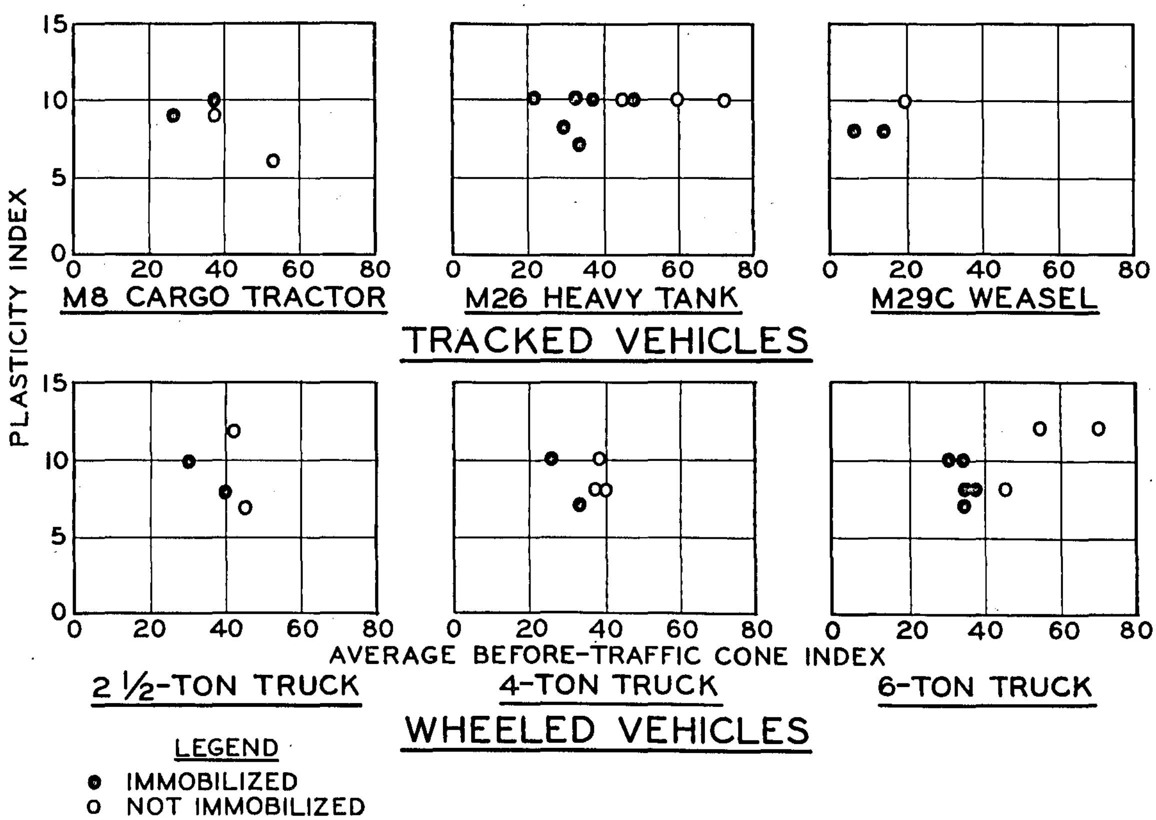

Fig. 3. 1947 trafficability tests, Yuma, Arizona

50 passes (i.e. no-go conditions); the open circles represent go conditions. Note that there is generally a relatively definitive separation between go and no-go conditions, even though there is a "zone of uncertainty" in some cases.

Remolding index and rating
cone index--fine-grained soils

Following tests in prepared soils, a program was conducted on natural soils. Here it became apparent that the in situ cone index alone was not sufficient to quantify the trafficability of a fine-grained soil, because vehicles which had previously operated on given cone indexes now appeared to require much higher cone indexes on the same soil types. The explanation for this turned out to be that the soil was actually becoming weaker under the action of the vehicle. This phenomenon forced the development of a test to determine the strength change to be expected. This test, performed by measuring the cone index of a sample of the soil before and after compacting the soil, yields a number called remolding index, which is the proportion of original strength that will be retained under traffic. When cone index, the value obtained by the cone penetrometer, is multiplied by remolding index, the value obtained by the remolding test, the product is a number called rating cone index. This number is representative of the trafficability of the soil. It can be used at the present time, after testing with hundreds of tests on a range of vehicles in a variety of soil types, to predict with approximately 90 to 95 percent confidence (a) whether a given vehicle can traverse any fine-grained soil once, (b) whether 50 vehicles moving in the same track can pass or not, (c) how much drawbar the vehicle can develop on one pass, (d) the average drawbar pull that any one of 50 successive vehicles in echelon can develop, and (e) how steep a slope can be climbed by the vehicle on the first or the fiftieth pass.

Sand tests

A similar ability also exists for sands and other coarse-grained soils, but with two major differences. On these soils, there is no need to measure a remolding index, but tire-inflation pressure is a tremendously important factor in the performance of wheeled vehicles. A typical set of data for tests on sand is shown in fig. 4. Performance is on a one-pass basis, since it has been found that if a vehicle can make one pass in a sand it can nearly always make an indefinite number of passes. This set of data is neither better nor worse than the dozens of others that have been accumulated. In the graph on the top a visually determined curve of best fit has been drawn between immobilizations, indicated by solid circles, and traverses, indicated by open circles. The relation shows that as the CI increases, the slope performance of the vehicle increases. This vehicle, a 2-1/2-ton 6x6 truck mounted with 11.00-20, 12-PR tires and single rear end tandem, has a tire pressure of 10 psi. The chart on the bottom shows the family of curves that show the effect of

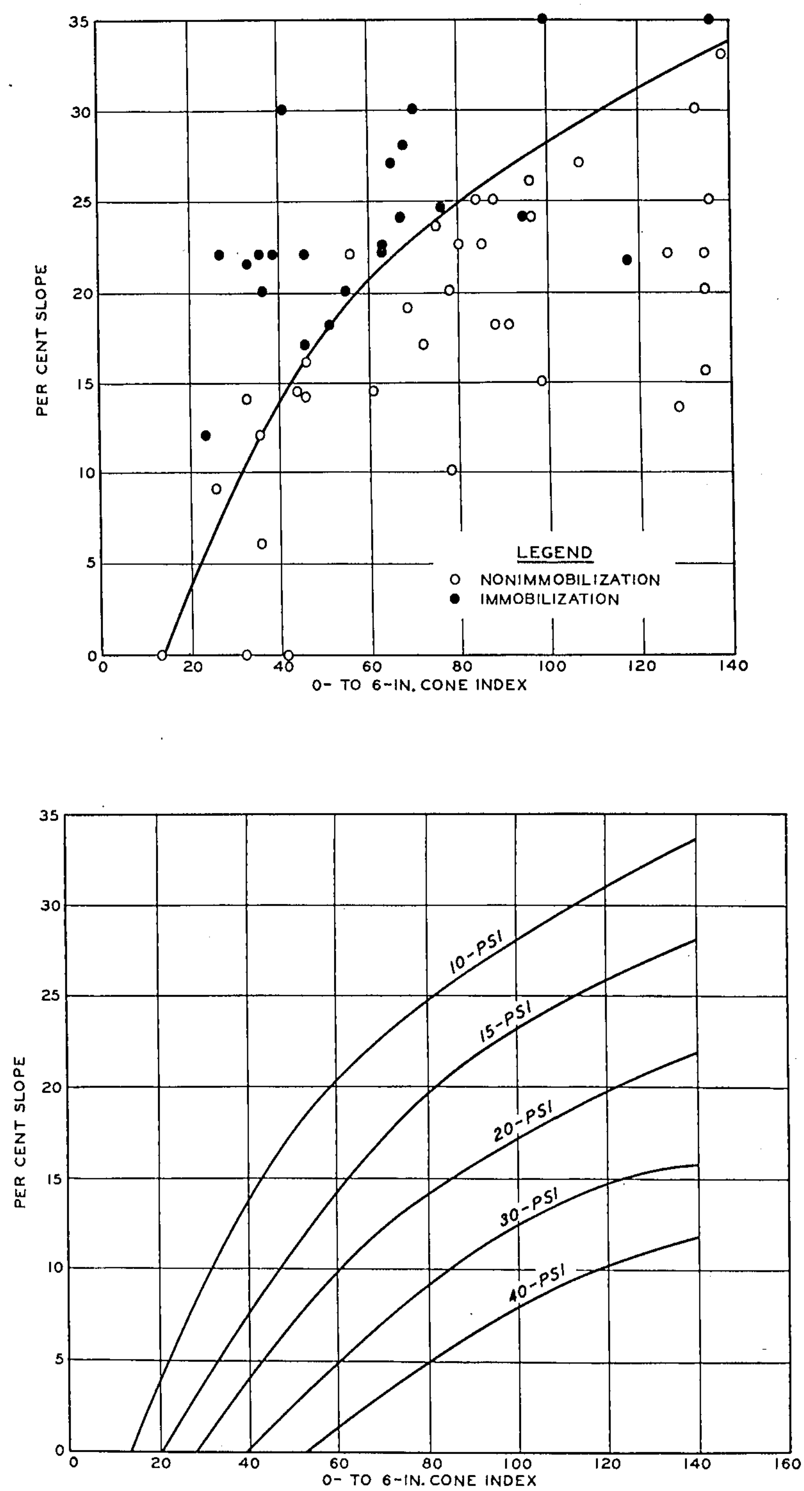

Fig. 4. Vehicle performance, single self-propelled vehicle tests, 2-1/2-ton 6x6 truck, 11.00-20, 12-PR tires (single), percent slope versus cone index

tire pressure on vehicle performance. For example, at a CI of 80 and a tire pressure of 40 this vehicle can negotiate about a 5 percent slope, but at 10 psi at the same CI it can negotiate a slope as great as 25 percent.

Snow tests

As previously indicated, trafficability testing has also been performed on subarctic and arctic snows. While this work has not yet advanced as far as it has in soils, a technique is available for measuring the trafficability of snow such that vehicle performance can be predicted with about 75 percent confidence. A vehicle moving across arctic snow develops a "stress bulb" pattern, as illustrated in fig. 5. The snow is fine grained and dry.* The snow that was formerly in the area that is rutted is now compacted into the area delineated by the stress bulb. The size of the pattern is dependent upon snow conditions and the characteristics of the vehicle. The greater the pounds per square inch ground pressure and the softer the snow, the deeper the bulb. At the limit of influence, the strength of the snow at the outer perimeter of the bulb is strong enough to resist the stress induced by the vehicle and equilibrium is established. Fig. 6 shows the strength of dry fine-grained snow in

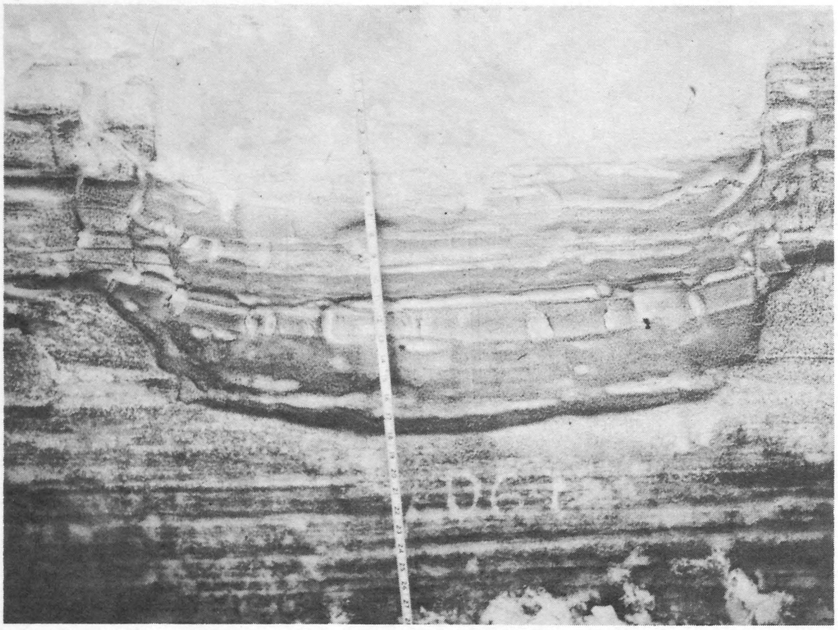

Fig. 5. Stress pattern after one pass. D6 engineer tractor with 30-in. tracks in dry snow of Greenland

* Fine-grained snows are less than 2 mm; coarse-grained snows are greater than 2 mm. Dry snows are powdery and cannot be packed into a snowball, whereas moist snows can be; wet snows provide free water when squeezed into a snowball.

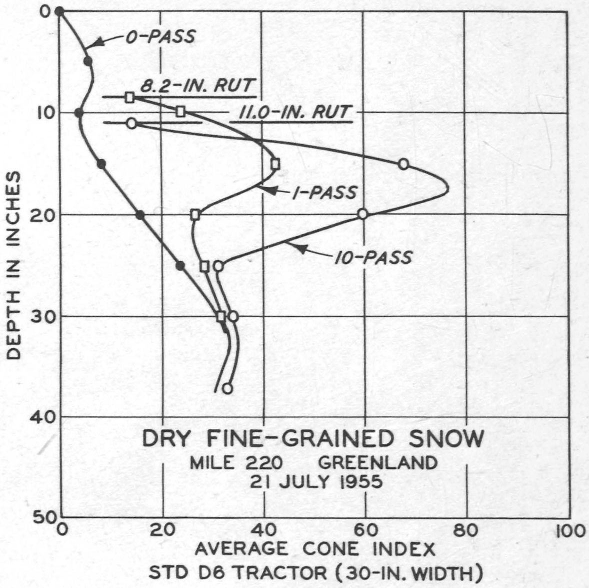

Fig. 6. Comparison of before- and during-traffic data

Greenland before traffic and after 1 and 10 passes of a D6 tractor. It should be noted that the greatest amount of rutting occurs after the first pass. Ruts are at a depth of 8.2 in. Rutting thereafter is gradual, and after 10 passes is only at a depth of 11 in. Furthermore, the maximum depth of stress influence is attained on the first pass, in this case at 25 in. Below this depth the strength of the snow is about the same as it was before traffic. After 10 passes there is still no significant change of snow strength below 25 in. Above 25 in., however, the strength of the snow has increased from about 40 CI for one pass to about a maximum of 80 CI after 10 passes as a result of further compaction of the snow. As a result of age-hardening, the strength of the compacted snow still may be increased appreciably within a period of less than 24 hr. Fig. 7 shows an M48 tank in dry, fine-grained virgin snow of Greenland. It is apparent that sinkage is not appreciable. Despite the weight of this vehicle, 50 tons, and low strength of the snow, about 10 CI in the surface 2 ft, rutting after one pass was only about 10 or

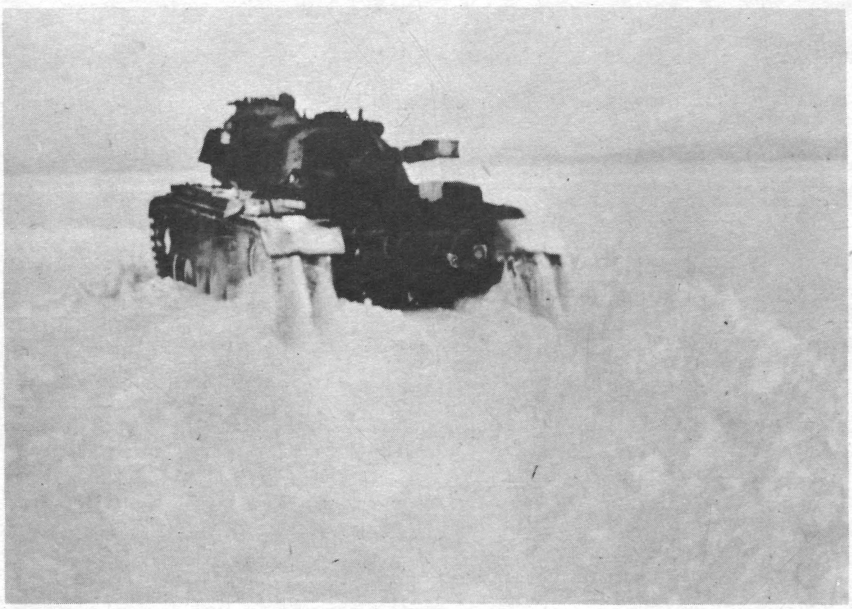

Fig. 7. Rutting produced by an M48 tank in Greenland snow

Fig. 8. Wave pattern in test lane after 12 passes of M48 tank, Greenland

12 in., and no immobilizations occurred. One characteristic of arctic snow surfaces is that ridges and swales occur along a trail as a result of repetitive vehicular traffic. Fig. 8 shows the wave pattern developed by the M48 tank after 12 passes. The highs and lows are of small magnitude after the initial pass and progressively become more pronounced as the number of passes increase. The amplitude and distance between waves are a function of the vehicle's unit ground pressure, location of dynamic center of gravity, and track length, as well as of the characteristics of the snow. Although these patterns do not cause immobilization, they do impede movement and cause great discomfort to the driver and riders of the vehicle. Fig. 9 shows one of the basic relations developed between snow properties and vehicle characteristics. The graph shows the relation between the ground-contact pressure and one-pass drawbar coefficient for tracked vehicles operating in dry fine-grained snow of Greenland. It can be seen that as ground-contact pressure increases, drawbar coefficient decreases. For example, if it is desired that a vehicle be capable of

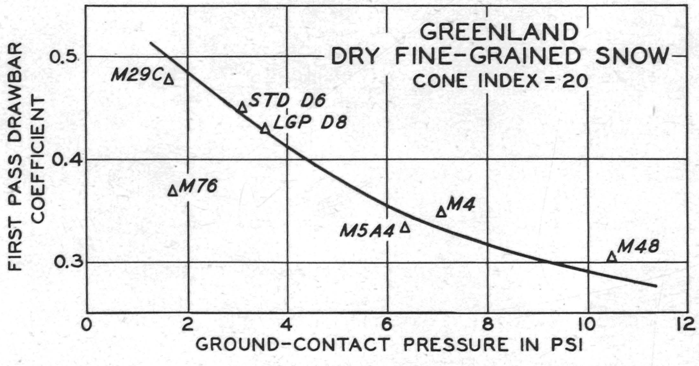

Fig. 9. Tracked vehicle performance, ground-contact pressure versus tractive coefficient

developing a drawbar coefficient of 40 percent, its ground-contact pressure should not exceed about 4 psi.

Muskeg tests

The investigation of the trafficability of muskeg (organic terrain), is even less advanced than that of snow. Tests have been conducted in organic terrain during the past two summers in Parry Sound, Ontario, Canada. The work has been a joint effort between the AMRC and a Canadian research group under the direction of Dr. Norman W. Radforth of McMaster University. During tests many mechanical and physical properties of muskeg were measured, and vehicles that include a range of characteristics were tested. Preliminary results of tests indicate that profile strength instruments, such as the cone penetrometer or shear vane, along with organic terrain characteristics, such as type of surface cover, depth of organic layer, and water regime, can be used to quantify trafficability of muskeg. Exact techniques to predict vehicle performance in this media have not yet been evolved.

Noncontact Phase

There have been two principal approaches to the problem of estimating trafficability characteristics of an area by noncontact methods: (a) by the study of the effects of weather on soil moisture and hence the strength of various soils in various environments, and (b) by the study of the use of the visible and other portions of the electromagnetic spectrum to photograph or "fingerprint" terrain conditions in suitable trafficability terms.

Soil moisture-strength studies

In the first approach a study was made of soil moisture and strength data collected at many sites, mainly in the United States. From these data a system has been devised wherein the moisture content of a soil can be predicted with about the same degree of accuracy as rainfall amounts can be predicted. It should be mentioned that the success of this system is largely due to the fact that a given soil in a given situation will attain a maximum moisture content (and corresponding minimum strength) in the wet season and a minimum moisture content in the dry season. Fig. 10 shows

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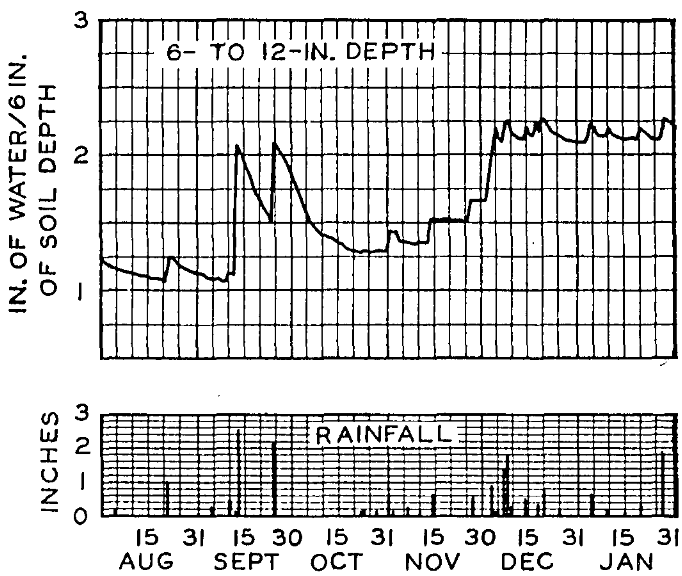

Fig. 10. March of soil moisture, clay soil, Mound, Louisiana

the march of soil moisture content for a clay soil at Mound, Louisiana. The bar graphs in the bottom of the figure show the rainfall amounts for corresponding days. The graph shows consistently high moisture contents with little fluctuation in the winter wet season in contrast to the widely fluctuating moisture contents for the summer months. Since the maximum and minimum moisture limits are fairly well defined, the problem of correlating changes in moisture content between these limits with rainfall amounts and drying periods has not been particularly difficult.

Soil trafficability classification

One of the by-products of the noncontact studies has been the development of a scheme for classifying soils from a trafficability standpoint. When dry, all soils are generally good from a trafficability standpoint and there is little need to distinguish one from another; however, when soils are wet, they reveal varying trafficability depending on soil type and several other factors. The wet-season maximum-moisture content provides a convenient datum for comparing the trafficability of soils.

The scheme developed is simply a statistical treatment of data on some 1100 samples collected in humid-temperate climates. It considers soil type, topography, and general wetness level, but ignores vegetation, parent material, climatic variation, and other factors known to be of significance. Other factors will be considered when additional data have been collected. The scheme is illustrated in fig. 11. In this figure the soil types are in Unified Soil Classification System (USCS) terms. The scheme also provides for U. S. Department of Agriculture (USDA) types. The topography class is low (there are only two classes, low and high), and the wetness

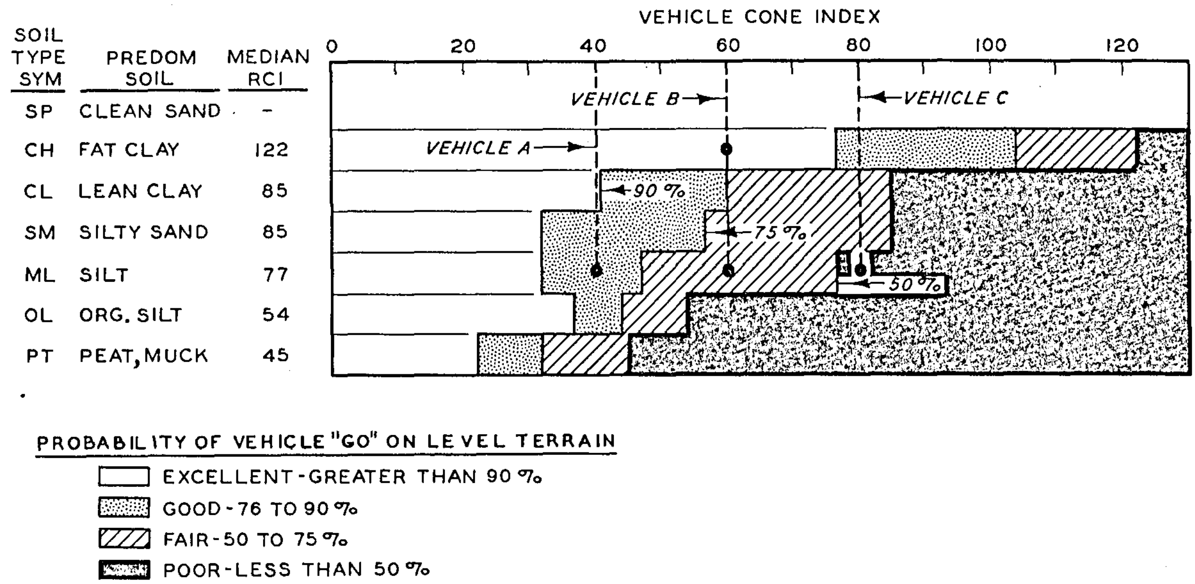

Fig. 11. Soil trafficability classification in USCS terms, low-topography, wet-season condition

level is average wet season (there is another wetness level known as high moisture condition). Vehicle A with a vehicle cone index (VCI) of 40 has a good probability of "go" on an ML soil; vehicle B whose VCI is 60, only fair; and vehicle C with a VCI of 80 has a poor probability of "go." Additional details of the scheme and a wealth of data on properties of surface soils are contained in a WES report published in 1961.

Aerial photos

Existing techniques for the deduction of terrain details and soil types from aerial photos have been applied to the specific objective of trafficability prediction by field trafficability data, and samples have been collected in wet and dry seasons to go with specific airphotos of representative terrain types. This study has been mostly performed by contract with Purdue University. The results of the study are in effect a catalog of typical airphoto patterns with accompanying trafficability data on a seasonal basis. By photographing a portion of enemy terrain and matching the photograph with one in the catalog, a reasonable estimate of trafficability by analogy is possible, if due allowance for differences in climate are made. A report on this work, in two large volumes, will be published before the end of the fiscal year.

Terrain-sensor studies

The latest effort in noncontact studies is the study of the feasibility of using infrared and radar to measure or deduce trafficability characteristics. This work is being conducted by the Terrain Analyzer Section of AMRC.

In general terms, the ultimate goal of the Terrain Analyzer Project can be described as achievement of the ability to predict quantitatively the effect of terrain on military activities through utilization of remote terrain-sensor data. Over the past two years the project has been directed toward the study of soil types and soil conditions, since these are of paramount importance in trafficability. As progress is made in these areas, the study will be expanded to include other features of the terrain, such as microrelief, slope, vegetation, and hydrographic factors. The end product is visualized as an aircraft equipped with a multisensing terrain analyzer system capable of perceiving, registering, and integrating terrain data of the region over which it flies with sufficient accuracy and in such terms that the military commander will immediately have readily interpreted, quantitative measures of the terrain factors that will affect his mission.

In the initial consideration of the terrain-sensor project, it was realized that no one sensor would provide all of the information needed for determination of terrain characteristics. For example, sensors utilizing the infrared portion of the electromagnetic spectrum would provide information on only the surface of the terrain; whereas, sensors operating in the radar frequencies would give information on soil conditions in the upper several feet of terrain. Since both of these areas are important in the consideration of military maneuvers over unknown terrain, the study has been designed to include several different portions of the spectrum.

Initially, infrared tests were conducted in the laboratory to determine the usefulness of this portion of the spectrum. Fig. 12 illustrates typical types of results obtained with an infrared spectrophotometer. This is a plot of percent moisture content in three different types of soil versus the percent of infrared reflectance at a wavelength of 1.4 mu measured from the surfaces of the soils. It may be noted that for the three soil types tested, the moisture content of the soil increases as the percent reflectance decreases.

Radar studies have recently been initiated in the Ka-, X-, C-, and P-band portions of the electromagnetic spectrum. Fig. 13 shows the facility. The arch permits testing of the soil sample, which is located in the box in the center of the facility, at different angles of incidence. Investigations in other portions of the electromagnetic spectrum are planned for the near future.

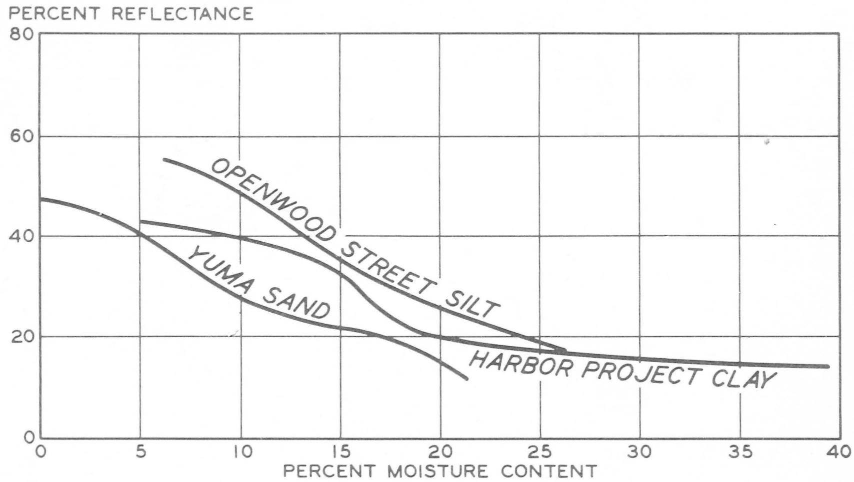

Fig. 12. Effects of moisture content, wavelength, 1.4 mu

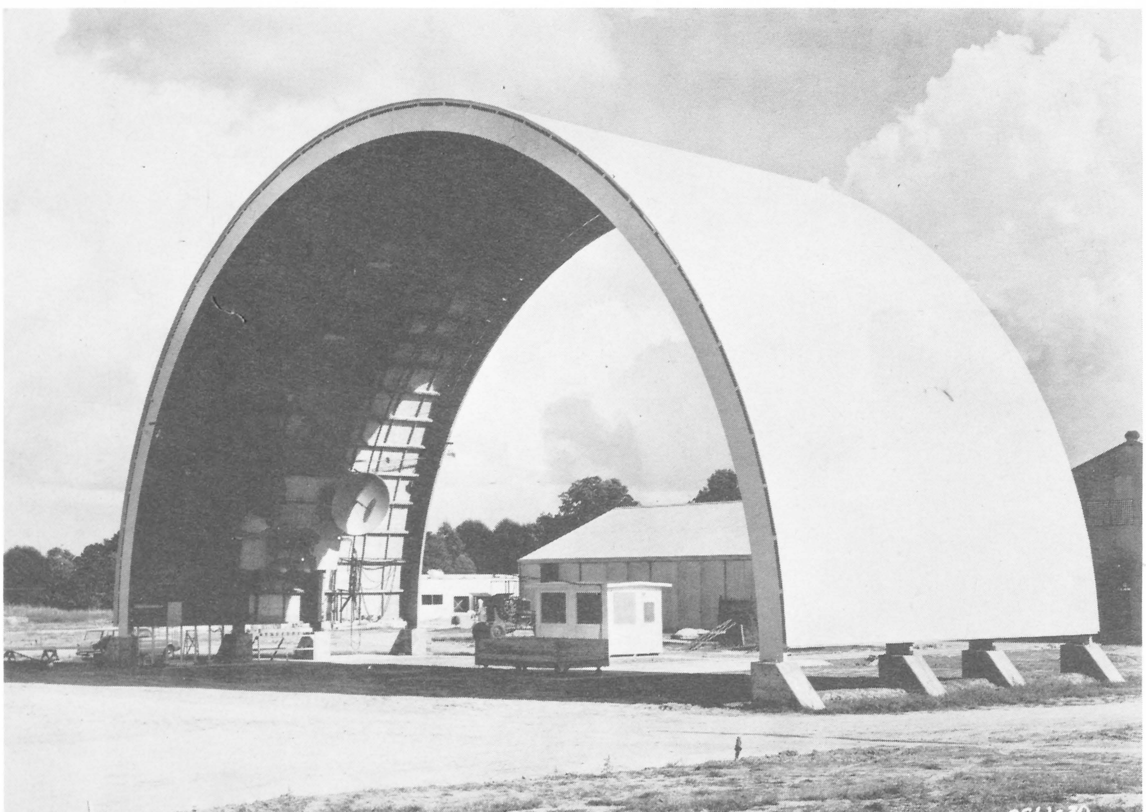

Fig. 13. Terrain analyzer arch test facility, WES

Fig. 14. Trafficability map of Ft. Stewart, Georgia

Trafficability Mapping

Although not directly charged with the responsibility for the production of techniques for trafficability mapping, the AMRC has worked closely with the U. S. Army Map Service and the Military Geology Branch of the U. S. Department of the Interior in developing the trafficability maps which exist today. The result is illustrated by fig. 14, a tactical map of Fort Stewart which is probably one of the most accurate trafficability maps existent. It was drawn after a 10-day field-data-collection period and concurrent and subsequent analysis of detailed aerial photographs. The map units are based on soil strength requirements for an M48 tank.

Conclusions

It is felt that the tools and techniques for measuring the trafficability of fine- and coarse-grained soils are adequate. Furthermore, it is believed that no system is likely to be developed that will be significantly better. This is not to say that the cone penetrometer is the perfect instrument, but only that soil conditions vary so widely, even in small areas, that some method of averaging conditions quickly seems to be the crux of the problem, and not some more sophisticated measuring device which may be capable of more precise measurement in one spot, but which requires considerable time to make measurements in enough spots to characterize an area. The contact work in snow and muskeg has not progressed far enough, but a modest amount of additional field testing should provide the experimental evidence to develop an acceptable system for measuring the trafficability of these two media.

Much remains to be done in noncontact studies. Current emphasis is on the prediction of the trafficability of tropical soils. Data have been collected from Hawaii and Puerto Rico, and presently projects are going on in Panama, Puerto Rico, Colombia, and Costa Rica. Soils whose strength is primarily affected by the presence of a water table and soils subject to freezing and thawing are also being studied.

Preliminary work has been done toward the prediction of the trafficability of sands and snow by noncontact means, but no real progress has yet been made. Little has been done in muskeg, but it is hoped that airphoto techniques can do the job. Further progress with aerial photo techniques for predicting trafficability of fine-grained soils is doubtful without some significant breakthrough in quality of camera, film, or processing method. Finally, it is believed that the electromagnetic spectrum offers a tremendous potential in the field of terrain analysis by noncontact means, but will undoubtedly require a long-term effort.

HYDROLOGIC GEOMETRY FOR MILITARY PURPOSES

by

Warren E. Grabau[1]

Attempts to develop a meaningful and quantitative descriptive and classification system for water bodies have proven difficult and, up to this time, relatively unproductive. One reason for this is the simple fact that it is inordinately difficult to define what is meant by a water body, and even harder to define the effects of water bodies on military activities or material. The whole factor family, with its peripheral implications, is astonishingly elusive.

At first glance, this seems quite unreasonable. However, reflection discloses some unsuspected pitfalls. For example, the tendency is to use common terminology as the point of departure for a classification system, and simply define ranges of values within the classes to achieve the required quantification. A handy classification of shape might be: lake, stream, canal. Everybody knows what these are--or do they? Fig. 1 is a simplified map of the drainage pattern north of Vicksburg, Mississippi. Note that, according to the map, the Yazoo changes from a river to a lake to a canal. Size obviously means nothing, for Long Lake is obviously much narrower than either the Yazoo Canal or the Yazoo River. If it is assumed that a stream has a current and a lake does not, the map takes care of this. The current through Yazoo Lake is quite strong all the time; Chickasaw Bayou rarely flows at all. It is because of such confusions that common terminology as the basis for classification has been abandoned.

Even factors which appear to be inherently quantitative are troublesome. For example, everybody knows what is meant by the depth of a stream. But again, a moment's reflection will suggest that it isn't quite that simple. For example, let depth be defined as the maximum vertical distance between water surface and bottom, as measured on a cross section taken along a direction at right angles to the direction of the thread of maximum current velocity. Normally, in a stream or canal or long thin lake, this

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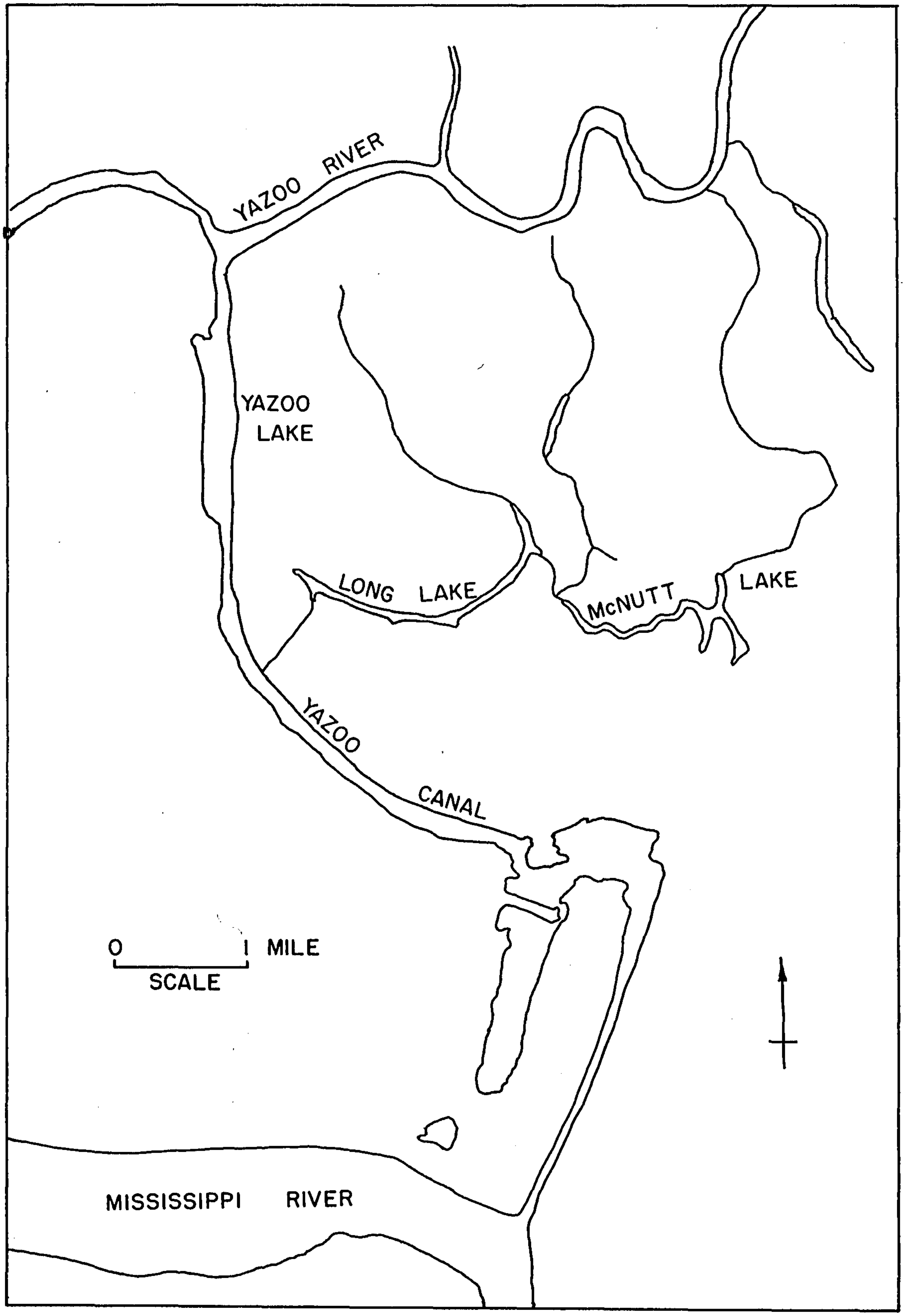

Fig. 1. Simplified drainage pattern near Vicksburg, Mississippi

will result in a relatively easily identifiable value. Of course, a profile taken a few yards upstream or downstream will yield a different value and, worse, measurements taken a few days sooner or later will also tend to yield a different value.

The point is obvious; we are dealing with a dynamic situation, constantly changing in time and space. For such conditions, there are two basic courses open. The first of these courses might be called the "snapshot" scheme. This scheme involves recording all pertinent characteristics at a number of different points in both space and time. Specifically, a given reach of a river might be described by several cross sections; one in a meander, one in a crossover, and so on. The maximum depth would then be recorded at each locality at specified times, throughout the cycle of rise and fall. While this "works," in the sense that the pertinent data are available, it results in an extremely cumbersome data-storage system. It also offers no ready means to classify the water body so that it can be compared with others.

The second method might be called the "continuum" scheme. In general, each factor would be regarded as continuous in either time or space, and the values which record the properties would be coefficients in the equation describing the spatial or temporal variations. For example, it is known that most natural streams are successions of pools and riffles; that is, deep and shallow spots. This generalization is as true of the Mississippi as it is of the brook running through the grounds of the Waterways Experiment Station. It would be possible to describe the thread of maximum depth in the channel by an equation. For example, a simple trigonometric function could be used; in practice a somewhat more complex function would probably be required. The bottom configuration function might look like this (fig. 2):

$$ax = b \sin y - c$$

when a is a coefficient describing the length of a pool-to-pool cycle, b is a coefficient defining the difference in elevation between pool and riffle, and c is a constant defining the position of the water surface at any instant in time. Thus, for any given reach, a and b would be constants, or nearly so, while c would be a variable with time. The

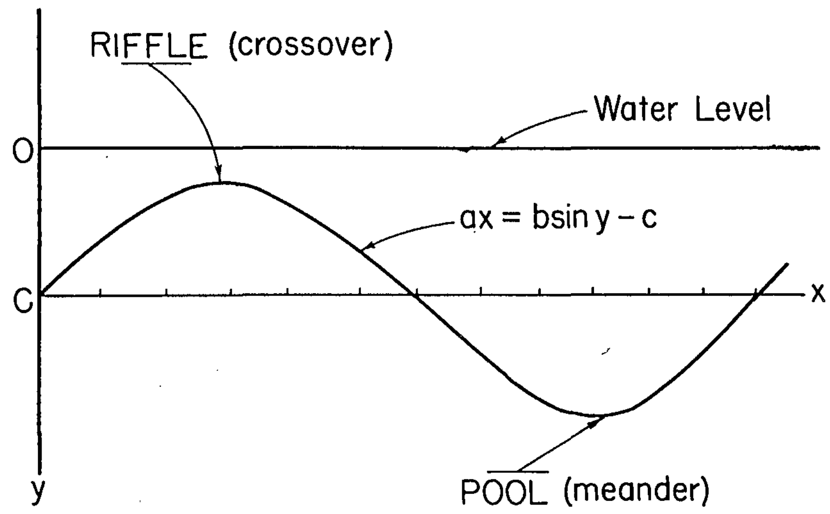

Fig. 2. Schematic representation of longitudinal profile

c value could be recorded as a coefficient from an equation describing the stream hydrograph to deal with the average changes in level through the seasonal cycle (fig. 3).

With this device, the probable maximum water depth at any point along the stretch being

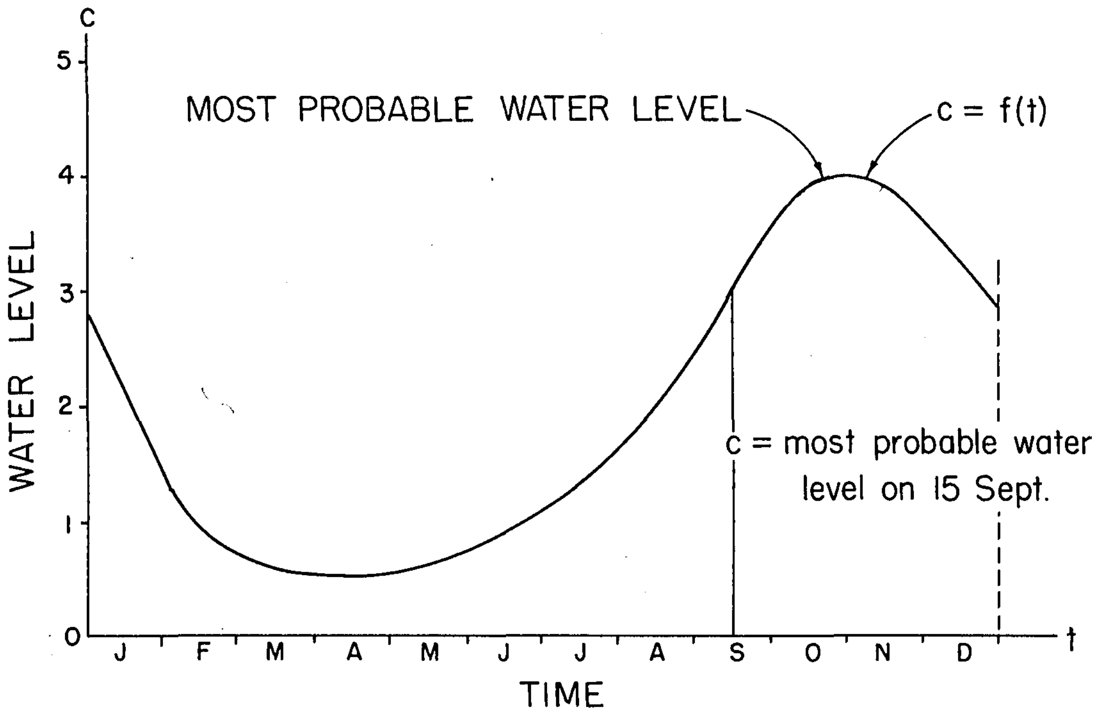

Fig. 3. Schematic representation of stage variations with time

described for any point in time could be calculated. The only values that would need to be recorded would be the coefficients of the equations describing the longitudinal stream profile and the stream hydrograph. This obviously takes less space for storage than the snapshot method and at the same time it offers convenient handles for classification. It is easy to define the similarities or differences between two equations.

Data concerning maximum depth is, of course, inadequate for many purposes. Experience with vehicles has demonstrated, for example, that the configurations of bed and banks, and the relation of the water surface to those configurations are of basic importance. To deal with this requirement, a device is needed to record the shape of the cross-sectional profile to a point at least slightly above the height of maximum flooding. Unfortunately, one cross-sectional profile will rarely characterize channel shape. More commonly, two or three are required. Normally these would be located at a crossover at the point of maximum curvature in a bend and at an intermediate point (fig. 4).

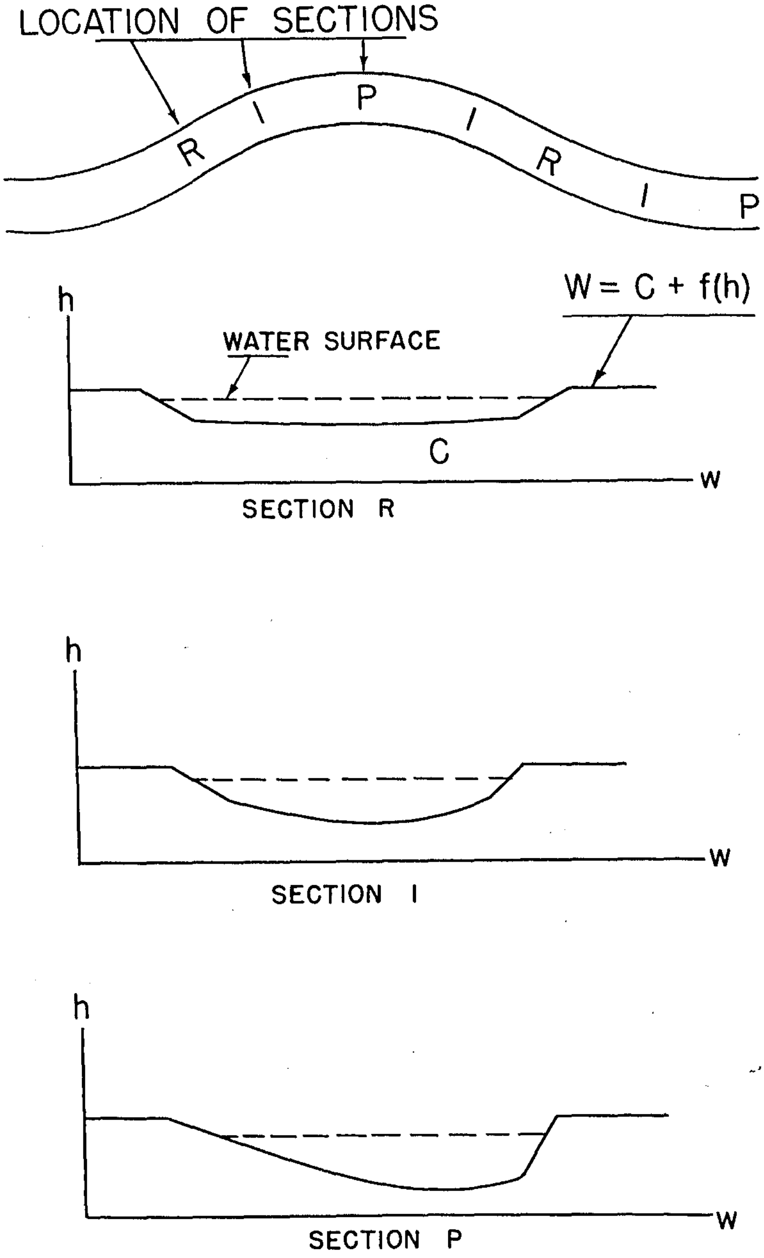

Fig. 4. Schematic representation of variations in channel cross sections

The profiles can be described without great difficulty and to a fair degree of accuracy by algebraic expressions of several types. One type which has been suggested is the Chebyshev polynomial which assumes this form:

$$T_n(w) = \cos [n \cos^{-1} w] = \cos (n\theta)$$

where n is any positive integer and θ is greater than 0 but less than pi (π). By normalization so that the channel width, w, is stated as values between +1 and -1, this polynomial can be used with considerable accuracy. Various modifications of this basic form make it amenable to the description of relatively complex shapes.

Another method involves the use of Fourier expressions of the form:

$$w = a + b \sin h + c \cos y \text{-------} n \cos y ,$$

the number of terms depending on the complexity and shape of the curve being described. Using this scheme, the profiles illustrated in the figure could be recorded by three sets of coefficients, one set for each profile.

To avoid becoming snarled in mathematics, this problem can be simplified, even at the risk of oversimplification. Thus, it can be assumed that the cross-sectional profile can be described by some equation of the general form

$$w = f(h) ,$$

where w is the width and h is the vertical expression. The h value may, of course, assume a relatively complex form as in the Chebyshev or Fourier expressions. One advantage is that the curve can be "moved" up or down with respect to an arbitrary index line by adding a constant to the f(h) expression. This means that it should be possible to consider such an index as the water level, and specify the "degree of filling" of the channel by an appropriate added constant. The equation would look like this:

$$w = c + f(h) ,$$

where c is the constant. But a depth value is already available for all times during the hydrographic cycle from the equation describing the "stream hydrograph." If the descriptive equations are properly designed, the depth value from the stream hydrograph should be directly transferable to the equations describing the stream cross sections, thus defining the depth of filling and the relation of the water surface to the configuration of bed and bottom.

One thing now remains: consideration of current velocities. In this case, the problem is probably not so serious because it has long been known that there is a direct but exponential relation between stage and velocity in any given stream (fig. 5). The equation would possibly look like this:

$$V = f(S^x) ,$$

where V equals maximum velocity, S is the water level, and x is an exponent of indeterminate value. If a single form holds for all streams, then current velocity at any point in time could be specified by recording the value of the exponent since the stream hydrograph equation already records the value of S for all points in time.

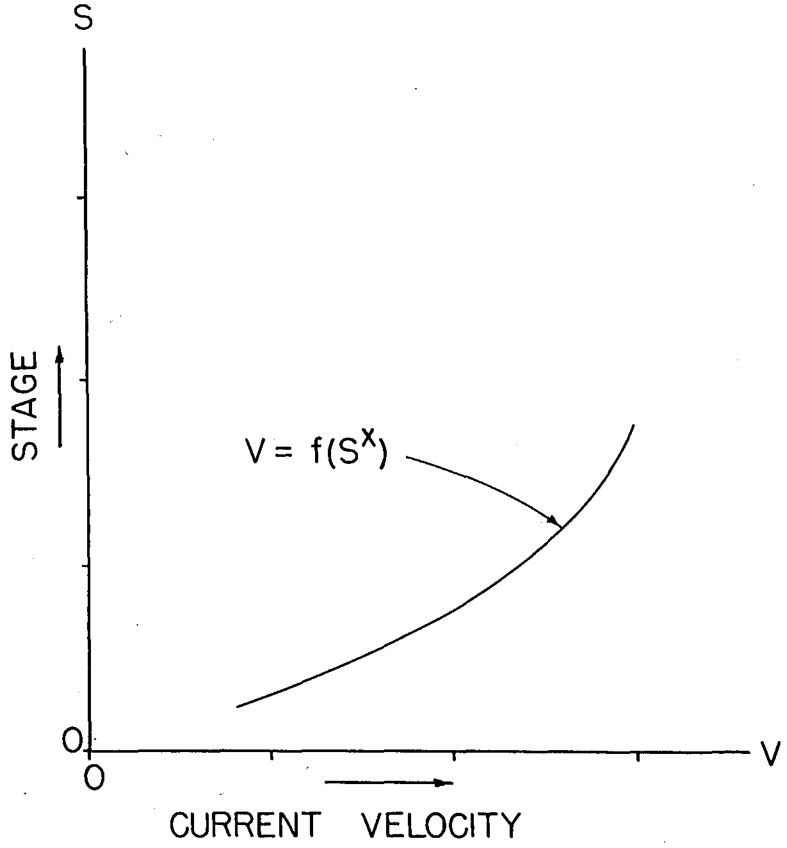

Fig. 5. Schematic plot of relation between current velocity and stage

At the present time, a system of this or any other form is not available. The general problem was studied during 1959-61 by the Drexel Institute of Technology and some of the concepts just discussed have come from that source. Despite the Drexel study, however, the problem persists. It is not known whether a system such as that just proposed is adequate, or meaningful, or usable for military purposes. As a result, the best that can be said is that systems of this form should be evaluated for practicality and utility.

APPLICATION STUDIES

by

Edward E. Garrett[1]

Since its inception a decade ago, the "Military Evaluation of Geographic Areas" (MEGA) project has evolved through several approaches: first, the codification of the effects of environment on military activities by means of a study of wartime operational records; second, the studies to establish the environmental characteristics of the research and development test stations at Yuma, Arizona, Fort Sherman in the Panama Canal Zone, Fort Churchill, Canada, and Fort Greely in Alaska; third, the development of analytical descriptive systems and the erection thereon of classification schemes for the various environmental factor families; and finally, the establishment of relations between causative elements of the terrain and the resultant performance of military materiel, personnel, and operations.

Inevitably, as these new and heretofore relatively unproven approaches to environmental research pass from the "ivory tower" stage of theorizing, they must be applied to practical problems. This application phase of the MEGA project, in fact, developed concurrently with the theoretical phase, but has in the past two years increased in importance and emphasis, as confidence in the techniques has grown and as awareness of the MEGA methods has spread, to an almost embarrassing degree. The Area Evaluation Section (AES) has frequently been called upon to do things which manpower limitations do not permit.

Early in the development of the project it was decided to use the data derived from the terrain analysis study of the Yuma Test Station, by Purdue University, to develop a descriptive and classification system for desert landforms or terrain types, and to apply the resultant system concurrently to other world deserts. It was hoped that an adequate classification system would evolve in the course of this study, and that the final product would be a determination of the representativeness of the Yuma

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Test Station as opposed to other world deserts. At that time it was assumed that the deserts constituted a unique assemblage of distinctive landforms, and that therefore a separate classification system would be required. A classification did, in fact, emerge and the study is now essentially complete (Broughton; "Desert Terrain Analog Study," pp 43-51).

The desert classification system evolved into an instrument of sufficient precision to permit its use in the comparison of desert terrains anywhere in the world. This being so, it follows that one could conduct performance tests at Yuma in terrains of known type and be quite confident that the performance would be equivalent elsewhere in the world in regions described as similar by the classification scheme. The Transportation Corps planned to conduct a series of cross-country mobility tests at Yuma with its experimental Overland Train. They asked the Waterways Experiment Station (WES) to select a series of test courses which would be representative of as much of other world deserts as possible. Such courses were selected, studied, and marked in preparation for the test program, which is currently in progress (Shamburger; "Overland Train Terrain Evaluation," pp 52-59).

The detailed information made available through the Overland Train Terrain Evaluation Research Project (Project OTTER) has also been directly exploited by AES. It was felt that it would be most useful to test the response of a standard vehicle to variations in terrain, hoping in this way to determine whether the entirely quantitative descriptive systems, which have only recently become available, could be meaningfully applied to the prediction of vehicle performance. Accordingly, additional test courses parallel to the Project OTTER courses were laid out, and a series of tests were run on them (Friesz; "Desert Terrain Effects on Vehicle Performance," pp 60-72).

As the initial descriptive and classification system evolved from the desert study, it became apparent, more or less to everyone's surprise, that it was applicable on a worldwide basis and not just to deserts as had been originally assumed. This notion was sufficiently upsetting to warrant a test of the application of the basic scheme to the humid tropics--specifically to Panama and Puerto Rico (Dornbusch; "Quantitative Terrain Mapping in the Humid Tropics, Puerto Rico and the Canal Zone," pp 73-81).

The field collection systems were by this time sufficiently advanced to make it practical to at least attempt their application to field exercises. The hope was that enough precise data could be gathered in this way to make it possible to establish the nature and magnitude of environmental effects on cross-country movement in the humid tropics. Accordingly, when the Transportation Corps invited WES to send observers to their exercises in Panama, preliminary investigations into this problem were initiated (Garrett; "Mobility Studies in Humid Tropics, Panama," pp 82-95).

At about the same time, WES was asked to take part in an exercise to predict the construction effort required to build airfields of specified types in remote areas. The quantitative descriptive systems proved easily adaptable to this purpose, enabling the development of analytical solutions to this problem (Ahlvin; "Application of Environmental Study Techniques and Information to Airfield Construction Effort Determinations," pp 96-97).

Finally, the increasing precision and sophistication of the descriptive systems, especially of that dealing with vegetation, suggested that some of the more subtle aspects of environmental effects might be profitably investigated. Consequently, a recent series of tests were conducted near Vicksburg in which the effect of tree spacing on vehicle performance was examined, primarily in an effort to learn how to design valid environmental tests (Addor; "The Effect of Stem Spacing on Vehicle Performance," pp 129-142).

DESERT TERRAIN ANALOG STUDY

by

Jerald Broughton[1]

The Desert Terrain Analog study was initiated in 1953. This study was assigned to the Waterways Experiment Station (WES) by the Chief of Research and Development, Department of the Army. The decision to test men and materiel under a desert environment of the Yuma Test Station (YTS), Yuma, Arizona, necessitated a study of this type to determine the suitability of the station as a testing site for world desert terrain conditions. The suitability and adequacy of YTS are obviously related to the extent of occurrence of Yuma terrain types or conditions in other world desert areas, and to whether significant desert terrain types occurring elsewhere are present or absent at Yuma.

The immediate objective of the Desert Terrain Analog program was to compare the terrain at Yuma with that of other world deserts, and to develop a technique to (a) determine the suitability of a small area as a representative testing site for world desert conditions, and (b) compare two desert areas of similar or differing sizes. Obviously, the value of a test conducted at a site such as Yuma depends on the extensive distribution in world desert areas of the terrain factor combinations found at Yuma. Utilizing the technique and resulting maps, the distribution and extensiveness of individual or combinations of terrain factor ranges can be determined, and the suitability of the area as a test station for specific or combined terrain factors can be effectively established.

For a valid comparison to be made between the terrain conditions at Yuma and world desert areas, it was necessary to establish a system of describing, classifying, mapping, and comparing desert terrain factors. Researchers attempting to compare two areas are continually plagued by the qualitativeness and subjectivity of terrain description. The qualitative or classical approach to geomorphology consists primarily of written descriptions of terrain and landforms dealing extensively with the genetics

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of the various landforms and surfaces. This approach depends almost entirely on the skill of the individual, both as an analyst and as a master of descriptive prose. Terrain descriptions have also been imprecisely categorized into flat, rolling, hilly, mountainous, and so on. The same landscape may be described by one observer using one set of terms, and by another observer--or even the same observer at a later date--using an entirely different set of terms. Because there is no other system of description available, the observer is forced to use qualitative terminology that varies to suit the occasion.

On the other hand, a quantitative terrain description is simply one that uses numerical values or ranges of numerical values rather than words to define terrain. The obvious advantages of such an approach are its objectivity and the fact that mapping units can be rigorously defined. A more subtle, but considerably greater, advantage is that quantitative factors offer the possibility of being manipulated mathematically so the effect of individual terrain factors or of factors acting in concert can be determined.

In the desert terrain analog study a middle course was chosen between the qualitative and quantitative approaches. In the first place, it was recognized that a quantitative approach is ideally suited for terrain analogs or comparison purposes and every attempt was made to be quantitative. Where attempts at quantifying terrain concepts resulted in overcomplexity, however, a simpler qualitative or semiquantitative mapping system was introduced. Soils, for example, are expressed in standard qualitative terms, i.e. silt, clay, sand, etc., rather than resorting to a quantitative representation such as median grain diameter, cohesive strength, etc. In the second place, the quantitative approach heretofore has been applied primarily to small homogeneous areas for which large amounts of terrain data were available. The scarcity of data in the vast areas mapped in the desert analog study dictated against introducing complex quantitative parameters for which landform-soils-physiographic ties and associations were very difficult, if not impossible, to establish.

Considering that the descriptions of terrain were to be such as to permit the identification of cause-effect relations between the terrain and military activities and/or items of materiel, two approaches to the problem of terrain-analog development were theoretically possible. One could map and compare terrain factors or terrain effects. Thus, the possible choices were: (a) to map and compare ranges of selected terrain factors, such as slope, relief, soils, etc., or (b) to describe and map areas in terms of critical values of such factors at which adverse effects are produced on such military considerations as cross-country movement, firepower, earth construction, radio communications, etc.

Several considerations that militate against the scheme of classifying and comparing areas in terms of terrain effects are:

a. Single terrain factors do not have independent critical values, e.g. the critical slope value for a given vehicle varies with the strength of the slope surface.

b. A given terrain factor may have greatly differing critical values for different activities, e.g. the density of vegetation when considered in relation to foot movement as against signal communications. In addition, variations of critical values may occur within a general class of materiel or equipment, e.g. critical slope values are different for different vehicles.

c. Critical values are not presently known for many activities and/or items of materiel.

d. Critical values are not constant, but change with technological advances and obsolescence.

Terrain factors eventually mapped were chosen chiefly because of (a) their military significance, (b) their importance in developing "suitability" or test site analogs, (c) their importance as a basic element of terrain, and (d) their capacity, when viewed in concert, to provide a reasonably complete picture of a given terrain. The stratification of each factor, or breakdown of the factor's range into mapping units was based on such considerations as (a) natural divisions, (b) availability of data, (c) military significance, and (d) adaptability of the unit to precise, and wherever possible, quantitative definition.

An important reason for selecting the mapping unit values to coincide as closely as possible with the natural groupings or ranges was to assist in the establishment of a landform-landscape association. Once this type of an association was established it could be used as a tool for mapping regions of the world desert areas where data are restricted to form lines on a map or a qualitative description of landforms by a traveler. This landform-landscape association was set up through the utilization of the results of studies dealing with the various landforms. For example, detailed reports concerning alluvial fans have concluded that the slope of these features rarely, if ever, exceeds 10 deg and in the majority of cases the value is less than 6 deg. Research on barchan dunes has revealed that the windward slopes range from 5 to 14 deg. These data, in addition to spot-mapping of world desert tracts for which both large- and small-scale maps were available, have provided numerous landform-landscape associations that were most valuable during the map preparation of the desert areas included in this project.

Fig. 1 illustrates the landform tabulations prepared in the desert analog study. Note that each landform is defined both in written description and in numerical values and ranges of the mapping units for each of the four landscape factors. These ranges are given for YTS, the particular study area--in this case the southwest United States--and for all the desert areas of the world.

Eight terrain factors were chosen for mapping and analog development:

<u>a</u>. Geometry factors
- (1) Characteristic plan-profile
- (2) Occurrence of slopes greater than 50 percent
- (3) Characteristic slope
- (4) Characteristic relief

<u>b</u>. Ground factors
- (1) Soil type
- (2) Soil consistency
- (3) Surface rock

<u>c</u>. Vegetation factor
- (1) Vegetation

As previously mentioned, each of these terrain factors has been rigorously defined in this technique. For example, the plan and profile are the spatial distribution and configuration in both plan and profile of the topographic highs and lows. Detailed explanations of the factors are included in WES Technical Report No. 3-506.

Once the terrain classification and analog technique were developed, the technique could be used in the comparison of any two desert areas of

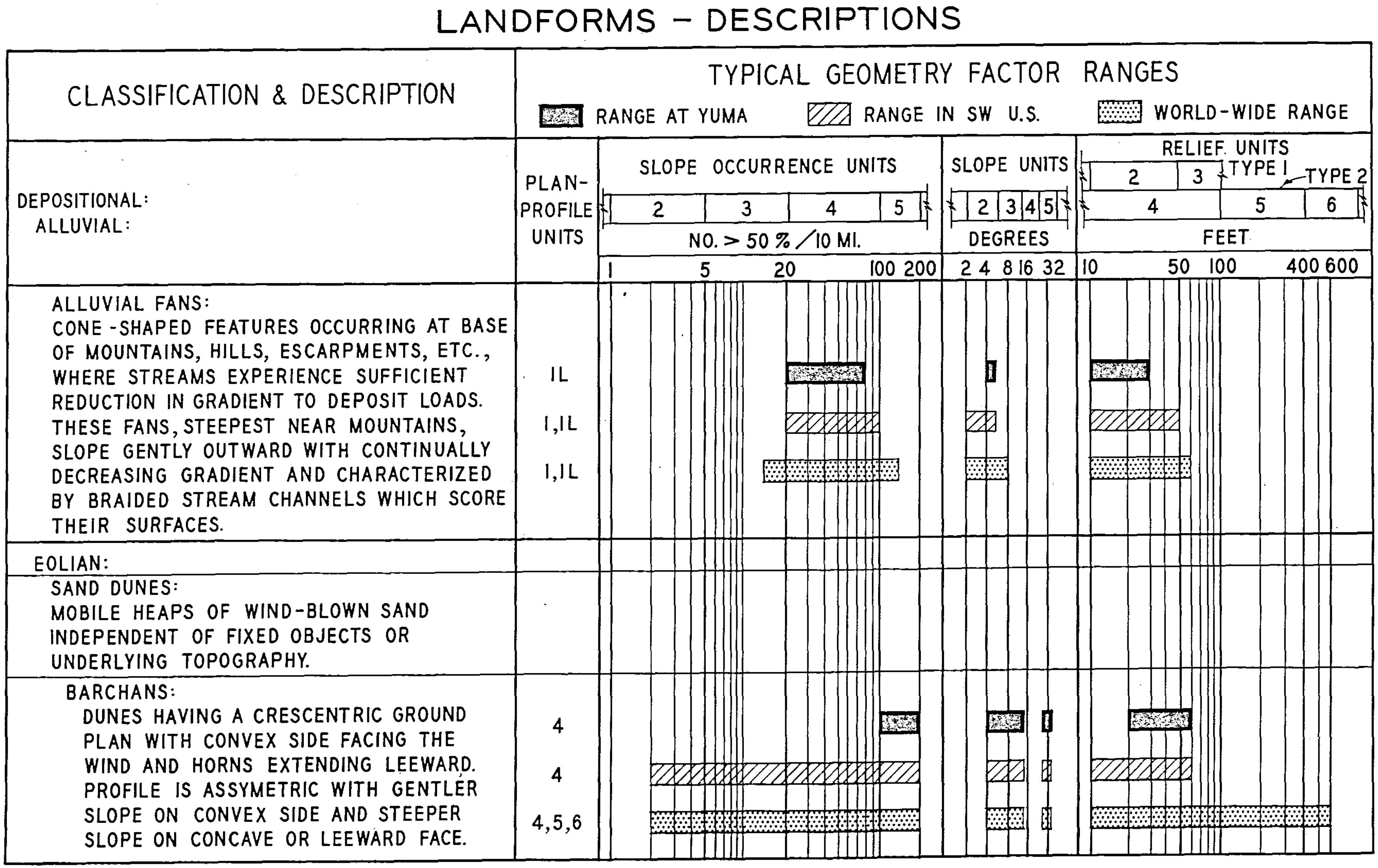

Fig. 1. Landform-landscape association as developed for the Desert Terrain Analog Study

either similar or dissimilar sizes. Areas of analogy in various world deserts can thus be readily determined.

This system first classified landscapes in terms of surface geometry, the pertinent factors being characteristic plan-profile, slope occurrence, characteristic slope, and characteristic relief. The landscape is thus identified by an array of four numbers (or number-letter symbols) each representing a mapping unit within one of the four geometry factors. It should be emphasized that while slope occurrence, characteristic slope, and characteristic relief are measures of specific or individual properties of the landscape, the characteristic plan-profile is in reality a combination of four specific attributes or factors. These four factors describe the spatial distribution and configuration in both plan and profile of the topographic highs and lows. The specific factors which are measured are peakedness, areal occupancy, elongation, and alignment or parallelism of the topographic highs.

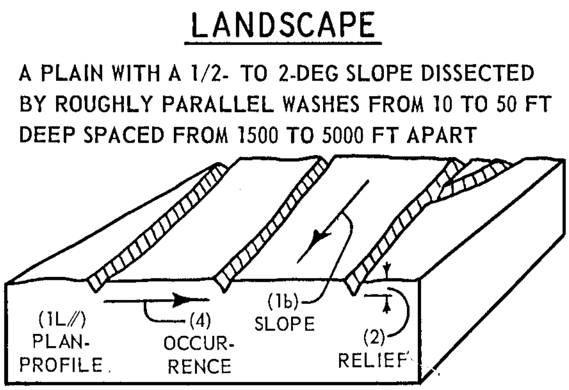

Fig. 2. Component landscape

Fig. 2 is an illustration of a mapped landscape consisting of a plain sloping 1/2 to 2 deg dissected by roughly parallel washes from 10 to 50 ft deep and from 1500 to 5000 ft apart. As previously mentioned the characteristic plan-profile factor is an indication of four attributes. This particular characteristic plan-profile designation of 1L// signifies that the topographic highs are flat-topped, occupy greater than 60 percent of the area, are linear, and are parallel.

After all of the factor maps have been prepared, the next step is to establish degrees of analogy or similarity between the mapped desert area and the Yuma Test Station. Four analog maps are prepared which include geometry, ground, vegetation, and terrain type. Fig. 3 is a portion of the ground analog map of the Middle Eastern Desert indicating degrees of analogy of the Middle East ground factors to those at Yuma. The geometry and vegetation analog maps are similar comparisons of their respective factors.

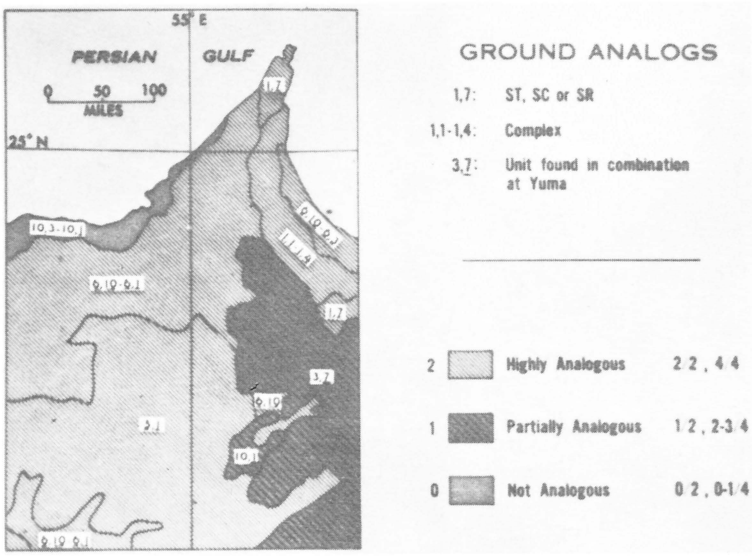

Fig. 3. Section of a ground analog map of the Middle Eastern Desert

The terrain-type analog map is a synthesis of all eight terrain factors indicating the overall analogy of a mapped world desert to the Yuma Test Station. These analog maps are included in the folio reports of the desert areas.

At the present time the desert regions of Northwest Africa, Northeast Africa, South Central Asia, the Middle East, Mexico, and Southwest United States have been mapped and folio reports prepared (figs. 4 and 5). The folios are made up primarily of a

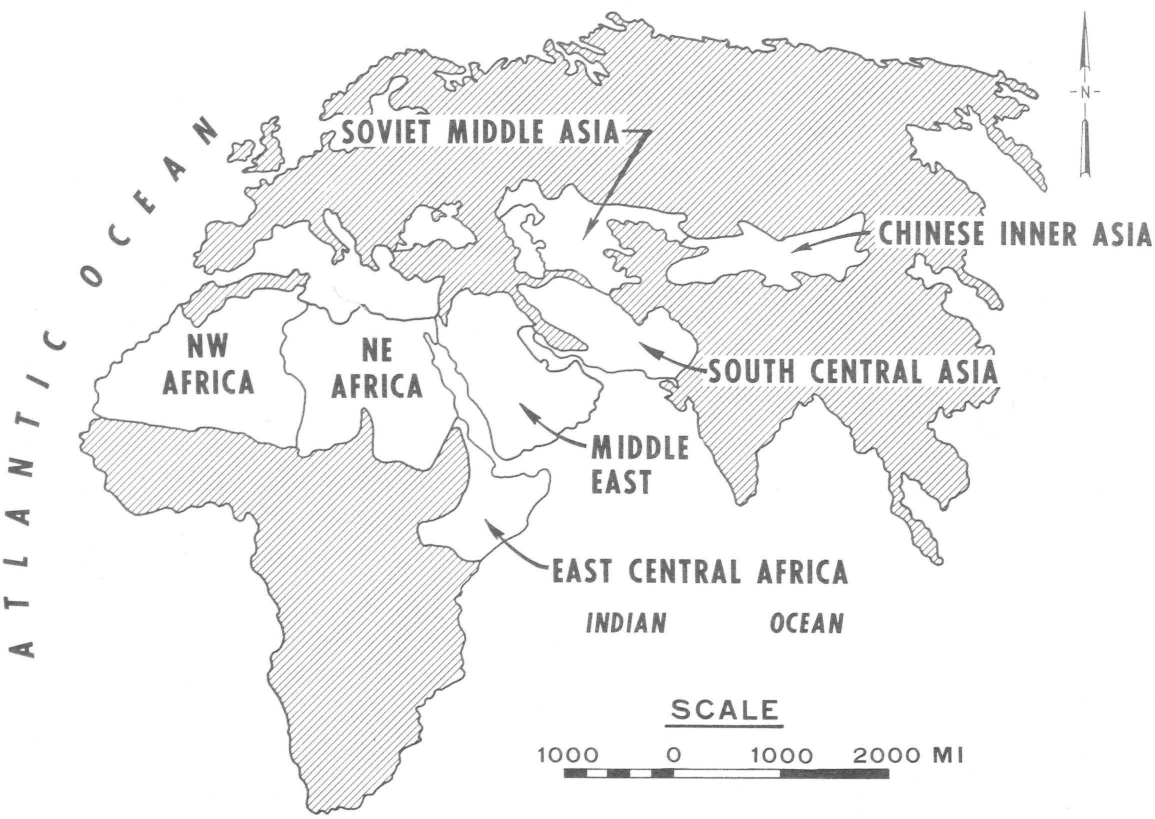

Fig. 4. Location of desert regions of Asia and Africa

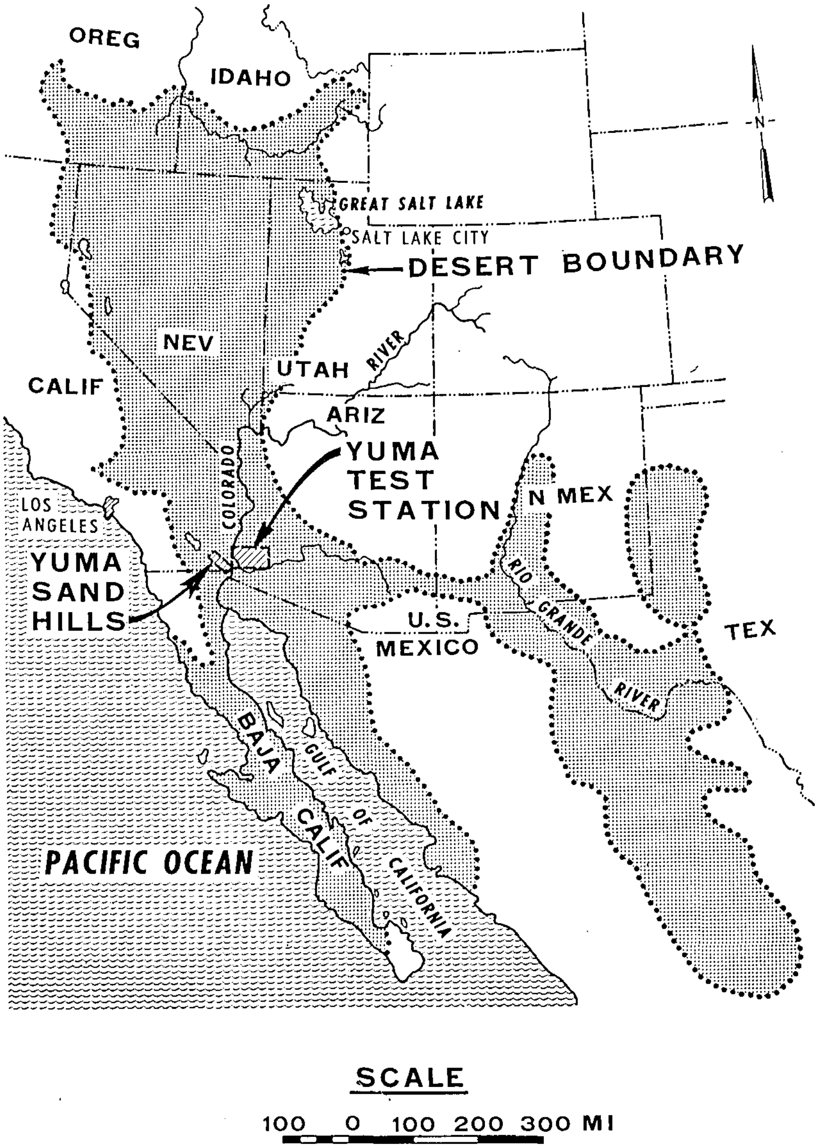

Fig. 5. Location of desert regions of Mexico and Southwest United States

series of plates, each consisting of a map of the particular study area and a map of YTS in the upper right-hand corner for ready comparison. In reality all of the factor maps are also analog maps, since any area in a world desert mapped similarly to an area at YTS will be analogous to YTS, insofar as that factor is concerned.

These folios were prepared almost entirely from published reports, maps, and photographs by means of the landform-landscape association technique as previously described in this paper. Only the Southwest United States and Northwest Africa folios are being reproduced in sufficient quantities for wide distribution; reproduction costs have prevented printing the others in sufficient numbers to permit distribution. Basic data collection has also been accomplished for the Soviet Middle Asian, the Chinese Inner Asian, and the East Central African Deserts (fig. 4).

The development of a technique for preparing desert terrain analogs was the first, and a very important, step toward the goal of predicting quantitative impacts of terrain on military activities in world desert areas. Further steps necessary for the attainment of this goal include: (a) collecting data on the effects of terrain on military activities, (b) forming theories of the nature of the cause-effect relations between terrain and military activities, and (c) establishing these concepts through actual testing programs such as the Overland Train Terrain Evaluation Research Program.

OVERLAND TRAIN TERRAIN EVALUATION

by

John H. Shamburger[1]

Testing the cross-country capabilities of the Overland Train in a desert environment is presently being conducted at the Yuma Test Station (YTS) in Arizona. These tests are being carried out jointly by the Waterways Experiment Station (WES) and the U. S. Army Transportation Research Command (TRECOM). TRECOM's interest is centered on conducting tests across terrain that is representative of desert conditions throughout the world.

Procedures used in the past to select test courses, to measure terrain characteristics, and to observe them have been subjective, qualitative, and incomplete. These tests leave no valid basis for translating operational experience in one area to other areas of the world. In order to ensure that tests conducted over terrain in a specific area such as the YTS are applicable to deserts throughout the world, a comparative knowledge of the terrain conditions at Yuma and those in other desert areas must be available. Under the project "Military Evaluation of Geographic Areas" (MEGA), terrain analysis and evaluation studies have been conducted at WES for the past eight years. During this time several world deserts in the Northern Hemisphere have been mapped and compared with the YTS, utilizing a semiquantitative system of terrain classification which allows reasonably objective comparison of different areas. Thus, with detailed worldwide data on deserts available and a desire to test the WES descriptive and mapping technique through a field testing program, the WES was entirely sympathetic to TRECOM's objectives. Accordingly, the Overland Train Terrain Evaluation Research project, referred to as Project OTTER, was initiated. The WES responsibility is fivefold, as follows:

- a. To select test courses at the YTS for the Overland Train that are representative of as much of other world deserts as possible;
- b. To measure the environmental characteristics of each test course;

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[1] Chief, Military Projects Section, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

c. To identify those areas of other world deserts that are similar to the test courses;

d. To instrument the Overland Train and record its performance in each identifiable terrain type; and

e. To analyze the performance data and determine, if possible, the cause-effect relations between environmental factors and vehicle performance.

The Overland Train (fig. 1) is a 13-car, rubber-tired logistical cargo carrier built for the Transportation Corps by R. G. LeTourneau, Inc. The Train consists of a control car, two power-generating cars, a tanker car, and nine cargo cars. Its total length is 575 ft. The Train is supported by 54 wheels, each 10 ft in diameter, and is powered by a high torque d-c electric motor mounted inside the wheel rims. Each wheel is sprung to the vehicle on ball joint, air bag, and shock absorbers. The cars are connected by a tongue-and-link system in a manner which permits each car to track the lead car automatically.

The primary power plant is composed of three 600-kw, 600-volt d-c generators and three 150-kva, 480-volt, 60-cycle a-c generators which are driven by three Solar gas turbine engines. The auxiliary power plant is one-third the capacity of the primary power plant and is located in the control car. This power system permits solo operation of the control car. Other vital statistics are:

a. Width, 16 ft 6 in.

b. Height of control cab, 17 ft 8 in.

c. Cargo capacity, 150 tons

d. Net weight without fuel, 270 tons

e. Ground clearance, 30 in.

f. Speed range, 0-20 mph

Project OTTER can be conveniently divided into two major phases: (a) selection, classification, and marking of the test courses, and (b) selection, recording, and analysis of data to determine cause-effect relation of terrain factors during the cross-country operation of the Overland Train.

The work that was involved in the initial stage of the project is considered first. Before the test courses were selected, a comprehensive office study was made of the terrain maps of the Northeast African,

Fig. 1. The Overland Train

Northwest African, Middle Eastern, and South Central Asian deserts. The areas occupied by individual Yuma terrain types in these four world deserts were computed for areal significance. After this was accomplished the following criteria were established for the selection of courses:

a. Terrain types selected should be areally significant in world deserts.

b. Courses should include as many areally significant terrain types as possible.

c. Courses should not cross terrain that obviously exceeds the capabilities of the Overland Train.

d. Courses over terrain which will obviously have little or no adverse effect on performance should be kept to a minimum.

e. Courses should be at least 4 miles in length and wide enough to allow several traverses without tracking. A width of 400 ft was arbitrarily selected.

f. Each terrain type should cover a minimum length of 2000 ft.

Fourteen courses were originally selected to test the Overland Train's performance at Yuma. For various reasons, four of these courses have been eliminated; the remaining courses (nine at Yuma and one in the California Sand Hills) have been surveyed and marked (fig. 2). The type of

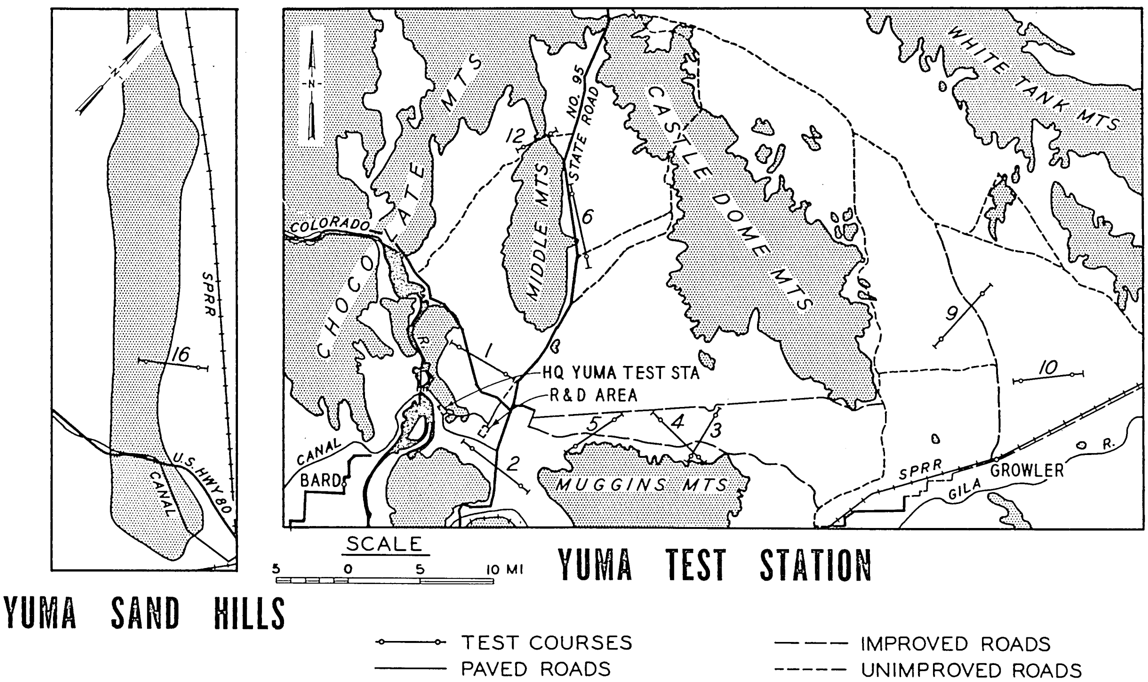

Fig. 2. Location of courses at the Yuma Test Station and in the California Sand Hills

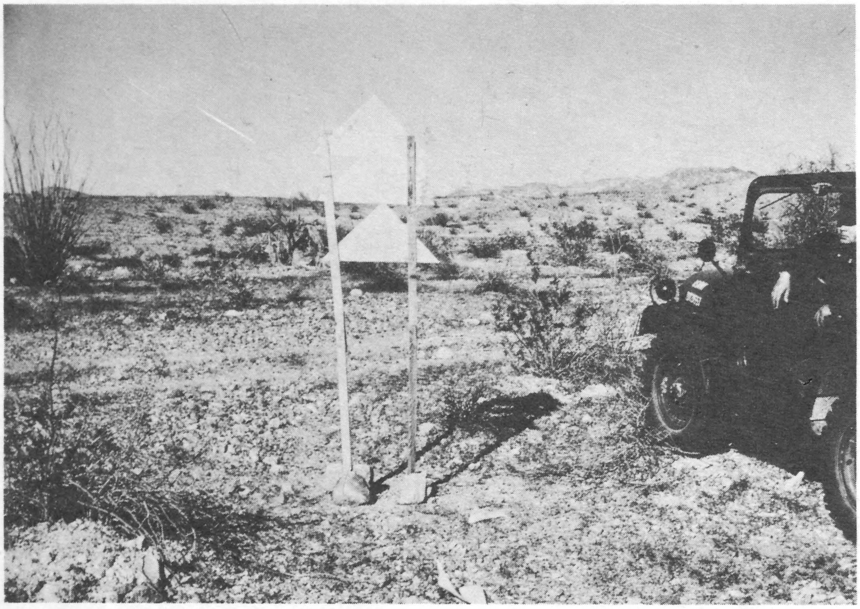

Fig. 3. Side stake used to mark limits of course. The triple triangle designates the end of a course

marker used to designate the side limits of a course is shown in fig. 3.

Descriptions of the surface geometry, soil characteristics, and vegetation have been made along each course. Because complete topographic map coverage at a usable scale was not available of Yuma, aerial photographs were made of each course. From these photographs, strip topographic maps were made at a scale of 1:5000, with a 5-ft contour interval (fig. 4); photo mosaics (fig. 5) were also made. All environmental data collected prior to testing have been plotted on these maps, and data collected during the field tests will also be referenced to these maps.

In addition to the panchromatic photographic coverage, the Cold Regions Research and Engineering Laboratory (CRREL) made color and infrared photographs of the courses.

The second phase of this project concerns selection, recording, and analysis of environmental data. The purpose of this phase is to collect sufficient data during the field tests to (a) measure the nature and magnitude of terrain effects on the Overland Train's mobility, (b) evaluate the significance of WES mapping unit ranges on the Train's mobility, (c) predict terrain effects along other routes on similar terrain, and (d) develop a reasonably objective procedure for mapping world deserts in terms of Overland Train performance.

The factors considered most important in determining terrain effects on the performance of the Overland Train were selected for measurement.

TERRAIN TYPES

1,1,1b,2-6,9/6,10-2/4	4,4,3,4-6,10/6,9-1/4

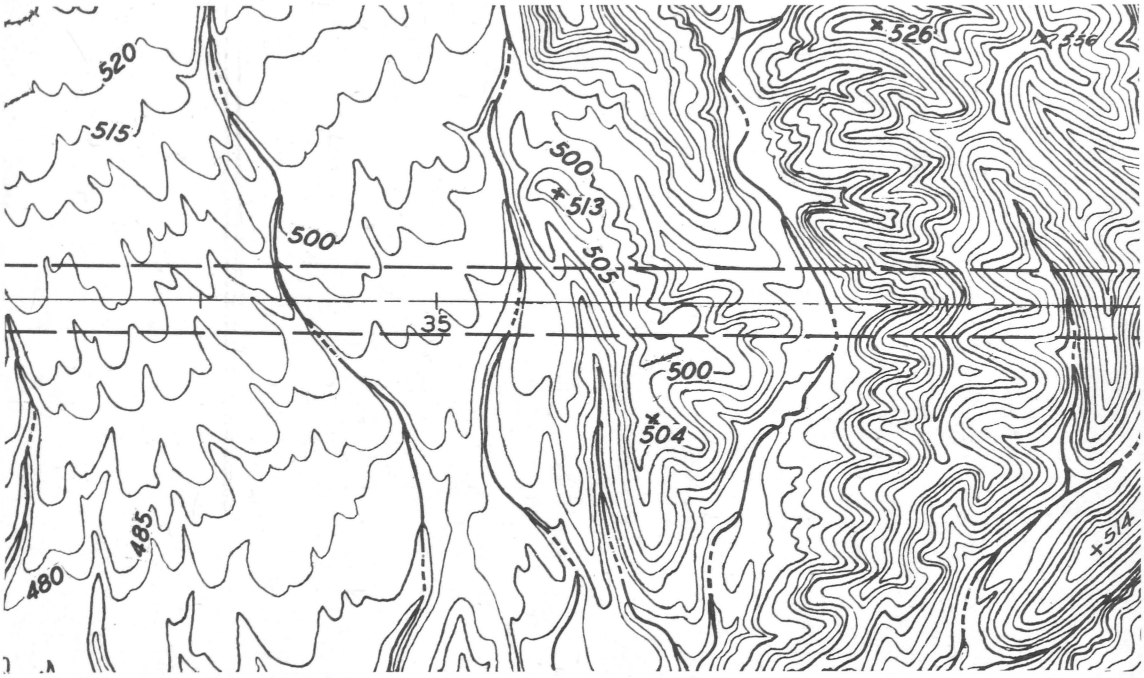

Fig. 4. Part of a strip topographic map of test course 5

TERRAIN TYPES

1,1,1b,2-6,9/6,10-2/4	4,4,3,4-6,10/6,9-1/4

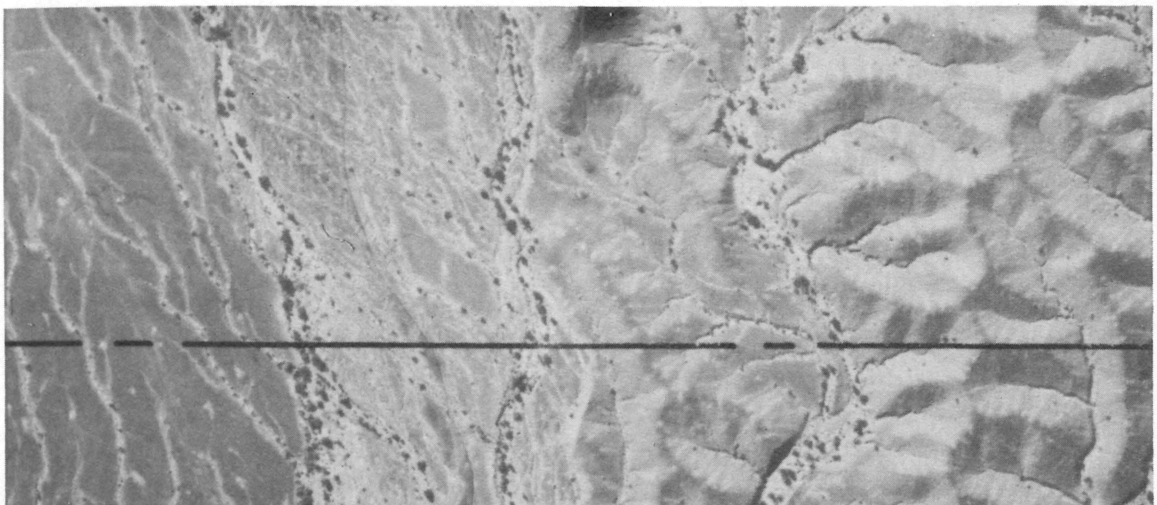

Fig. 5. Part of a photo mosaic of test course 5

These factors are referred to as "selected performance indicators" and will be measured for each terrain type. These indicators are: time lapse, distance traveled, electrical energy in watt-hours required to operate the drive, steering, and braking systems, fuel consumed to generate electrical current, vertical axle acceleration, vertical and longitudinal acceleration of a cargo-car bed, dust density, and terrain conditions at immobilization points. As shown in fig. 6, all of these data are being recorded on two Brush oscillographs in the form of "pips." These data will be converted to actual values.

Fig. 6. Interior of instrumentation shack on cargo car 8, showing the equipment used to record performance data

In order to assure maximum uniformity of test results, certain set procedures have been established which are being followed during the field tests. At least four traverses--two in each direction--are being made by the Train on each test course. This will permit easier identification of performance variations that might be caused by changes in terrain effects due to the direction of travel, or to the operators increasing familiarity with the course. The tracks left by four traverses made across test course 12 are illustrated in fig. 7.

For the purpose of the tests the Train will be considered mobile as long as its forward motion continues within the limits of the test course and it does not follow the tracks of a previous traverse. The Train will be considered immobile when its forward motion ceases because of one of the following reasons: (a) terrain conditions, (b) it goes outside the limits of a test course, or (c) it follows in the tracks of a previous traverse to avoid difficult terrain.

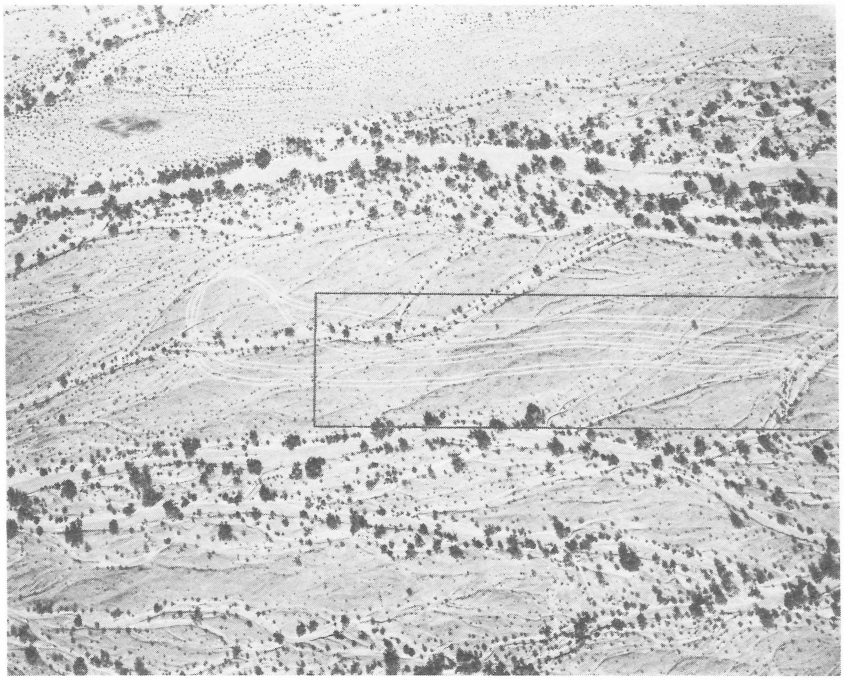

Fig. 7. Aerial photo of part of test course 12, showing the tracks left by the Overland Train after four traverses across the course

Mechanical or electrical failures that are not directly caused by terrain conditions will not be considered as terrain-induced immobilities; however, they will be noted. If failures are minor and repairs are made in less than 2 hr the Train should continue the traverse. When breakdowns of longer duration occur, the traverse will be rerun from the beginning.

Performance data will be measured over a conveniently located road so that "base values" can be determined for each of the oscillograph traces. It is planned to use a 5-mile segment of gravel road for this purpose, and possibly a paved road as well.

After the test results have been tabulated, an attempt will be made to correlate the Overland Train's performance with the terrain factors mapped along the test courses. Once a correlation of this type has been established, these data can be extended to other world deserts. In other words, the effects caused by a specific Yuma terrain condition should exhibit similar effects over a similar environment in another world desert. It is believed that the system for describing, classifying, and mapping terrain will permit the identification of similar terrain in other world desert areas, and that therefore the test results can be used to formulate terrain effects maps for the Overland Train's cross-country mobility over any of the world deserts mapped according to the WES system.

DESERT TERRAIN EFFECTS ON VEHICLE PERFORMANCE

by

Richard R. Friesz[1]

Since test courses had already been laid out at the Yuma Test Station (YTS) for the Overland Train, it seemed a waste not to use them for testing the effects of environments on standard vehicles. Accordingly, a test program designed to record the effects of desert terrains on a conventional military vehicle, the M38 1/4-ton utility truck or jeep, was conducted at YTS during the latter part of 1961. This program had three principal objectives:

a. To determine whether desert terrains which were described as dissimilar by the MEGA descriptive systems actually imposed variations in cross-country mobility of a small wheeled vehicle.

b. To correlate, if possible, the values obtained for each of the selected performance parameters with the terrain characteristics as described by the MEGA descriptive systems.

c. To evaluate the feasibility of extrapolating the results of these tests to other desert areas of the world, and thus be able to predict in quantitative terms the effects of similar terrain environments on vehicles similar to the test vehicle.

Seven test courses which encompassed most of the significant variations of surface geometry, surface composition, and vegetation found at Yuma were selected for testing. All courses were straight, 200 ft in width, and varied from 4 to 6 miles in length. By visual inspection, the areas of topographic similarity were identified and the courses were subdivided into these units. These topographic units have been termed "terrain types." A total of 46 such terrain types were delimited on the seven test courses in this manner. Each terrain type has been classified as to surface geometry, surface composition, and vegetation. A brief description of the methods used to describe each is as follows.

Two subfamilies are recognized within the surface geometry family. These are macrogeometry and microgeometry. The distinction between them,

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however, is arbitrary. Since the available maps for the test courses are drawn with a 5-ft contour interval, this value was selected as the limiting criterion. For the purpose of this project, then, all geometric attributes of the surface that are definable by mapping the topography with a 5-ft contour interval are considered to be macrogeometry features. Seven factors comprise this family. They are: structural cell diameter, local relief, characteristic slope, elongation, parallelism, profile area, and peakedness. The first three parameters are dimensional; the last four are dimensionless numbers. Sufficient measurements are taken to permit the establishment of modal values for all parameters.

a. Structural cell diameter is a measure of the spacing of hill or ridgetops. It is also a more or less direct measure of the maximum number of scour channels that would be encountered along a line running at right angles to the dominant drainage direction.

b. Local relief is a measure of the height of hills or ridges. It is actually the difference in elevation between the lowest and highest points in a structural cell.

c. Characteristic slope is a measure of the most commonly occurring slope within that terrain type.

d. Elongation is a measure of the tendency of topographic highs to be ridgelike. A value close to 1 indicates a nearly equidimensional feature, while a value close to 0 indicates a long, narrow form.

e. Parallelism is a measure of the tendency for topographic highs to occur in oriented arrangements. A value close to 1 indicates a nearly random arrangement, while a value close to 0 indicates a strongly oriented one.

f. Profile area is a measure of the cross-sectional shape of topographic highs. A value close to 1 indicates a predominantly convex surface, whereas a value close to 0 indicates a predominantly concave surface.

g. Peakedness is a measure of the tendency for topographic highs to be peaked. A value close to or greater than 1 indicates a strongly peaked crest, while a value close to 0 indicates a flat-topped feature.

Due to the lack of a quantitative method for describing microgeometry, an attempt was made to introduce into the descriptive systems a measure of that part of the surface configuration which imposes a critical effect on the movement of a specific vehicle. This factor has been termed "critical surface geometry configuration."

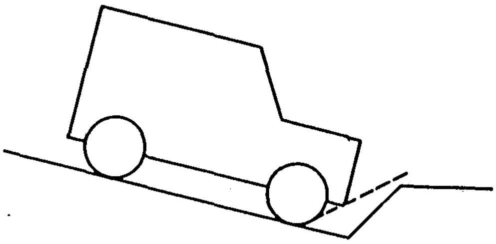

Fig. 1. Concave configuration

It has been found that three fundamental configurations result in vehicle immobilization. These are: slope, concave configurations, and convex configurations. Assuming that a slope must be climbed from an essentially standing start, immobilizations occur when such slopes exceed the climbability of a vehicle. Concave configurations (fig. 1) become critical when the slope being approached is such that the body overhang strikes the forward surface before the wheels. Convex configurations (fig. 2) become significant when the junction between two or more slope facets touches the undercarriage and the vehicle "bottoms out."

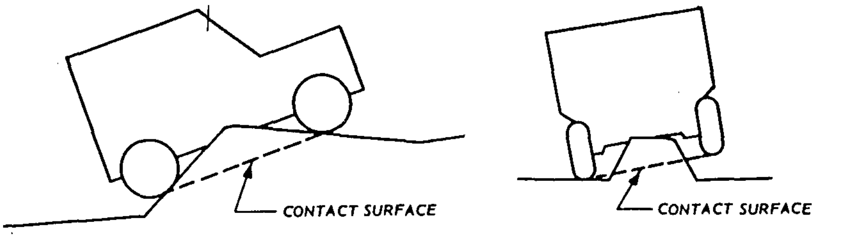

Fig. 2. Convex configuration

Unfortunately for the purposes of classification, each vehicle is responsive to a specific set of critical values. Critical surface geometry types related to the M38 jeep were determined, and the courses were then classified according to the frequency of occurrence of these configurations per terrain type.

The surface composition factor family is subdivided into soil type and soil consistency. A total of 21 samples of soils were taken at various locations on the test courses in order to determine soil type. Grain-size analyses were made, and the soils were then classified according to the Unified Soil Classification System. Soil consistency was based on the relative density and bearing strength of the uppermost layer of soil.

A meticulous sampling procedure was used to describe and classify the vegetation at Yuma. Fourteen structural types were identified on the seven test courses. Assemblages characteristic of each of these structural types were selected and sampled, using a standard circular area with a diameter of 180 ft. This area was estimated to be of adequate size to define the structural or gross physical characteristics of all plant assemblages.

Distributional diagrams for each of the sampled areas were then prepared. Illustrations of several different assemblages, ranked according to their relative degree of difficulty, and examples of distributional diagrams for each are shown in figs. 3 through 12. On the distributional diagrams each dot represents an individual plant, and the diameter of the dot is proportional to the crown diameter of the plant. Species or groups of species having similar growth forms are also identified by special symbolization. Using the distributional diagrams and large-scale aerial photography, the vegetation on the test courses was then classified as to the percentage of occurrence of a structural type within each terrain type.

It is now apparent that measurements of all terrain factors known or assumed to be producing or contributing to an effect on the test vehicle have been meticulously recorded. Each terrain type can now be identified by an array of number and letter symbols corresponding to the values derived for each factor or factor family.

In order to provide the necessary quantitative performance data, three important parameters or vehicle performance were selected: fuel consumption, traverse time, and actual path length compared with straight-line distance. Fuel consumed in traversing each terrain type was measured in a burette consisting of a 24-in.-long steel pipe; a number of these burettes were welded upright to a steel plate and mounted between the front seats of the jeep (fig. 13). Individual shutoff valves were attached to the burettes to permit the use of a single burette at one time. A dip stick was used to measure the fuel level in each burette before and after each traverse. The actual distance traversed within each terrain type was measured by a trailing bicycle wheel mounted to the rear of the jeep; wheel revolutions were recorded by a set of electrical counters installed inside the vehicle. Switches connected to each counter permitted the operation of a single counter at one time. A stopwatch was used to record the amount of time required to traverse each terrain type.

The same vehicle and driver, a constant tire pressure, and a standard

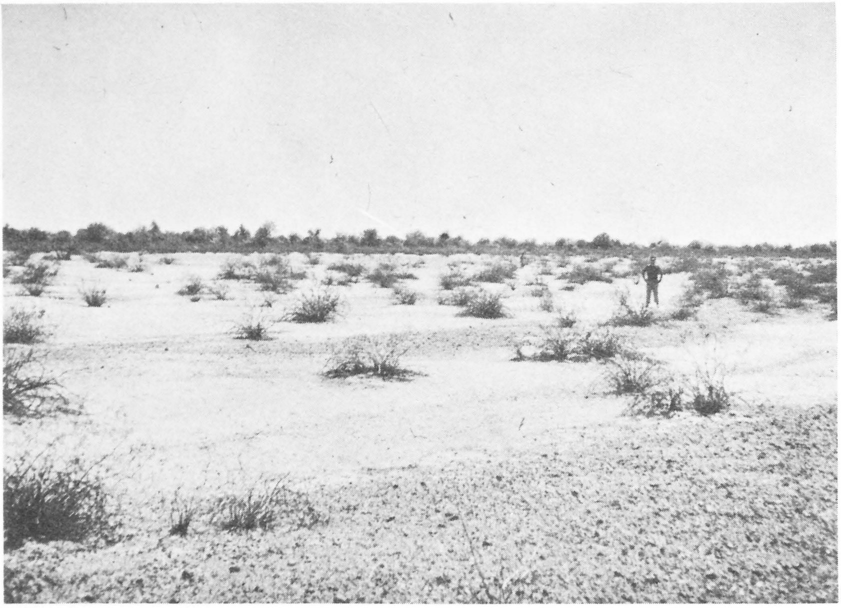

Fig. 3. A pure creosote assemblage located in a semiplaya area

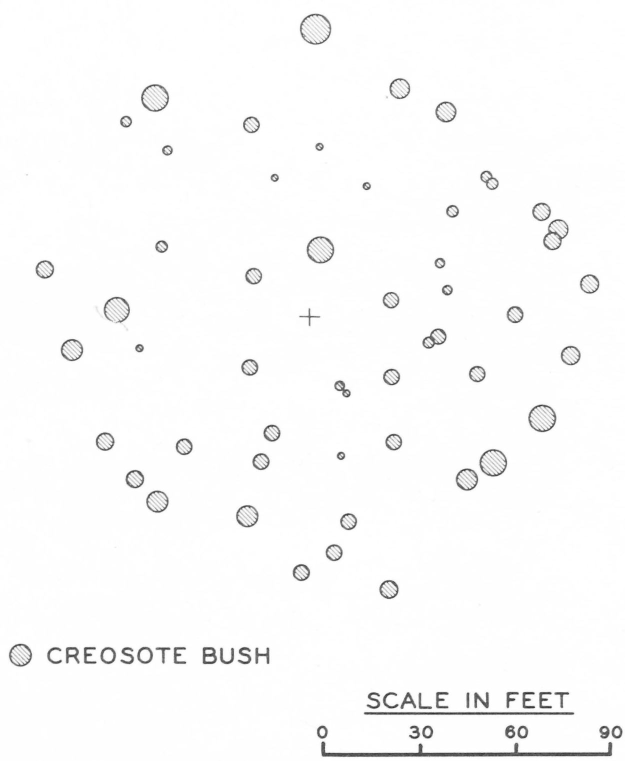

Fig. 4. Creosote assemblage

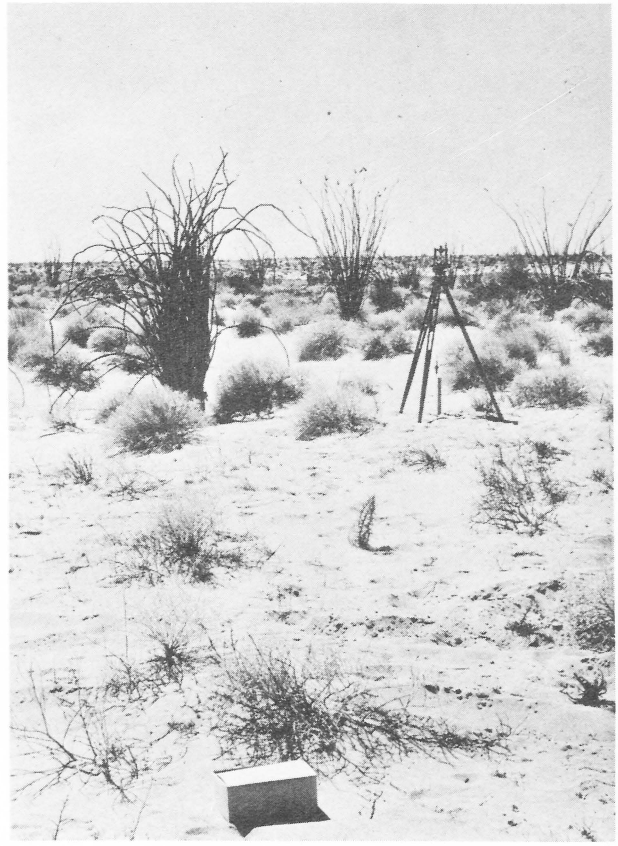

Fig. 5. A turret dune assemblage consisting primarily of low, rounded burro bushes, with some scattered creosote bushes and a few ocotillos, which are the tallest plants

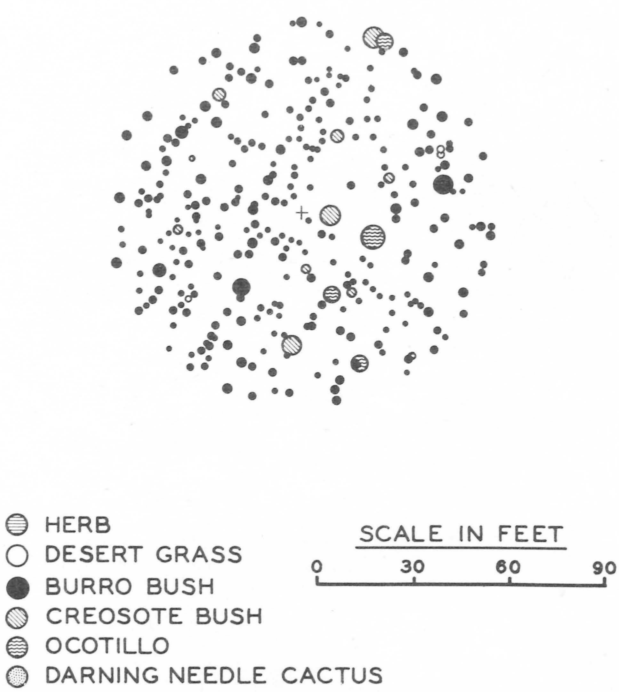

Fig. 6. Turret dune assemblage

Fig. 7. A complex assemblage in a medium-sized wash

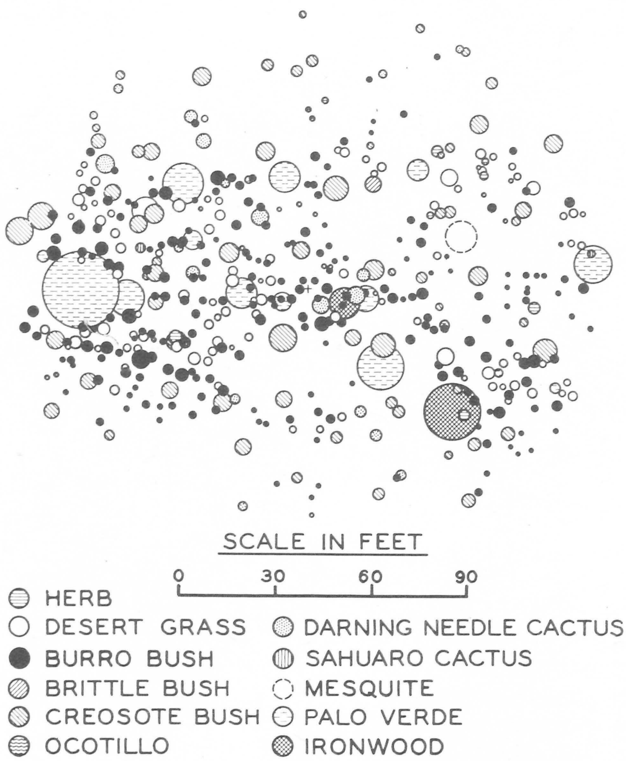

Fig. 8. Medium wash with sandy bed

Fig. 9. A dense assemblage lining the banks of a small wash in a slightly dissected semiplaya area

Fig. 10. Small wash with gravel bed

Fig. 11. One of the principal washes that drains part of the Yuma Test Station area

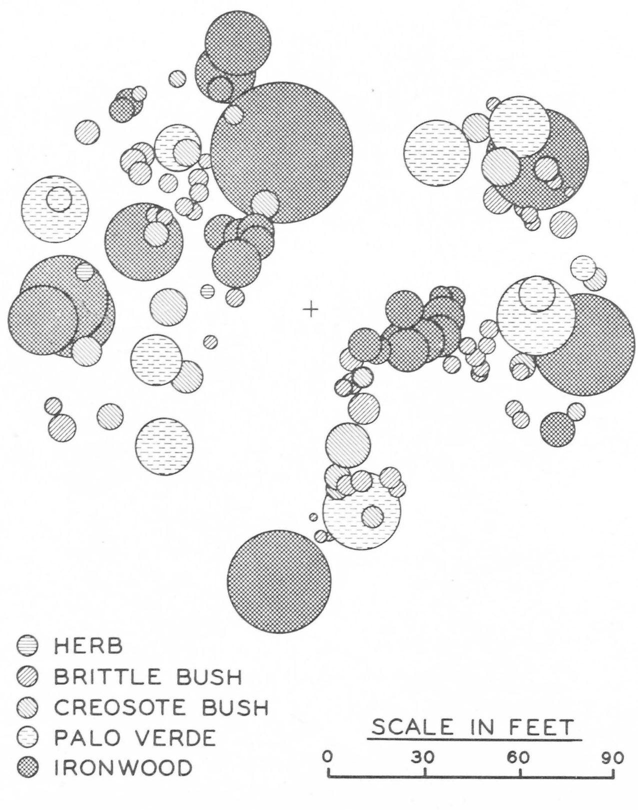

Fig. 12. Large wash with gravel bed

Fig. 13. The test vehicle and equipment used to record the various performance data

load of three persons were maintained throughout the testing program. Eight traverses, four in each direction, were completed over each course. No unnecessary stops were permitted over the entire length of the course. If stoppages occurred because of immobilization caused by the effects of the terrain, the location, stoppage time, and type of terrain condition causing immobilization were recorded. Tracking was not permitted. No stops were made at the boundaries separating terrain types; test apparatus was switched over when the vehicle crossed the boundaries.

Wind and temperature observations were recorded for each traverse. Wind velocity and direction were observed from a field recording station established at one end of each course. Wet and dry bulb temperature readings were taken with a sling psychrometer.

An analysis of the test results revealed that significant differences in performance of the test vehicle occurred frequently in the same terrain type. Although a number of inconsistencies in performance were believed to be attributable to changes in the skill of the driver, driver fatigue, and to microrelief, many variations could be attributed to terrain differences due to direction of traverse and to the angle at which various terrains were crossed. Steep slopes will inhibit movement more in one direction than in the reverse direction. Movement parallel to the drainageways was considerably easier than movement across the drainage channels.

All immobilizations were a result of one or more of four terrain factors: slope, soil consistency, critical surface geometry configuration, and vegetation. The effect imposed by vegetation, however, was that of limited visibility along scour channels, and no standard procedures are currently available for measuring this element. Conversely, adequate measures of the other three factors are available. A few of the various types of immobilizations which resulted from a combination of terrain factors are illustrated in figs. 14 through 16.

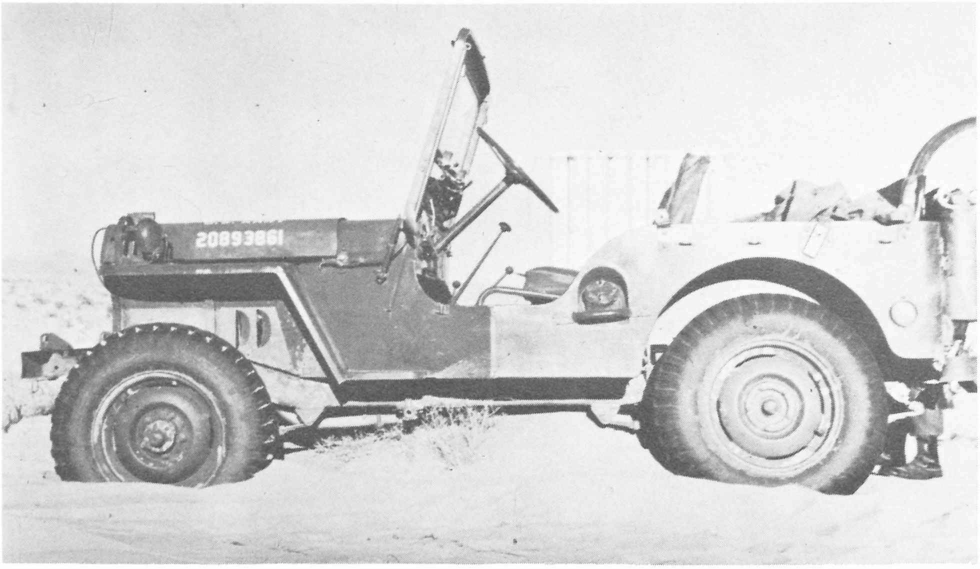

Fig. 14. The test vehicle "hung up" on a small turret dune. This immobilization was caused by a convex critical surface geometry configuration coupled with soil consistency

A statistical analysis of the test data revealed good correlations between each performance parameter and the combined terrain factors as described by the MEGA classification systems. Conversely, poor correlations between the performance parameters and individual terrain factors were obtained. Based on the results of this analysis, then, it can be concluded that it is a combination of all terrain factors that the vehicle senses, and no one terrain element of those considered can be eliminated from the terrain descriptions.

Fig. 15. The test vehicle "bottomed out" attempting to go down a steep, but shallow wash bank. Although the immobilization was a direct result of a concave configuration, vegetation lining the wash bank contributed to the condition by masking the steep bank from view

Fig. 16. This immobilization was the direct result of a concave configuration coupled with slope and loose soil. The rear of the vehicle has been wedged against the side of a V-shaped gully, and the vehicle could not obtain sufficient traction in the loose soil to climb the forward slope

Formulas have been developed through computer analyses of test data for predicting performance in terms of the three parameters in Yuma-type terrain for vehicles similar to the test vehicle. The statistical validity of these formulas has been proved by a test for significance using the analysis of variance method. However, the accuracy of the predicted values are yet to be tested in the field.

Principal findings of this test program were:

a. The MEGA classification system is apparently a valid semi-quantitative model of the terrain, at least for use in the analysis and prediction of cross-country mobility.

b. It is considered possible to predict performance of a vehicle in a given terrain on the basis of performance data derived from tests using a similar vehicle in another area, when the areas have been described as analogous by the MEGA classification systems.

c. The values obtained for each of the performance parameters are correlative with a combination of the terrain factors as described by the MEGA classification systems. That is, a purely analytical prediction of cross-country mobility is at least theoretically possible.

QUANTITATIVE TERRAIN MAPPING IN THE HUMID TROPICS, PUERTO RICO AND THE CANAL ZONE

by

William K. Dornbusch, Jr.[1]

Introduction

The purpose of the Quantitative Terrain Mapping Study in the Humid Tropics is to apply the Waterways Experiment Station (WES) terrain classification system, developed during the Desert Analog Project, to tropical environments. Previously the WES mapping system had been restricted to desert environments; it was not known whether it could be applied to map terrain conditions in other environments without major changes. In fulfilling the objectives of this study, the possibility of modifying the existing system to make it adaptable to tropical areas was not overlooked.

The humid tropics are defined as any land mass lying between the Tropic of Cancer (23°27' North latitude) and the Tropic of Capricorn (23°27' South latitude) having constantly warm temperatures and over 30 in. of rainfall per year. Puerto Rico and the Panama Canal Zone were selected as the areas to be mapped for the following reasons: (a) the availability of large-scale (1:20,000 and 1:25,000) topographic maps and aerial photographic coverage, (b) the abundance of published data, (c) the lack of political complications, and (d) the initiation of a terrain research project by the Area Evaluation Section and the Army Mobility Research Center, which would furnish considerable amounts of detailed information from selected localities.

At the beginning of the study, the terrain factors as used in the Desert Analog Study, and their mapping units with the exception of vegetation, were applied directly to Puerto Rico and the Canal Zone. These included the landscape evaluations and the ground factors: soil type, soil consistency, and surface rock. It was found that the mapping units indicating features of the landscape could be applied with almost equal utility

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to the humid tropics. Table 1 shows the units that were mapped in Puerto Rico and the Canal Zone. However, as might be expected, the soil mapping units used in desert areas were less suitable for use in the humid tropics. The abundance of rainfall, high humidities, and less daily range in temperature have resulted in the formation of certain soil types and soil consistencies in Puerto Rico and the Canal Zone that are not encountered at all in desert areas. The depth of soil is greater and areas of bare rock outcrops, mapped so extensively in desert areas, are rare. These conditions resulted in revision of the soil type and soil consistency mapping units and the elimination of the surface rock factor. The mapping of the vegetation factor is being undertaken by an Area Evaluation Section contractor.

Mapping Procedures

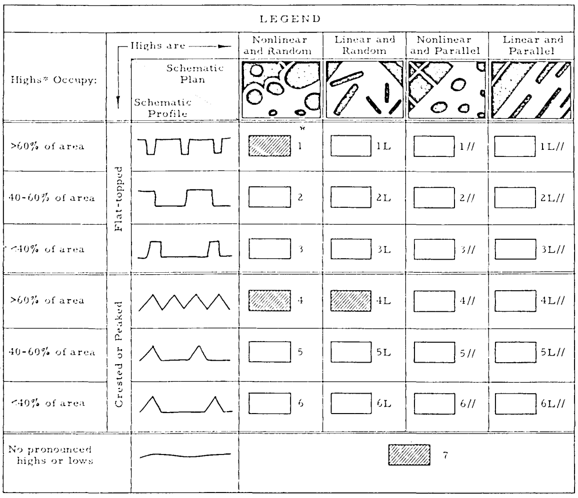
A landscape type may be divided into four measurable units: plan-profile, slope occurrence, characteristic slope, and characteristic relief. Prior to this study the accepted method of preparing the landscape map was to map each of these factors individually. The four factors were then superimposed to form the landscape map. However, during the initial phase of mapping these factors in Puerto Rico and the Canal Zone it became apparent that this method of preparation of the landscape map would be very time consuming and unnecessary. It was found that concurrent delineation of the four factors was feasible provided a certain sequence in mapping was followed. It was discovered that certain factor boundaries that occurred on the maps were either identical with other factor boundaries or were at least significant in their development. For example, certain slope unit boundaries defined the limits of plan-profile types while these plan-profile boundaries in turn furnished control for mapping slope occurrence and characteristic relief. As a result the following sequence was established for mapping the four factors: slope, plan-profile, slope occurence, and relief. The method used in preparation of these maps will be discussed in this recommended order.

Because the basis for the delineation of all the geometry factors is slope, it was only logical to map this factor first. To expedite mapping

Table 1

Geometry Factors Mapped in World Desert Areas and the Humid-Tropics (Puerto Rico and the Panama Canal Zone)

Plan-Profile



L indicates linearity of highs. A high is considered to be linear when its length is greater than 5 times its width.

// indicates roughly parallel arrangement of highs or aligned highs.

Occurrence of Slopes Greater than 10%**

1. The number of slopes steeper than 10% is less than 1 per 10 miles or such slopes are characteristically lacking
2. The number of slopes steeper than 10% ranges from 1 to 5 per 10 miles
3. The number of slopes steeper than 10% ranges from 5 to 20 per 10 miles
4. The number of slopes steeper than 10% ranges from 20 to 100 per 10 miles
5. The number of slopes steeper than 10% ranges from 100 to 200 per 10 miles
6. The number of slopes steeper than 10% exceeds 200 per 10 miles

Characteristic Slope

Flat: Characteristic slope between 0 and 2 degrees (approximately 0 to 3.5%)

1a. Between 0 and 1/2 degree (approximately 0 to 1%)

1b. Between 1/2 and 2 degrees (approximately 1 to 3.5%)

2. Gentle: Characteristic slope between 2 and 6 degrees (approximately 3.5 to 10%)
3. Moderate: Characteristic slope between 6 and 14 degrees (approximately 10 to 25%)
4. Declivitous: Characteristic slope between 14 and 26.5 degrees (approximately 25 to 50%)
5. Steep: Characteristic slope between 26.5 and 45 degrees (approximately 50 to 100%)
6. Precipitous: Characteristic slope greater than 45 degrees (greater than 100%)

Characteristic Relief

I. Relief in areas where the characteristic slope is less than 6 degrees (approximately 10%)

1. Characteristic relief between 0 and 10 ft
2. Characteristic relief between 10 and 50 ft
3. Characteristic relief greater than 50 ft

II. Relief in areas where the characteristic slope is greater than 6 degrees (approximately 10%)

4. Characteristic relief between 0 and 100 ft
5. Characteristic relief between 100 and 400 ft
6. Characteristic relief between 400 and 1000 ft
7. Characteristic relief greater than 1000 ft

Note: The mapping units of the occurrence of slopes were greater than 10%.
Characteristic slope, and characteristic relief factors were all mapped in Puerto Rico and the Canal Zone.
* Shaded blocks denote units mapped in the humid-tropics.
** Occurrence of slopes greater than 50% was mapped in desert areas.

of characteristic slope, which is the range of the most commonly occurring slope, a transparent template, fig. 1, was constructed with a series of circles so designed to equal the contour spacing at the maximum value of

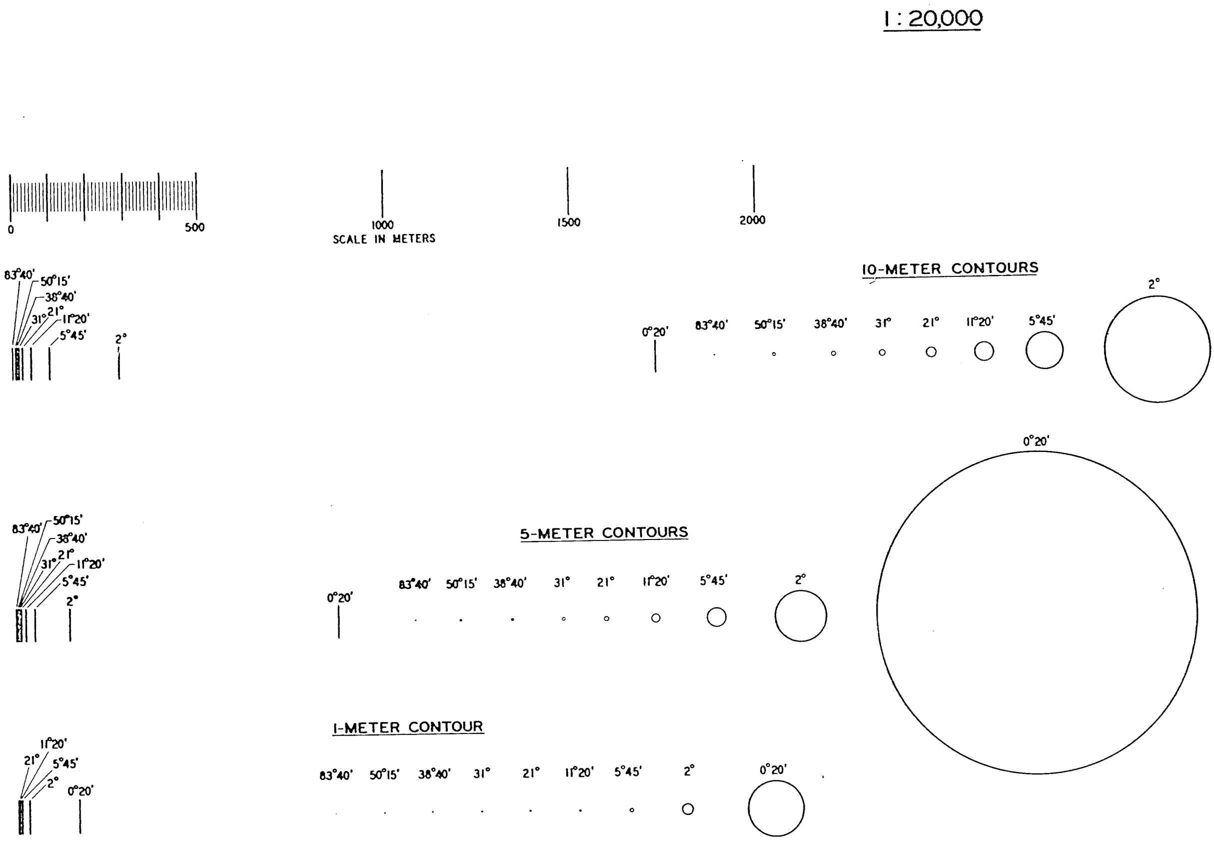


Fig. 1. Slope occurrence template for scale 1:20,000

each slope mapping unit. Using this guide, the various slope mapping units were outlined. Due to the enormous size of the area to be mapped at such large scales (1:20,000 and 1:25,000) and the final scale at which the maps were presented (1:75,000), a certain degree of generalization was necessary.

The plan-profile was the next geometry factor mapped. The plan-profile, or pattern of relief, is the spatial distribution and configuration in both plan and profile of topographic features. A topographic feature is an area bounded on two or more sides by slopes greater than 6 deg. Areas answering the criteria of topographic features were outlined from the slope map. Peakedness, areal occupancy, and degree of elongation or linearity of the topographic features were then mapped. Topographic features were mapped as flat-topped where the summit area was characterized by slopes less than 6 deg and occupied more than 25 percent of the basal dimension. Otherwise the features were mapped as peaked. Topographic features whose length was greater than five times the width were considered linear. The parallelism factor used in mapping desert areas is an indication of the alignment of topographic features and not a condition within the features themselves. Therefore, because the scale of mapping used in Puerto Rico and the Canal Zone was sufficiently large to outline the features individually, the parallelism factor was not mapped. Areas failing to meet the criteria of topographic features were mapped as anomolous, since they are not mappable with other plan-profile units.

The occurrence of slopes greater than 10 percent was measured within the boundaries established by the plan-profile units. The first step in mapping this factor was to select a number of sample points. A circular template with diameter one scale-mile and with a system of radiating lines oriented N-S, E-W, NE-SW, and NW-SE was placed at each point. The number of slopes greater than 10 percent intersected by each line were counted and the maximum value recorded at each point. After values had been recorded for a sufficient number of points within the plan-profile area, a modal occurrence class was mapped. Complete airphoto coverage of Puerto Rico and the Canal Zone was most useful in determination of this factor.

Two types of characteristic relief were mapped: Type I in areas where the characteristic slope is less than 6 deg, and Type II in areas where the characteristic slope is greater than 6 deg. Type I relief was measured as the modal vertical distance from interfluve crest to the immediately adjacent flow line, or in areas where drainage lines are poorly developed or lacking from summit to adjacent low.

The landscape factors delineated on the map were identified by an array of four symbols indicating mapping units of plan-profile, slope occurrence, characteristic slope, and characteristic relief, always designated in that order (fig. 2). A total of 33 landscape types were mapped in Puerto Rico and the Canal Zone.

As previously mentioned, the ground factor classification used in the desert studies needed considerable revision before use in Puerto Rico and the Canal Zone. After a survey of the available data and a study of

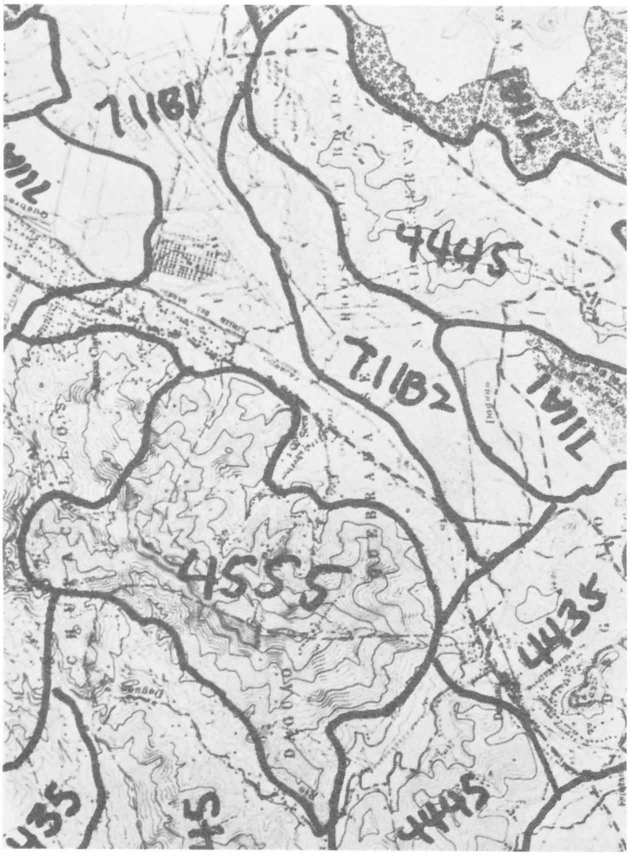


Fig. 2. Portion of work sheet, showing delineation of landscape types and designation of the factors

the intended applications of an acceptable humid-tropical soil classification, it was decided that the United States Department of Agriculture (USDA) system, while not purely quantitative in nature, was best suited to the needs of this study. The USDA system, essentially a textural breakdown of soils, required only that the soil series and phases occurring in Puerto Rico and the Canal Zone be grouped into 19 soil-type mapping units (fig. 3). Each USDA soil type has been correlated with the most nearly equivalent Unified Soil Classification System (USCS) soil type.

The development of the soil consistency units (table 2)

SOIL TYPE

1	CH	CLAY	11	SC, CL	SANDY CLAY LOAM
2	CH	SILTY CLAY	12	SM,SC	SANDY LOAM
3	CH,SC	SANDY CLAY	13	CL	STONY LOAM
4	CH	STONY CLAY	14	SM	LOAMY SAND
5	ML	SILT	15	SP, SM	SAND
6	CL	LOAM	16	GW, GP	FINE GRAVEL
7	CL	CLAY LOAM	17	PT	PEAT
8	ML,CL	SILT LOAM	18	MK	MUCK
9	CL	SILTY CLAY LOAM	19		ALLUVIUM
10	CL	STONY CLAY LOAM			

Fig. 3. Soil types mapped in Puerto Rico and the Canal Zone

Table 2

Soil Consistency

Classification Used in World Desert Areas	Classification Used in Humid-Tropical Areas
I. Homogeneous Consistencies: Soils unchanged to depths greater than 12 in.	Homogeneous Consistencies:*
A. Noncohesive: Materials in which the constituent particles do not adhere to each other	Noncohesive:
1. Loose: The ratio of voids to constituent grains is close to a naturally occurring maximum, i.e. the grains are loosely packed	Loose:
2. Dense: The ratio of voids to constituent grains is close to a naturally occurring minimum, i.e. the grains are closely packed	Dense:
B. Cohesive: Materials in which the constituent particles adhere to each other, either because of mutual attraction of the particles themselves, or because of the presence of a cementing material	Cohesive:
3. Soft (usually perenially wet): Little or no bearing capacity	Soft:
4. Firm: Moderate bearing capacity	Firm: Friable: Material crumbles easily Plastic: Material has remolding tendencies (pliable) Material has both plastic and friable horizons
5. Hard: High bearing capacity	Hard:
II. Layered Consistencies: Soils possessing two or more discrete layers within 12 in. of the surface.	Layered Consistencies:
A. Crusted surfaces: Surface crust may be either cohesive or noncohesive	
6. Hard, thin crust (commonly of cemented materials) overlying soft materials (commonly muck, ooze, or saturated silts)	
7. Hard crust (commonly of cemented materials) overlying noncohesive material (commonly sand or silt)	
8. Thin zone of firm materials over noncohesive material (most common development in areas of fixed dunes, with more or less continuous vegetative cover)	
9. Surface of closely fitted noncohesive pebbles or gravel overlying noncohesive materials (commonly sand or silt). (Such "desert pavements" also occur over bedrock or materials of firm consistencies, but this is less common)	
B. Noncohesive surface layer less than 12 in. thick	Noncohesive surface layer less than 12 in. thick
10. Dense layer within 12 in. of the surface	Firm layer within 12 in. of the surface
11. Hard layer within 12 in. of the surface (usually but not always caliche)	Hard layer within 12 in. of the surface (usually) caliche or hardpan)
	Cohesive surface layer less than 12 in. thick
	Hard layer within 12 in. of the surface
	Soil Consistency-Bedrock Associations: Areas where the parent rock is actually exposed, or lies at shallow depths
	Bedrock is within 12 in. of the surface
	Bare rock and stony soil
	Modifying Conditions: These are conditions that exist locally and are not to be considered as soil consistency units
	Plastic when wet
	Hard when dry
	Rock may be within 12 in. of the surface on steeper slopes
	Local rock outcrops and/or bouldery surfaces
	In certain areas it was found that two modifying conditions prevailed
	Local rock outcrops and/or bouldery surfaces and rock may be within 12 in. of the surface on steeper slopes
	Plastic when wet and hard when dry
	Plastic when wet and rock may be within 12 in. of the surface on steeper slopes
	Local rock outcrops and/or bouldery surfaces and plastic when wet

* Portions of the soil consistency classification common to both desert and humid-tropical areas are described in the desert classification.

Table 3

Soil Type

Soil Classification Used in World Desert Areas		Soil Classification Used in Humid-Tropical Areas
I. Soil-Rock Associations		
1. Areas characterized by a mosaic of bare rock and stony soils with a few scattered patches of coarse- and fine-grained soils. Bare rock and stony soils cover more than 90% of the area mapped		
2. Areas characterized by a mosaic of bare rock and stony soils with a few scattered patches of coarse- and fine-grained soils. Bare rock and stony soils cover from 50 to 90% of the area mapped		
3. Areas characterized by a mosaic of bare rock and stony soils with a few scattered patches of coarse- and fine-grained soils. Bare rock and stony soils cover from 20 to 50% of the area mapped	CH*	Stony clay:** Sample consists of 40% or more clay, less than 45% sand, and less than 40% silt and contains a large number of rock fragments larger than 10 in. in diameter
	CL	Stony clay loam: Sample consists of 27 to 40% clay and 20 to 45% sand and contains a large number of rock fragments larger than 10 in. in diameter
	CL	Stony loam: Sample consists of 27% clay, 28 to 50% silt, and less than 52% sand and contains a large number of rock fragments larger than 10 in. in diameter
II. Soil Associations		
Coarse-Grained Soils†		
4. Gravel: More than 90% of a typical sample consists of gravel		
5. Sand: More than 90% of a typical sample consists of sand	SP, SM	Sand: Sample consists of 85% or more sand; percentage of silt plus 1-1/2 times the percentage of clay shall not exceed 15%
6. Sand and gravel mixed with minor amounts of finer material: More than 50% of a typical sample consists of sand and/or gravel	GW, GP	Fine gravel: Sample consists of a mixture of sand and fine gravel mostly less than 10 in. in diameter
	SC, CL	Sandy clay loam: Sample consists of 20 to 35% clay, less than 28% silt, and 45% or more sand.
	SM, SC	Sandy loam: Sample consists of either 20% or less clay, with the percentage of silt plus twice the percentage of clay exceeding 30%, and 52% or more sand; or less than 7% clay, less than 50% silt, and between 43 and 52% sand
	CH, SC	Sandy clay: Sample consists of 35% or more clay and 45% or more sand
	SM	Loamy sand: Sample consists of at the upper limit 85 to 90% sand, and the percentage of silt plus 1-1/2 times the percentage of clay is not less than 15%; at the lower limit it consists of not less than 75 to 85% sand, and the percentage of silt plus twice the percentage of clay does not exceed 30%
Fine-Grained Soils		
7. Silt and clay with minor amounts of coarser materials: More than 50% of a typical sample consists of silt and/or clay	CH	Silty clay: Sample consists of 40% or more clay and 40% or more silt
	CH	Clay: Sample consists of 40% or more clay, less than 45% sand, and less than 40% silt
	ML, CL	Silt loam: Sample consists of either 50% or more silt and 12 to 27% clay, or 50 to 80% silt and less than 12% clay
	CL	Loam: Sample consists of 7 to 27% clay, 28 to 50% silt, and less than 52% sand.
	CL	Clay loam: Sample consists of 27 to 40% clay and 20 to 45% sand
	CL	Silty clay loam: Sample consists of 27 to 40% clay and less than 20% sand
8. Silt: More than 75% of a typical sample consists of silt	ML	Silt: Sample consists of 80% or more silt and less than 12% clay
9. Clay: More than 75% of a typical sample consists of clay		
10. Saline: A typical sample has a salt content of more than 25%; usually associated with silt or clay		
	Pt	Peat: Sample composed of dark brown to black, partially decomposed organic matter, commonly occurring in marshes and other wet areas
	MK	Muck: Sample composed of dark-colored soil that has a high percentage of organic matter, commonly occurring in wet areas
		Alluvium:†† Detrital deposits consisting of sand, silt, clay, gravel, and stones in varying percentages

* Each humid-tropical soil type has been correlated with the most nearly equivalent Unified Soil Classification System soil type.

** Grain size: Sand particles vary from 0.05 to 2 mm, silt particles from 0.002 to 0.05 mm, and clay particles less than 0.002 mm.

† Gravel particles vary from 76.2 to 4.76 mm, sand particles from 4.76 to 0.074 mm, silt particles from 0.074 to 0.0039 mm, and clay particles less than 0.0039 mm.

†† Alluvium is usually mapped in areas where there are insufficient data available to enable classification according to grain size.

was influenced strongly by the presence of existing soils data. With trafficability being the most important military activity under consideration at the time, it was decided to use the framework of the classification used in the desert areas. This stratification is based on the homogeneity or lack of homogeneity in the upper 12 in. of soil, this horizon being particularly meaningful from a trafficability standpoint. While the original framework of this classification was retained, it was found that certain of the units mapped so extensively in the deserts were not applicable in the tropics. By the same token, it was found that certain soil consistencies occurring in the tropics did not fit the desert classification. The resulting classification used in the humid tropic study has added those units apparently unique to the humid-tropical areas and deleted those units applicable only in desert areas. These relations are illustrated in table 3.

Conclusions

In summary, the classification system used in Puerto Rico and the Canal Zone to map landscape and the ground factors has proven successful. However, the fact has not been overlooked that refinements or revisions might be necessary when other humid-tropical areas are mapped. This is particularly true in areas where map coverage and other pertinent data are not available to the same degree that they were for Puerto Rico and the Canal Zone.

MOBILITY STUDIES IN HUMID TROPICS, PANAMA

by

Edward E. Garrett[1]

The U. S. Army Transportation Board has conducted three environmental tests in the Republic of Panama since 1960 which were designed to provide information on the operation of military vehicles in a tropical environment. The last two of these operations were attended by observers from the Waterways Experiment Station (WES). The first operation was known as Tropical Wet; the succeeding ones were designated Swamp Fox I and II. These operations were the responsibility of the Transportation Board which formed the nucleus and command agency for a combined team of specialists from the Technical Services, who studied the effect of the tropical environment on the operations or products of their respective services. The discussion at this time will be limited to Swamp Fox I and II since these operations were observed by staff members of WES.

Swamp Fox I

The mission of Swamp Fox I was "to conduct operations leading to improvement of difficult environment transportation capabilities." The "difficult environment" was defined as "tropical jungle, rainy season." Collateral objectives of the mission included service testing and evaluation of appropriate items of materiel.

In view of the Corps of Engineers growing interest in the terrain characteristics of tropical environments, WES was requested to send technical personnel to collect terrain data and to evaluate the effects of terrain characteristics on vehicle movement. The operational techniques developed at WES, specifically those used by the Area Evaluation Section (AES) and the Army Mobility Research Center (AMRC) under the "Military Evaluation of Geographic Areas" (MEGA) project, for the description and classification of related groups of terrain factors--vegetation, soils, and

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hydrologic characteristics--were to be employed by these observers. Two observers chosen from the AMRC staff were consequently given a brief period of training with the AES to familiarize them with the terrain descriptive systems developed by the Section. Limitations on time and personnel, and the fact that the Swamp Fox operation was set up as a tactical exercise, with little allowance made for the relatively time-consuming methods that must be used to make detailed quantitative measurements of the individual terrain factors, militated against the acquisition of any large amount of information. Thus, under the circumstances, the methodology available for measuring surface geometry could not be employed and consequently was given no consideration. Soil characteristics were measured at only 55 sites, and vegetation was studied in detail at only 16 locations.

The test program outlined for Swamp Fox I provided for a route which was to follow the projected line of the Pan-American Highway from its present terminus (fig. 1). Mechanical breakdowns as well as terrain problems

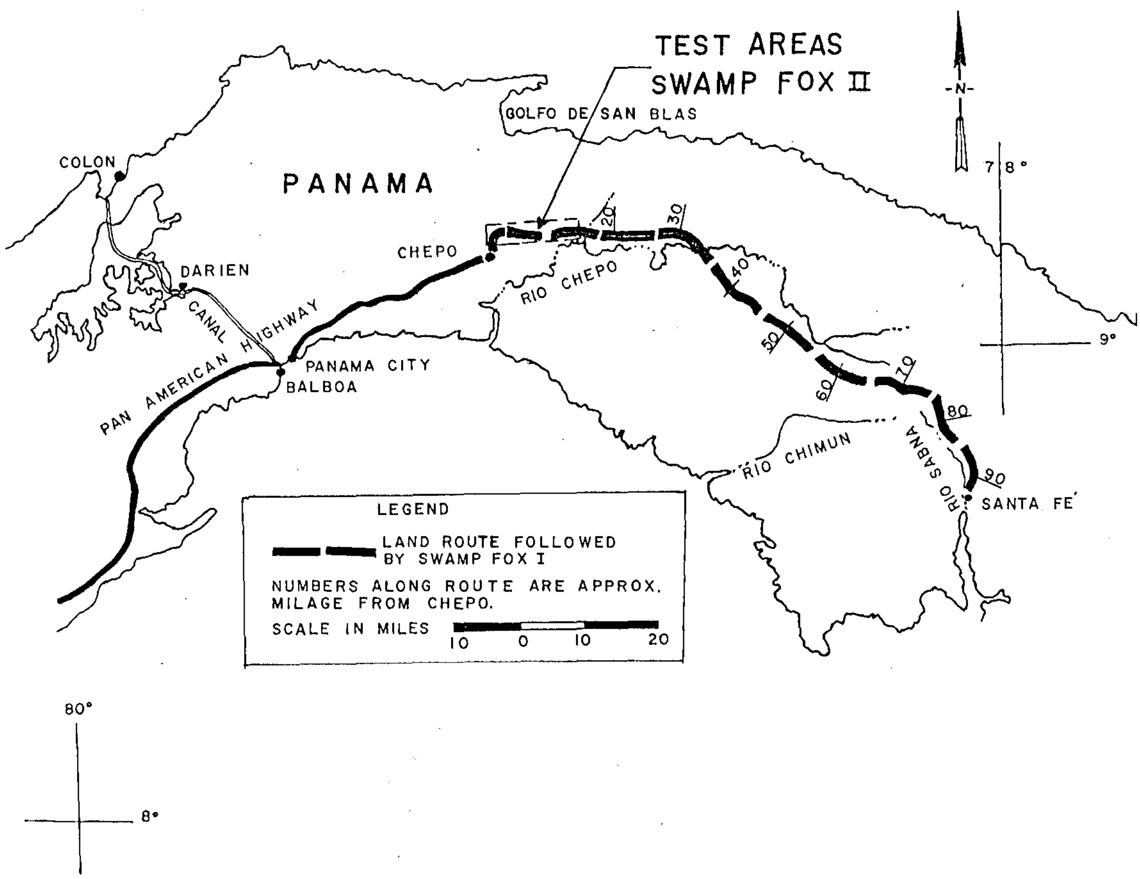


Fig. 1. Location map, Swamp Fox I and II

arising along the way prevented the completion of the planned course, and the exercise was finally terminated at Santa Fe, 150 km from the starting point. The test was begun with 14 self-propelled and towed, wheeled and tracked vehicles. These included commercial and standard military models. Only five vehicles, four tracked and one wheeled, completed the course. For the entire operation the vehicles followed each other on a narrow trail, in some cases tracking and at other times straddling the preceding tracks.

In forest areas where the spacing of the vegetation would cause difficulty, a sufficient number of trees were removed to allow passage (fig. 2).

Fig. 2. Cleared path through dense vegetation, Swamp Fox I

Some data on hydrologic characteristics were secured, consisting of river channel cross-section shape and width, as well as type of bottom material. Water depth and velocity were also recorded.

Detailed measurements of vegetation were made at 16 sample sites, consisting of circular plots from 15 to 46 m in diameter. Diagrams of the vegetation structure were then prepared showing the woody plants of size large enough to produce significant effects on vehicular movement.

At each site at which soil-strength measurements were made, topographic data were taken in a subjective fashion, the site being categorized as floodplain, upland flat, upper slope, middle slope, or lower slope.

Most of the data secured by the team from WES related to soil-strength measurements. Since standard WES procedures for conducting self-propelled type trafficability tests (i.e. 50 repetitive passes over a 100-ft lane) could not be carried out, one-pass traffic was used to evaluate vehicle performance. The 55 sites were considered to be representative of the soil variations occurring along the route. The soil data obtained included cone index, remolding index, density, and water content. Samples were taken for laboratory determination of soil type.

Analysis of the hydrologic data revealed the following generalizations. The channel cross sections of the larger streams were quite uniform, being roughly trapezoidal with generally wide, nearly flat bottoms; the banks were steep with slopes ranging from 60 to 100 percent. Fig. 3 illustrates one of the larger rivers being forded. Note that in this case the water depth produced an immobilization. The steepness of the bank on the far side is very evident.

Fig. 3. Fording major stream, Swamp Fox I

Stream velocity was not a major deterrent except in one or two places. Entrance and exit in many cases required winching procedures. The dry gullies presented a much more serious problem because of the narrow bottoms, frequently requiring such engineering effort as crib bridging.

The vegetation along the route consisted of two very broad types, forest and grassland. The forest of this area is in all cases second growth with a varying proportion of tall trees and understory vegetation, due to the practice of shifting agriculture. Grassland offered much less deterrent effect to vehicular passage than the forested areas, where the physical obstructions to movement, combined with decrease of visibility, reduced speed and maneuverability.

The soils encountered were sufficiently strong at nearly all places to support one-pass traffic. At some localities moderate rutting occurred; however, no vehicle immobilizations were recorded on level ground as a sole result of soil strength. Surface slipperiness frequently caused trafficability problems on slopes under wet conditions.

The conclusions derived from the WES team's observance of Swamp Fox I can be summarized as follows:

- a. Soils were generally strong enough to support the vehicles tested, though in some areas soil strengths would have been insufficient for conventional wheeled vehicles.
- b. A serious impediment to cross-country movement was presented by those gullies which were narrow in proportion to depth. Engineering effort was required in many cases to negotiate these.
- c. Steep slopes caused the most commonly occurring serious impediment to cross-country movement.
- d. Vegetation was an impediment to movement in the forested areas, where some engineering effort was required to clear trails.

The results of WES participation in the Swamp Fox I operation are reported in detail in Technical Report No. 3-609, August 1962, published by WES.

Swamp Fox II

The Transportation Board began planning for the second Swamp Fox exercise immediately on conclusion of the first. It was obvious that the most serious hindrance to significant research dividends had stemmed directly from the manner in which Swamp Fox I had been organized. In essence, the project amounted to a caravan of vehicles traversing terrain that had been studied in advance only in the most general way. The caravan had been pushed through as rapidly as possible to adhere to a set timetable. This clearly allowed only the most cursory observations to be made of the environmental factors. That so many observations could have been made and recorded under the circumstances is a tribute to the dedication of the people concerned in the test program.

On the basis of experience with Swamp Fox I, it was decided to conduct Swamp Fox II from a base camp (fig. 1). This would enable the scientific personnel to select test courses in nearby areas which would be chosen to characterize the basic terrain configurations. It was felt, and certainly justifiably, that this approach would make it possible to exert much more control over the data collection programs and enable the acquisition of more complete scientific and engineering data on the overall operational environment.

A large scientific party was assembled under the cognizance of the Director of Army Research. This group carried out evaluation of equipment and studied the environment and its effect on men and materiel. The Transportation Board interests were concentrated on a "go - no-go" evaluation of some 30 wheeled and tracked vehicles. The scientific party, during this evaluation period, sought to measure vehicle performance and terrain factors from an engineering standpoint with more sophisticated instrumentation, such as a dynamometer, bevameter, sheargraph, etc., than had been available in the previous year.

Since Swamp Fox II was to be held in a portion of the area covered by Swamp Fox I which had been observed the previous year by WES personnel, and also because of prior commitments of qualified personnel, WES participation was limited to a two-week period.

The test plan ultimately adopted called for vehicle-terrain relations to be studied in four types of environment deemed to be representative of tropical terrain. Very little reconnaissance study had been made on the specific area chosen for Swamp Fox II other than that Swamp Fox I had passed through it. It was planned that the base camp would first be established in an area of level grasslands where appropriate testing would be done, after which the camp would be moved into a canopy-forest area. However, on reaching the first site, the party found that movement of some of the vehicles onto the next projected site could not be readily accomplished. Hence, it was decided to utilize the first area as a point from which both grassland and canopy-forest environments could be reached. Localities considered representative of these terrains were then selected on the basis of a hasty reconnaissance. The camp was located on a low terrace of the Rio Terable adjacent to the projected Pan-American Highway near the village of El Llano.

The scientific personnel were divided into several testing and survey teams. A large group from Wilson, Nuttall, Raimond Engineers, Inc., under contract to the Transportation Board, included teams responsible for cross-country mobility and trafficability testing, soil testing, topographic mapping, and collection of ecological and taxonomic vegetation data. A group from the U. S. Army Tank-Automotive Command conducted drawbar-pull tests and obtained bevameter data. Several individual specialists in forestry, botany, etc., under contract to various participating organizations, carried out studies and observations in their respective fields.

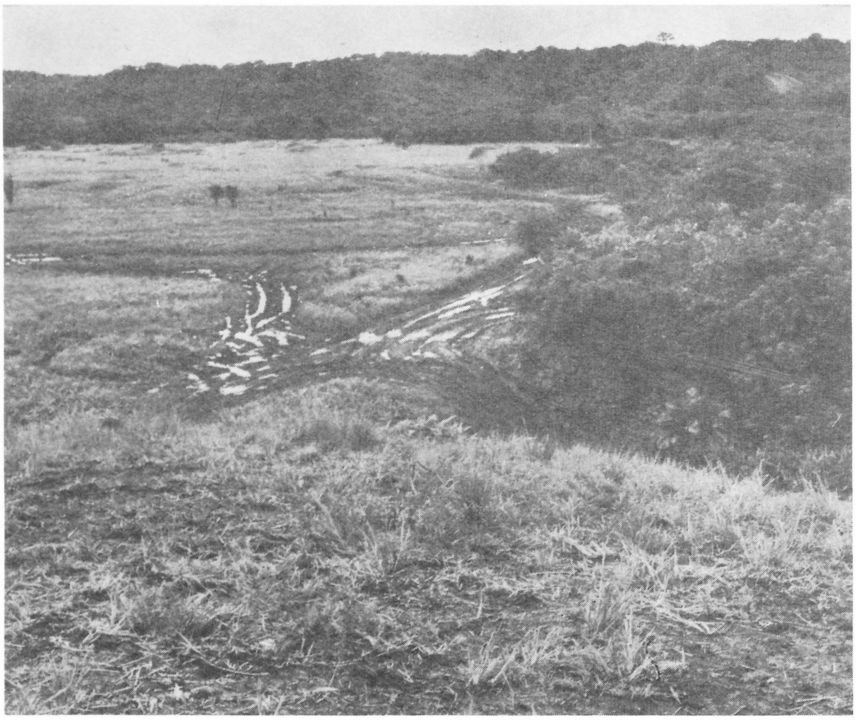


Fig. 4. Grassland test area, Swamp Fox II

The area chosen for the "lower grassland" tests was located on an alluvial floodplain back of the natural levees of the Rio Bayano. Fig. 4, taken after the test program had been completed, shows the general aspect of this test area. Rutted areas are clearly visible. It was a low, open surface covered with grass 30 to 60 cm high. On it were several drainageways with shallow running water. Entry and exit slopes on these channels ranged from 20 to 50 percent. Studies performed in this area were cross-country and trafficability tests, and drawbar pull.

The cross-country tests were conducted on a course approximately 15 m wide and 1200 m long. Some of the small wheeled vehicles had difficulty in level areas, but in general the larger wheeled and the tracked vehicles encountered little trouble. All vehicles had difficulty in crossing the drainageways. A reference vehicle was run through the test course before and during tests of other vehicles to determine the effects of deterioration of the test course under traffic. Cone indexes and soil samples were taken before and during the test runs.

Several multiple-pass trafficability tests were conducted with five wheeled vehicles and one tracked vehicle. All but two of the vehicles completed 50 passes. Cone index determinations were made before and during the test runs. The rating cone indexes for each test were greater than the vehicle cone indexes. The most serious trafficability problem was encountered in the motor pool parking lot, illustrated in fig. 5, where the soil became rather thoroughly remolded. For some reason, no data were collected in this area.

Fig. 5. Remolded soil in motor pool parking lot, Swamp Fox II

The second area chosen for testing was designated "Canopy-Forest." A test course approximately 1200 m long, in the form of a loop with both ends on the highway, was prepared under the canopy by clearing vegetation, including some trees, to make a course approximately 6 m wide. In some places small logs were left, but generally the vegetation was cleared down to soil and litter. Five small streams were crossed by the test course; approach slopes ranged up to 44 percent, and maximum water depths up to 50 cm. The soil was quite strong, with cone indexes averaging 120 to 140 at a depth of 15 cm. No wheeled vehicles successfully negotiated this course without help (self-winching in some cases) and only a few tracked vehicles passed over the course without immobilization. In nearly all cases the cause of the immobilization was the occurrence of steep slopes at the stream crossings, or a change of direction coincident with slope, or the occurrence of surface slipperiness in conjunction with the other factors. Cone indexes at points of immobilization were between 60 and 100. The course became progressively worse with traffic as the surface became more rutted and rains saturated the loose soil. The surface soils were generally dark organic clay silts or silty clays of low plasticity, which contributed a large degree of slipperiness to the slopes.

Fig. 6. Trailbreaker on test course, Swamp Fox II

Scenes on the test course are shown in figs. 6-9. In fig. 6, the two-wheeled Trailbreaker approaches the crest of one of the slopes; fig. 7 shows a power wagon crossing the stream where crib-bridging had been resorted to; and figs. 8 and 9 show a power wagon negotiating a slope by a self-winching operation.

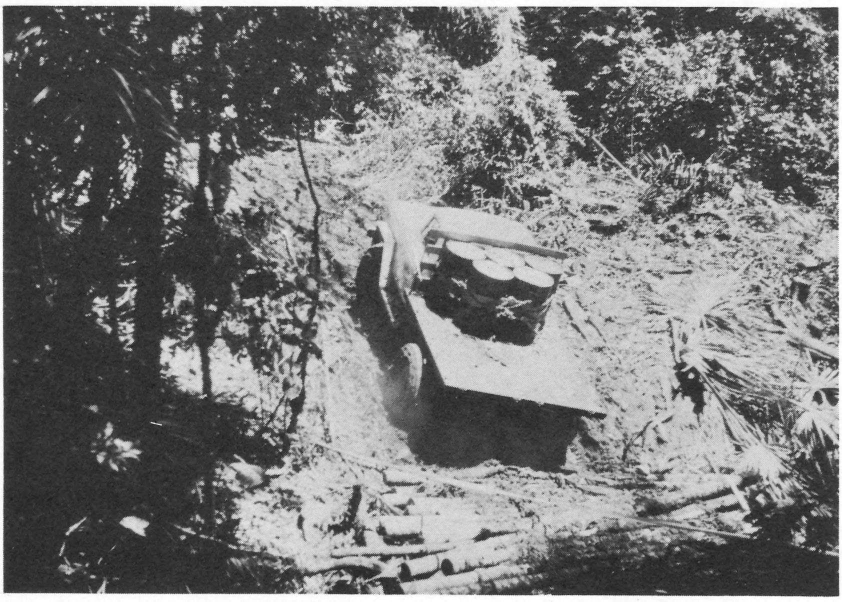


Fig. 7. Power wagon crossing a stream on crib-bridging, Swamp Fox II

Evaluations of performance were based mainly on the time required to traverse the test course. Observers were stationed at all stream crossings, and at the most difficult points along the course, to describe actions of the vehicles at these stations. Soil trafficability data were taken periodically during the test period.

Fig. 8. Power wagon negotiating a slope by self-winching, Swamp Fox II

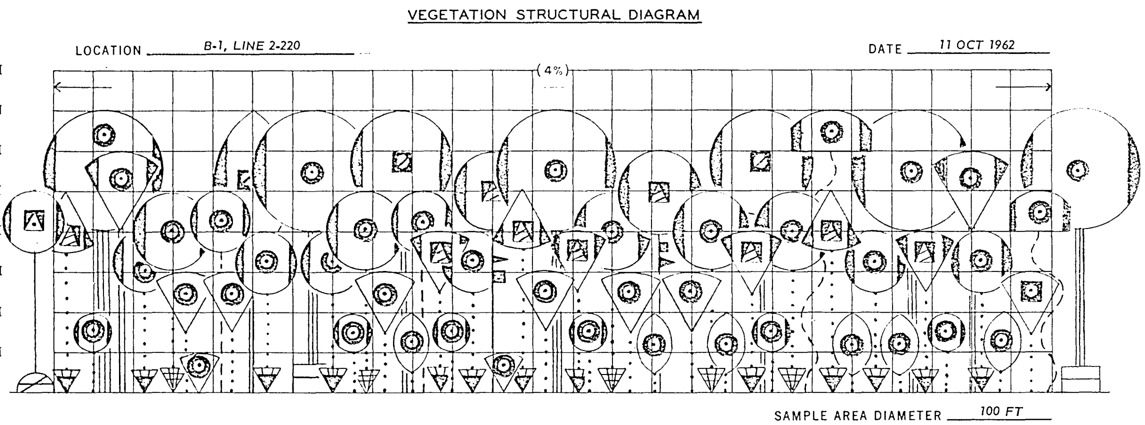
Fig. 9. Same power wagon shown in fig. 8, completing its self-winching operation

Drawbar-pull tests were conducted in a cleared area adjacent to the highway and the test course. Some bevameter data for the determination of soil shear strength were collected here as well.

Since it was apparent that the test course under the forest canopy was in no way a test of the effects produced by vegetation, the WES observers suggested that a test be conducted through undisturbed forest in such a manner that the only impediment to vehicular movement would be the vegetation itself. The suggestion was accepted, and courses were laid out. No slopes capable of significantly affecting vehicle performance were encountered, and the soil was sufficiently firm to present no impediment. Three courses were delineated, each about 50 m wide and 300 m long. Six vehicles were taken over the course, each making one pass in each direction. The vehicle performance was evaluated on the basis of elapsed time and measurements of path elongation imposed by the vegetative obstacles. It was noted that the smaller vehicles as well as the larger ones consistently knocked down trees with stem diameters up to 7.5 cm, and only rarely were stems of larger diameter pushed over. Indications thus seemed clear that this diameter represents a significant point in vegetation measurements as related to vehicle mobility. Fig. 10 shows one of the small tracked vehicles (the Spryte) traversing the course; fig. 11 is a view of the vegetation site sampled on the course; and fig. 12 is the vegetation structural diagram of the same location. (A difference in the symbols employed in this diagram from those now in use is evidenced. The reason for this is that the vegetation system is not static; it has changed quite radically since this diagram was made.)

Fig. 10. Spryte traversing the through-forest course, Swamp Fox II

Fig. 11. The vegetation sample site on the through-forest course, Swamp Fox II



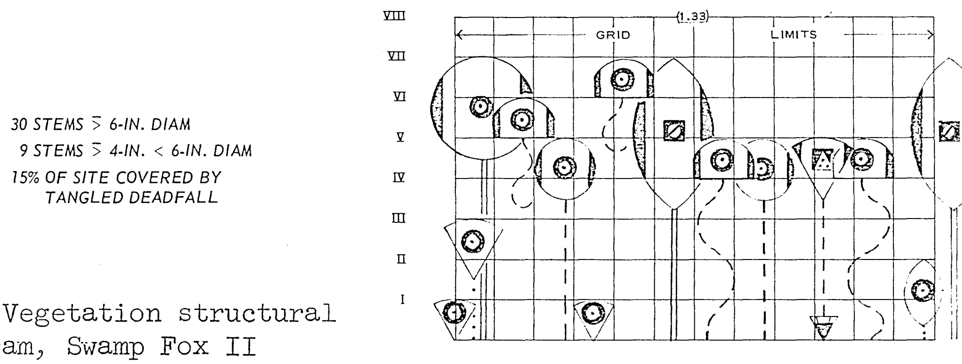


Fig. 12. Vegetation structural diagram, Swamp Fox II

A summary of the results of this test includes several significant points. Path elongation factors ranged from 1.2 to about 1.4 for the various vehicles. Speeds were very sharply reduced, in most cases to less than a walking pace. The most significant obstacles were stems over 7.5 cm in diameter, free-hanging vines, and fallen tree trunks. The latter, it should be noted, are placed in the microgeometry factor family. Tree spacing was less critical for the tracked vehicles than for those with wheels. Limitations on visibility magnified the effects of the physical obstacles. Other hazards noted were thorny vines and the presence of stinging or biting insects.

In order to supplement data from the grassland and the "canopy" testing areas, a third area designated as "upper grassland" was selected near the base camp, which combined steep slopes and grass cover. Vehicle tests were conducted during and immediately after heavy rains. The slopes ranged up to 55 percent. The grass aided vehicular traction, and once it was penetrated by wheel action, immobilizations were imminent. Cone indexes averaged about 180 at a 7.5-cm depth and 200 and 300 at the 15-cm depth.

The river-crossing tests were conducted subsequent to the departure of the WES observers, and no data from this test series are presently available. The operation was carried out on the Rio Momaní near the village of Chepo. The tests utilized vehicles equipped with flotation gear at a crossing site where the river is about 40 m wide, with depths of 1 to 2 m and a current velocity of 0.3 to 1.5 m per sec. It appeared that the major obstacle here would be the entrance and exit banks where the slopes, which ranged to approximately 70 percent, exceeded the gradeability of the vehicles. Accounts of the test results, verbally received at a later date, indicated that this was the case, and that all vehicles involved required some type of extraneous engineering aid in order to negotiate the banks.

Conclusions

In view of the experience gained to date in the testing of the effects of environments on vehicle performance, it is suggested that future tests be conducted with the following considerations in mind:

a. An adequate amount of time be made available prior to testing so that scientific and engineering teams can properly describe and evaluate the environmental conditions, and select test areas and courses which can thereby be established as characteristic of large and militarily significant regions.

b. The general area selected should include a number of significant environmental variations so that tests can be conducted against several ranges of values of environmental factors, thus providing data which might be extrapolated with some confidence to areas in which no tests have been conducted.

c. The tests themselves should be conducted with only a few, very carefully chosen vehicles or items of materiel. The choice should be made on the basis of fundamental variations of configuration, size, or mechanical principle. Exhaustive tests of a few such vehicles, conducted under a wide variety of conditions, are likely to provide far more usable data on cause-effect relations than a series of incomplete tests on a large number of vehicles.

d. Instrumentation of all pertinent aspects of vehicle performance should be included, so that records of all attributes and variations of performance could be examined. At the very least, measurements of performance should include fuel consumption, elapsed time, and total distance traveled. It would also be of value to record the vertical and horizontal accelerations in both the driver's and the cargo compartments. It is clearly as important to secure quantitative information on the response of a vehicle to the terrain as it is to measure and analyze the causative elements of the environment. To evaluate cause-and-effect relations, both factors are of equal importance.

APPLICATION OF ENVIRONMENTAL STUDY TECHNIQUES AND INFORMATION TO AIRFIELD CONSTRUCTION EFFORT DETERMINATIONS

by

Richard G. Ahlvin[1]

Findings of the Army Tactical Mobility Requirements Board, which was convened by the Secretary of Defense under the direction of General Howze, have placed increased emphasis on air mobile operational capabilities. In turn, the emphasis on air mobile capabilities places emphasis on airfield needs to support the airline-of-communication which is inherently required.

In response to these needs, the assistance of the Waterways Experiment Station has been mobilized in conducting several studies of the construction effort necessary to produce the airfields that are required to support typical military needs.

The fundamental problem involved the conversion of standard terrain intelligence data into quantitative measures of those properties of the terrain which would most significantly affect the construction of airfields, followed by the development of a mathematical relation between those factors and the effort which would be required to construct an airfield of specified characteristics. With such a relation established, it is relatively easy to estimate by purely analytical methods the amount of time required by a standard military construction unit to build an airfield in any part of the globe. Thus, the quantification of terrain factors, which is a major component of the "Military Evaluation of Geographic Areas" (MEGA) project, has been specifically applied to selected world areas in such a way as to yield quantitative estimates of construction effort. The assignment of utilitarian quantitative values to these factors was achieved despite the fact that presently available terrain information is largely qualitative in nature. The translation from qualitative to quantitative description was achieved by a mechanism analogous to, and derived from, the

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system of landform-landscape ties developed for the Desert Terrain Analog study (Broughton; "Desert Terrain Analog Study," pp 43-51).

In addition to the necessity for quantifying the various factors delineated above, it was also necessary to develop quantitative analytical expressions representing the interrelations of the various factors. This was necessary to permit extensions to construction effort in meaningful units.

This appears to be the first instance of an essentially completely analytical exploitation of terrain intelligence information to the solution of a specific problem in which the major independent variables were terrain or other environmental factors. More detailed and quantified assemblages of terrain information, coupled with a more precise knowledge of the correlations between construction effort and specific terrain situations, will greatly improve the precision of the estimates. However, the basic technique appears to be extremely useful even with the existing qualitative terrain intelligence as input construction effort.

These construction effort studies represent a technique which, in addition to further airfield construction effort applications, has application in other areas such as road networks, railroads, cross-country movements, etc. Reported results are being very well received by military planners.

VEGETATION DESCRIPTION FOR MILITARY PURPOSES

by

Eugene E. Addor[1]

The term "vegetation" encompasses a tremendous diversity; so also does the term "military activities." When the two are combined in an attempt to describe or analyze vegetation in terms of its effect on military activities, the complexity seems almost overwhelming.

How, then, should the problem be approached? After some study, the most logical method appeared to be to attempt the construction of a system for measuring and recording those features of any vegetation assemblage which might conceivably influence any military activity. The requirements of such a system were postulated as follows:

a. It must have predictive value. This implies that it must be universally applicable, either directly or by adaptation; that it must yield consistent results wherever and by whomever applied; and that it should be entirely objective and quantitative.

b. It should include all attributes of the vegetation which are known to, or conceivably could, exert an effect upon any military activity, whether or not those attributes are readily susceptible of quantitative analysis. It is a requirement of the system that a procedure be developed which will render them susceptible, if necessary.

c. It should be designed such that any combination of effect-producing factors could be extracted and evaluated without reference to any other factor, a requirement imposed by the fact that the different activities will be affected differently by different factors.

d. It should be simple, easily learned, and based upon an uncomplicated, rapidly executed sampling technique, since it is not anticipated that all military analysts will be trained botanists, and since the analyst may at times be working under duress of time and/or harassment.

Of the several approaches to the problem of vegetation description and classification, the advantages, for the present purpose, of the physiognomic approach are immediately apparent. Physiognomic description

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depends not at all upon floristics, but upon the outward, superficial appearances resulting from the life forms of plants; i.e. they describe the physical attributes of the vegetation. It is manifest that these are the attributes influential to most military activities.

Of the several physiognomic systems which were investigated for possible utility, that used by Dansereau appeared to have the greatest promise. The scheme described in this paper is an adaptation and extension of his work.

Those attributes of vegetation which were thought to have potential military significance, and therefore were selected as prime parameters for this system are:

a. Growth form
b. Height
c. Coverage
d. Stem characteristics
e. Branching habit
f. Root habits
g. Foliage characteristics
h. Armature
i. Distribution
j. Stem spacing

Each of these parameters is assigned a basic symbol, which is modified to indicate prescribed class intervals, or quantitative values. This symbol system is shown in Appendix A to this paper.

The parameter symbols can be assembled into total plant symbols, each of which represents a given association of parameter classes, and the plant or plants which it represents are referred to as a structural element. An example of how these symbols are assembled into a total plant symbol is illustrated in Appendix A.

Certain of the parameters, such as height, stem diameter, leaf size, etc., are represented in nature by continua and are readily amenable to quantification; the only problem relative to them is the determination of useful class intervals. Other parameters, such as leaf texture, stem hardness, etc., can readily enough be rendered into at least subjective class intervals, the only problem being establishment of adequate definitions.

Once the class intervals are assigned, any plant in the world is necessarily capable of being identified as a structural element in terms of these parameters. Then, any vegetation sample in the world should be amenable to description in terms of the structural elements which are present therein. (In this case "none of these" is included as a class interval, and a plant entirely characterized by "none of these" would not be recorded, i.e. it would be considered irrelevant to the description.) It is to be emphasized that the "structural elements" are independent of species definition, as explained in the example in Appendix A.

After the field data are collected, they are transcribed into the total plant symbols, and these are arrayed against a grid on which are quantified the heights and coverage values. Such an array, called a structural diagram is a semipictorial device intended to convey a visual impression of a plant assemblage while also providing a graphic record of the quantitative data pertinent thereto.

Figs. A1 through A16 illustrate some plant structures, and how they are interpreted in terms of this system.

The question is often asked why a photograph would not suffice. We agree that photos, especially stereophotos, are indeed useful adjuncts to the data, but we are convinced that alone they are inadequate for several reasons:

a. The scale in a photo varies from foreground to background, and from center to margins. Even with a scale of some kind included in the photo, it is impossible to quantify from it. Consider the photo shown in fig. 1: How tall is the tree in the background? How distant is it from the vicious little shrub in the foreground?

b. Photos do not show small but significant features. In the photo of an ocotillo (fig. 2), the spines are not at all in evidence. The assemblage shown in fig. 3 looks dense. More significant than its density is the fact that it is a plant which in effect is very like barbed wire, at least against personnel. Saw brier is the predominant plant in this assemblage; compare fig. A17, which is honeysuckle, and is without spines.

c. Photos present an inadequate picture of the total assemblage. In fig. 4, the spines are conspicuous but the total assemblage is entirely ignored.

There are two important aspects of vegetation which have so far

Fig. 1. The included scale does not permit actual measurement of distances or heights

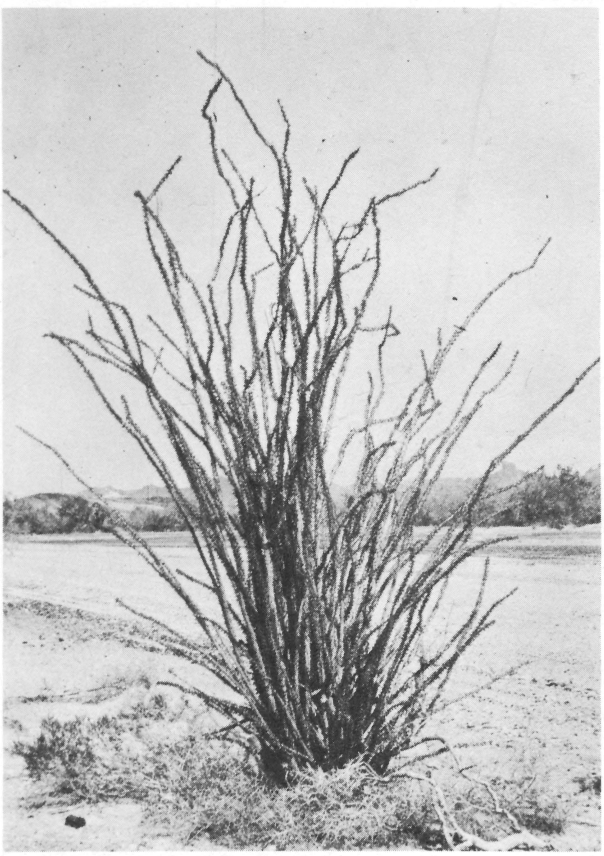


Fig. 2. The general habit of the ocotillo is illustrated, but the long spines are not evident

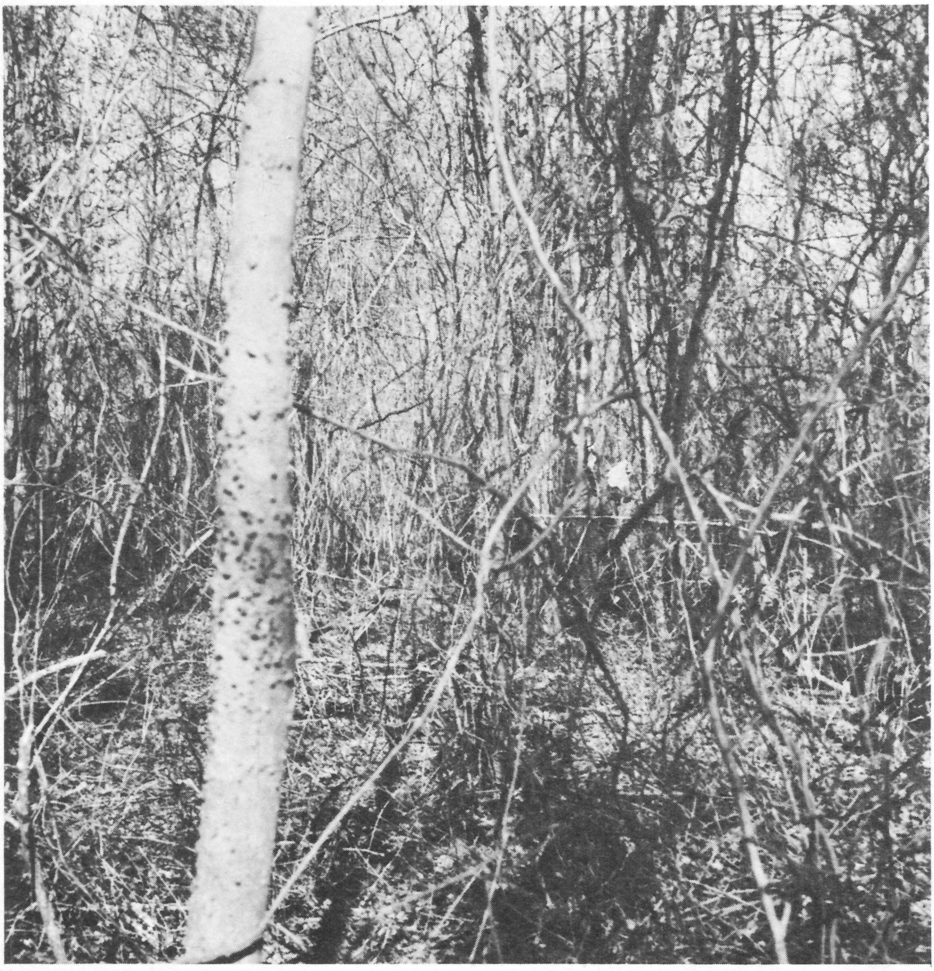


Fig. 3. The density of this assemblage is less important than is the fact that the predominant plant is a brier (cf. fig. A17)

defied satisfactory quantitation. Temporal aspects is one of these. Though deciduousness occurs to some extent in the tropics, the phenomenon is predominant in temperate climes, where during certain times of the year much of the vegetation is without leaves. A sample at any time will show some vegetation and include stem size, spacing, etc., which are constants, but the crown and its related attributes vary from season to season.

The problem here lies not entirely with the vegetation. Means have been proposed for quantifying, at least to some extent, seasonal variations. But if these quantifications are to be reliable, the analyst must be intimately familiar with the area, its weather, and its vegetation. This cannot always be assured.

Fig. 4. A photo which does illustrate spines is necessarily of such scale that the total assemblage is ignored

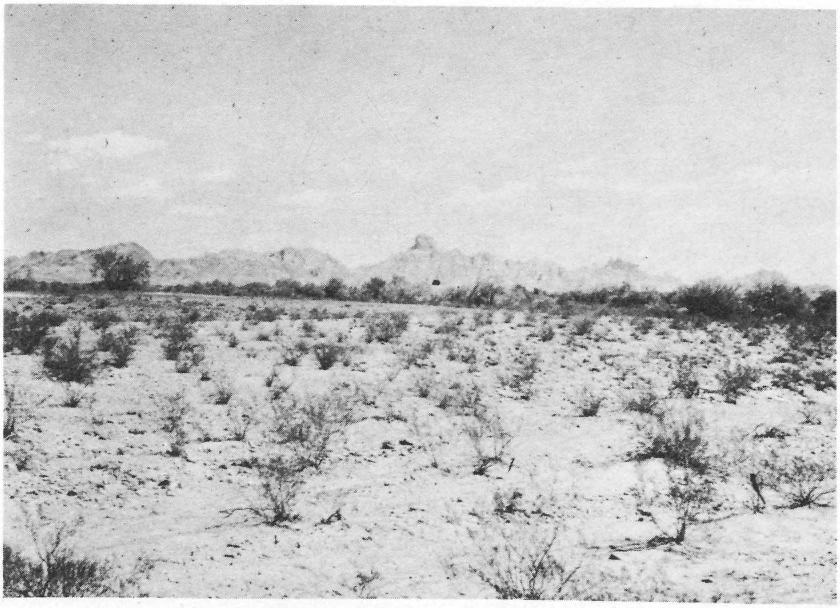


Fig. 5. A permanently bare area

Cultivated assemblages which are subject to irregular, not necessarily seasonal, variations are another case. Fig. 5 illustrates a relatively bare area, and since it is known to be desert, a sample taken at one time will be reasonably indicative of what one would expect to

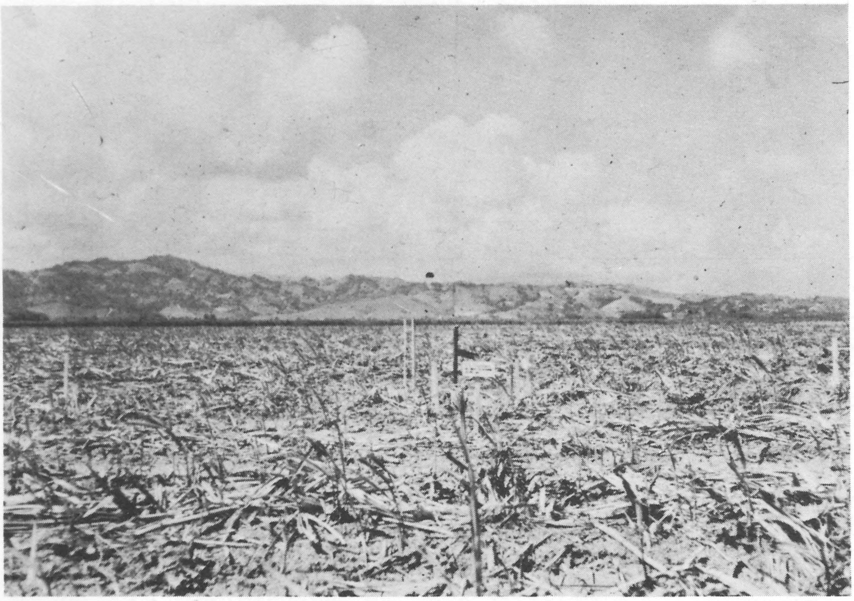


Fig. 6. A temporarily bare area

find at another time. Fig. 6 illustrates a similarly bare area, but it is a cultivated field, and sugar cane grows (fig. 7). At the stage shown in fig. 8 it is quite different from what it was a few months before.

It is concluded, at least temporarily, that the samples recorded with this system are "snapshots," i.e. they portray what was present at the time of sampling, and no more. Seasonal variations can be recorded by seasonal samplings, and other variations can be anticipated by analyses of land-use data.

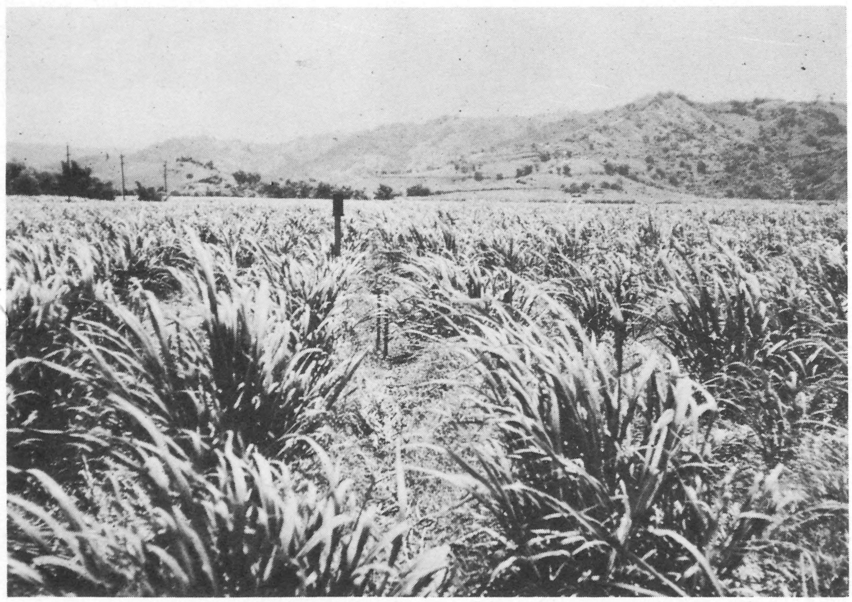


Fig. 7. Same area shown in fig. 6, a few weeks later

Neither has the problem of crown cover been quite solved. For each structural element, the "coverage" is recorded as the percent of the sample area covered by the crowns of that element. There may thus be recorded more than 100 percent total coverage in a given height class, or sometimes more than 100 percent in each of two or more height classes, when that coverage is produced by two or more structural elements. The result is that, graphically, an area will appear to be well-canopied,

Fig. 8. Same area shown in figs. 6 and 7, the height and density of the vegetation considerably greater than at either prior sampling

when in fact it may be only 50 percent canopied, due to a natural tendency of some plants to aggregate.

This problem is related to "crown density." In some cases where the coverage is 100 percent, the density may be so thin as to provide little concealment from observation, either by eye or by radar, even when the trees are fully leaved (fig. 9).

Fig. 9. Illustrating the problem of crown coverage versus crown density. The crowns of these cypress offer little concealment from air observation, even though they are fully leaved and the coverage is 100 percent

It is in fact not coverage per se which is of interest, but crown density, or resistance to light (or other wave) penetration. (And, to be still more refined, density of crown above various heights, e.g. that which could conceal a man might not conceal a vehicle.) This problem, though easily recognized, has only recently been approached, and a wholly satisfactory solution has not yet been obtained.

Though the imposition of certain limitations upon the present system is antipodal to the postulated requirements set forth earlier, useful analyses of some factors for some activities would not only introduce undue complexities, but would also require an intimate knowledge of the particular assemblage being analyzed, as well as a thorough knowledge of that particular activity. Thus, leaf size, texture, and shape, and even crown shape, would be of paramount importance to predicting camouflage requirements. But camouflage techniques involve an extensive array of subtleties, such as color, shadows, etc.

The problem of survival is a similar case. Potential food plants include some with poisonous leaves but edible roots, or edible leaves but poisonous roots, or they are poisonous when raw, and all sorts of complexities.

Terrain analysis for these and similar activities constitute complete specialties in themselves, and are entirely beyond the scope of the present scheme.

There are indeed some other problems to be solved, but most of these are considered minor. In spite of the few remaining deficiencies, this description system has been found generally satisfactory for recording quantitative vegetation data, and it is the consensus that present inadequacies and inconsistencies do not present insuperable difficulties.

Further, the feasibility of coding the data into computer cards has been investigated, with encouraging results. The procedure is a simple matter of assigning to each parameter and subparameter a column number, and to each class interval an item number. This done, it is possible to sort the cards for samples similar or identical in any given attribute or attributes. Thus analogies in terms of these attributes are easily and quickly detected. Also, such a procedure should render the samples susceptible of a cluster analysis, thus providing analogies for combinations of effect-producing attributes.

One other concept which should be mentioned is that this description system is dependent upon the recognition of an appropriate sample size, for it is upon this that all values of coverage and spacing depend. The related problems of sampling techniques and the recognition of sample areas have not been discussed here; they are discussed in detail in the paper by Dr. Mills of Marshall University ("Quantitative Environmental Studies, South Florida," pp 147-167).

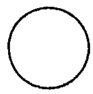
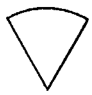
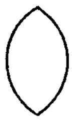
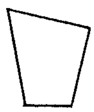
Though the present description system seems entirely functional, continued research is needed to determine the utility of the selected parameters and data classes. Such research should also minimize the deficiencies within the description itself, and should provide a procedure for obtaining a truly quantitative comparison between two or more vegetation assemblages in terms of their effect on military activities.

APPENDIX A: STANDARD VEGETATION SYMBOLS

(Adopted March 1963)

Growth-form

Crown (or Plant) Shape: (leaf and/or branch mass projected upon a vertical plane)

Symbol	Definition
	Round: top of crown hemispherical or nearly so, base of crown rounded or broad
	Flat-topped: top of crown flat or nearly so, base of crown rounded or compressed
	Pointed: top of crown conical or pointed, base of crown rounded or broad
	Spindle: top of crown conical or pointed, base of crown slender or long-tapered toward stem
	Irregular: crown shape not classifiable, or undeterminable.
	Conforming: leaf or branch mass essentially conforms to configuration of ground or to shape of plant used as support; use only with decumbent, twining, and free stem symbols
	Crownless: leaf and branch mass absent; use appropriate stem size symbol terminated with a small circle or dot, depending upon whether hard or soft (see Stem properties). This symbol conveys no areal significance (i.e., no coverage value)

Crown Diameter: (measure crown area by polygon method, normalize area to circular area, determine diameter of resultant circle)

Symbol Width in Grid Units	Range of Values
1	Less than 0.5 m
1.5	0.5 to 2.0 m
2	2.0 to 6.0 m
2.5	6.0 to 15.0 m
3	More than 15.0 m

Height

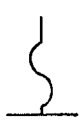
Class	Range of Values	Measure Stem Diam at:
VIII	More than 35 m	1.5 m
VII	13 to 35 m	1.5 m
VI	5 to 13 m	1.5 m
V	1.8 to 5 m	1.0 m
IV	0.7 to 1.8 m	0.3 m
III	0.3 to 0.7 m	0.1 m
II	0.1 to 0.3 m	Ground level
I	Less than 0.1 m	No stem symbol used

Stem Characteristics

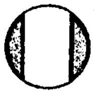
Stem Diameter: (see height table for point at which stem diameter is measured)

Symbol	Range of Values
	Less than 2.5 cm
	2.5 to 7.5 cm
	7.5 to 15 cm
	15 to 30 cm
	30 to 60 cm
	More than 60 cm

Stem Habit: (use only on height classes II to VIII)

Symbol	Definition
	Erect: stem supports crown by its own strength
	Decumbent: stem supported partially or wholly by ground or other plants; attitude essentially horizontal
	Twining: stem twines around or adheres to the stems of other plants for support. (Symbol drawn only a short way below crown, not to base of diagram)
	Free: stem free of other plants, but leaf mass supported by other plants

Stem Hardness: (measure at same point as stem diameter is measured)

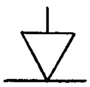
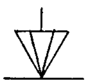
Symbol	Definition
	Hard, woody; stem strongly resists penetration of pencil point, i.e., edge of crown symbol is blackened
(None)	Soft, nonwoody; stem can be relatively easily penetrated by pencil point

Stem Succulence: (place between crown outline and "leaf size" symbol)

Symbol	Definition
(None)	Stem <u>not</u> succulent
≡	Stem succulent and green
||||	Stem succulent and not green (fungi)

Branching Habit: (use only on hard-stemmed plants more than 0.3 m tall)

Type of Branching: (place symbol at base of stem symbol)

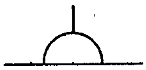
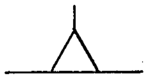
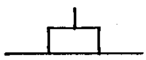
Symbol	Definition
	Horizontal: branches diverge from main stem at approximately right angles
	Divergent: branches diverge upward from main stem

Height of First Branching: (place symbol inside "type of branching" symbol)

Symbol	Definition
	Less than 0.5 m above ground
	0.5 to 0.1 m
	1.0 to 2.0 m
	2.0 to 3.0 m ("type of branching" symbol left blank)
(None)	More than 3.0 m (no modification of basic stem symbol)

<u>Root Habit:</u> (aboveground structures only; use only on plants more than 0.7 m tall, i.e., height class IV and up)

Type of Structure: (place at base of stem symbol)

Symbol	Definition
	Stilt or prop roots (e.g., mangrove)
	Enlarged base (e.g., cypress)
	Plank buttresses

Height of Emergence: (point at which root modification diverges from stem; place inside "type of structure" symbol)

Symbol	Definition
	Less than 0.3 m (not recorded; no modification of basic stem symbol)
(None)	0.3 to 0.6 m ("type of structure" symbol left blank)
—	0.6 to 2.0 m
═	More than 2.0 m

Spread: (diameter of root modification at ground level; place inside "type of structure" symbol)

Symbol	Definition
	Less than 2 × stem diam (not recorded; no modification of basic stem symbol)
(None)	2 to 5 × stem diam ("type of structure" symbol left blank)
/	5 to 15 × stem diam
Λ	15 to 45 × stem diam
▲	More than 45 × stem diam

Foliage Characteristics

Leaf Size: (area of leaf; place symbol in approximate center of crown symbol)

Symbol	Definition
△	Less than 1 sq cm
○	1 to 150 sq cm
□	More than 150 sq cm

Leaf Shape: (place inside "leaf size" symbol)

Symbol	Definition
○	Broad and flat (length/width less than or equal to 5)
△	Long and flat (length/width more than 5)
⬯	Awl (cross section approximately equidimensional; will not droop if held by one end)
⬭	Threadlike (cross section approximately equidimensional; droops if held by one end)

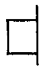
Leaf Texture: (place inside "leaf shape" symbol)

Symbol	Definition
(None)	Filmy, translucent
∴	Membranous (does not permanently deform when wrapped around a pencil; place ventral, i.e., "upper," surface next to pencil)
//	Hard (permanently deforms when wrapped around a pencil; place ventral, i.e., "upper," surface next to pencil)
	Succulent (more than 2 mm thick)

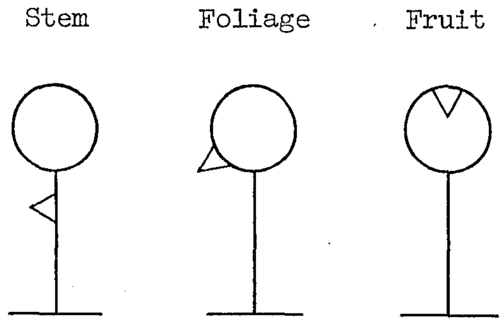
Leaf Condition: (place between leaf size and leaf shape symbol)

Symbol	Definition
	Leaves living, e.g. 
(None)	Leaves dead, e.g. 

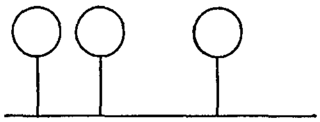
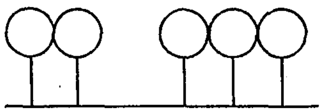
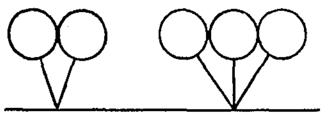
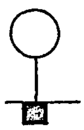
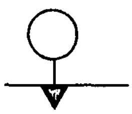
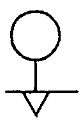
Armature

Symbol	Definition
	Spines more than 5 mm long
	Spines less than 5 mm long
	Cutting edges
	Stinging organs
	Poisons

Position



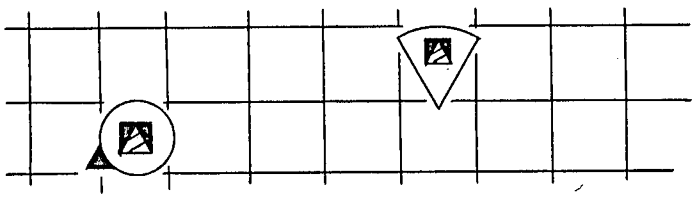
Distribution: (spatial arrangement of plants)

Symbol	Definition
	Random: symbols arranged in nonregular pattern (if coverage is 100%, all symbols touch)
	Aggregated: plants in groups, but mechanically independent; plant shape not obviously affected by associates
	Clumped: plants in close association; stems independent but plant shapes obviously affected by associates
	Grid: all plants approximately equally distant from nearest neighbors
	Row: plants closely spaced in one direction, much more widely spaced in another
	Strip: elongate patches

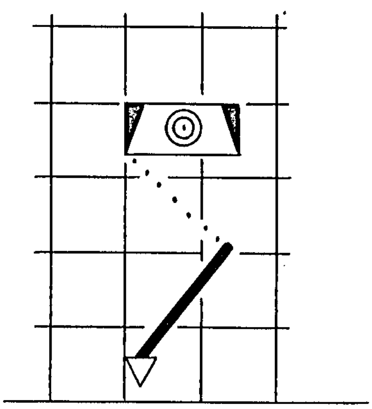
Special Elements

Epiphytes: (plants growing entirely upon other plants, not rooted in soil)

Symbol - use a symbol 1 unit × 1 unit, with base at height of attachment, otherwise comprised of appropriate combination of attribute symbols, e.g.,



Slash: (detached plants such as will not rot away within one season; specifically, larger stems with branches intact; a condition intermediate between vegetation and microrelief)

Symbol	Interpretation
	Height: appropriate to the majority height of the mass Crown symbol: 3/4 units deep × 1 grid unit wide indicates preponderance of major stem pieces to be less than or equal to 2.5 m long 1.5 grid units wide indicates preponderance of major stem pieces to be greater than 2.5 m long Other symbols associated with crown symbol are appropriate to the case Stem: the two units represent the range of diameters of the majority of the mass Base: the vestigial branch symbol is above the base line, indicating detachment

APPLICATION OF PLANT SYMBOLS

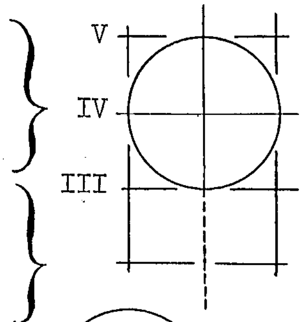
Example: Mangrove tree (the dimensions, though realistic, are assumed)

Crown shape is round, and the

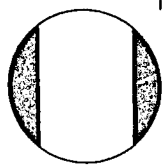
Crown diameter is 2 to 6 m, hence the symbol width is 2 units, and

Height of the plant (15 ft) is between 1.8 and 5 m, hence height class V:

Stem diameter is to be measured at 1 m, at which point it is (7 cm) between 2.5 and 7.5 cm, and the
Stem habit is erect, hence the stem symbol is straight:



Stem is hard, or woody, and not at all succulent: →



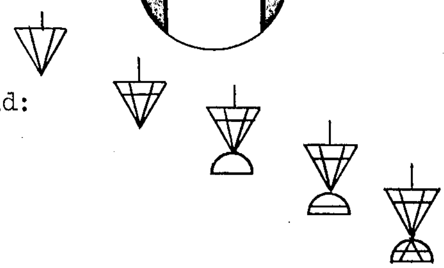
Branching habit is divergent, and the

Height of branching is between 1 to 2 m above ground:

Stilt roots are present;

they emerge at 1 m above ground,

and have a spread of 1.5 m, or 150 cm/7 cm = 21 times the stem diameter:

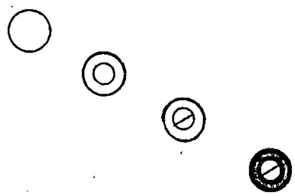


Leaf size is between 1 to 150 sq cm;

shape is broad and flat;

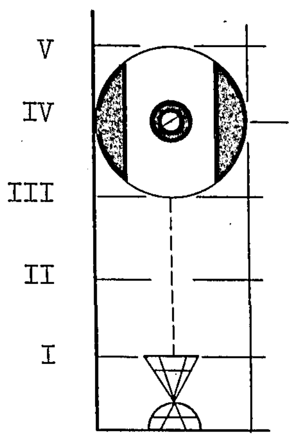
texture is hard;

condition is living:



Armature is wanting.

The total plant symbol, completed, looks like:



It remains now only to determine the distribution (random), coverage, and stem spacing. The symbols are arranged in the diagram to depict the distribution, with a sufficient number of symbols to depict the necessary coverage. Stem spacing is expressed as $S = 0.6\sqrt{A/n}$, where A is the area of the sample and n the number of plants in the sample.

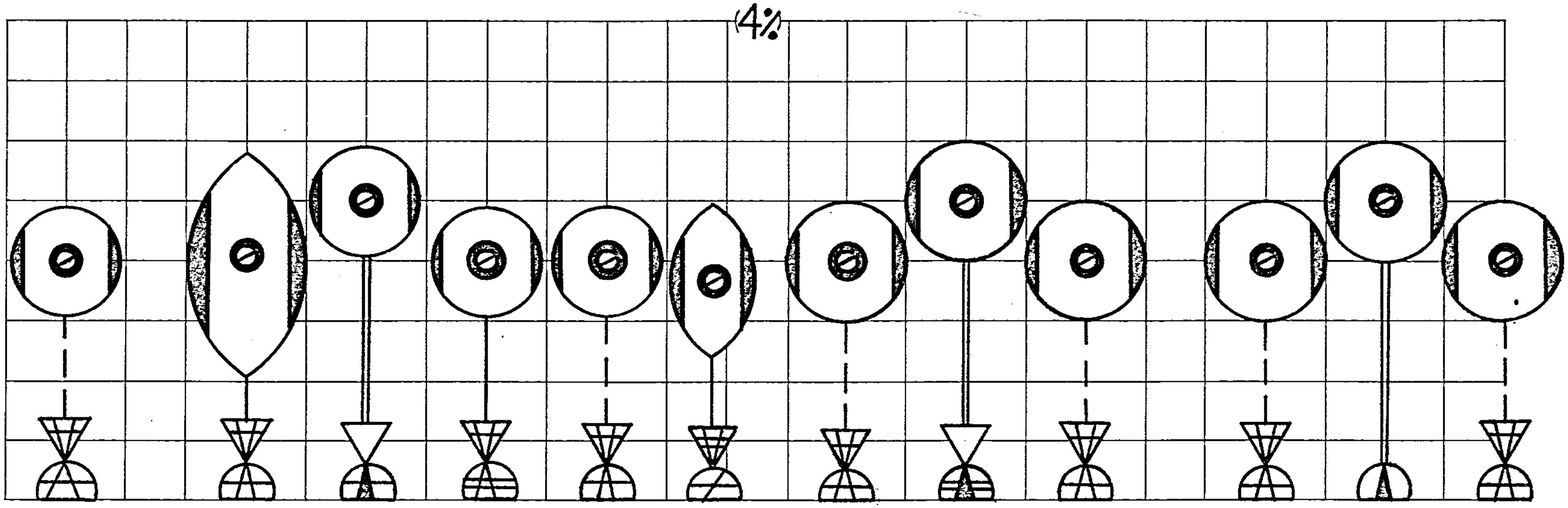
Note that in a pure mangrove forest, some trees may have narrower (spindle) crowns, some may have smaller or larger stems (in terms of prescribed class intervals), or different branching heights, etc. Each combination of these must be identified as a different structural element. (Thus it is manifest that "structural element" is irrelevant of species definitions.)

VEGETATION STRUCTURAL DIAGRAM

LOCATION HYPOTHETICAL MANGROVE

DATE ______________

VIII
VII
VI
V
IV
III
II
I



SAMPLE AREA DIAMETER ______________

VIII ( )
VII
VI
V
IV
III
II
I

WES FORM NO. 1162
REV MAY 1962

Fig. A1. Mangrove, with stilt roots, according to botanical interpretation

Fig. A2. A tropical upland species, with typical prop roots

Fig. A3. Roots of willow exposed by erosion, interpreted, in terms of effect, as prop roots

Fig. A4. Enlarged base

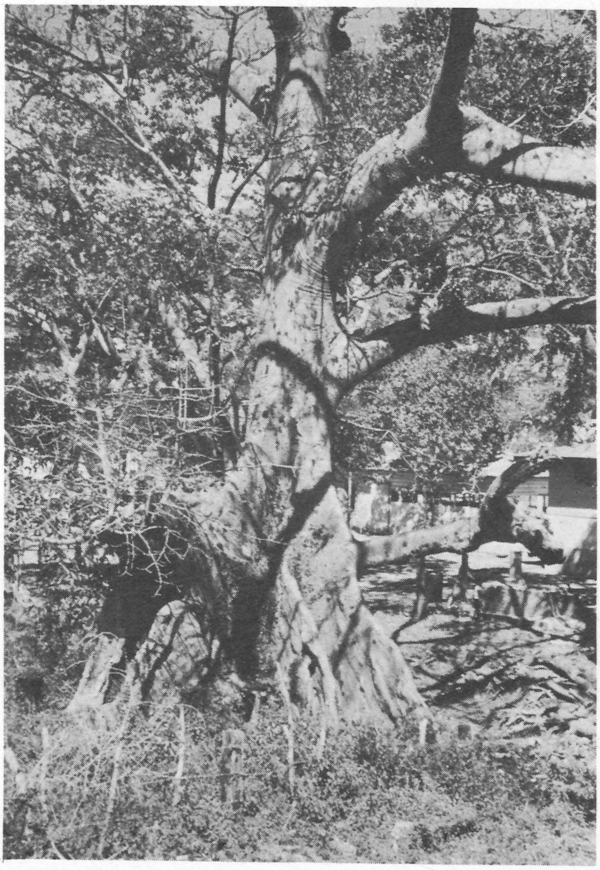


Fig. A5. Plank buttress

Fig. A6. A large snag. In terms of this system it is not considered to be different from a leafless tree

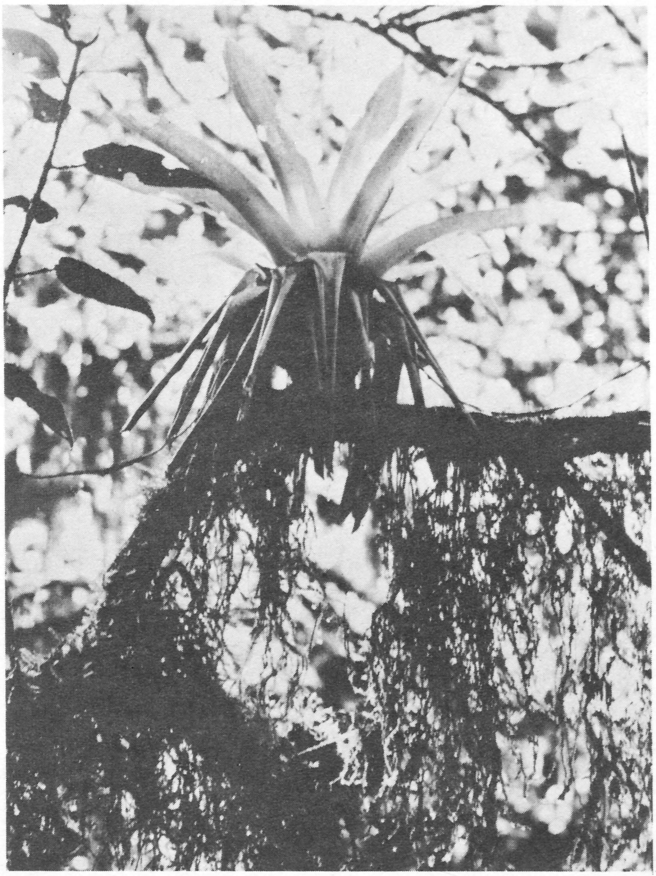


Fig. A7. Solitary epiphyte
(bromeliad), detail

Fig. A8. Effect of epiphytes on crown density. The assemblage includes several of the type shown in fig. A7, and others (mosslike plants)

Fig. A9a. Epiphytes (bromeliads) producing an effective leafy crown in an otherwise leafless tree

Fig. A9b. Epiphytes (mistletoe) producing an effective leafy crown in an otherwise leafless tree

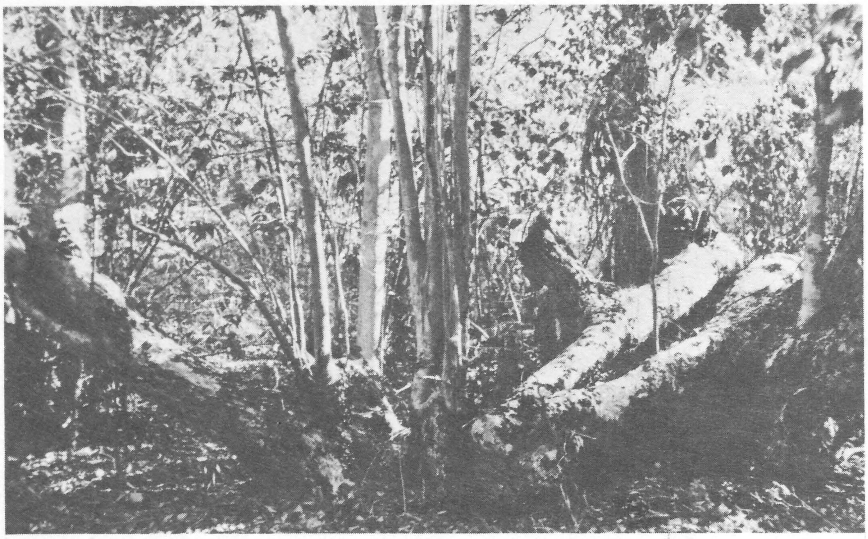


Fig. A10. A nearly horizontal log with live shoots. In usual botanical interpretation, the attitude of these large stems would be ignored; in terms of this system they are described as decumbent

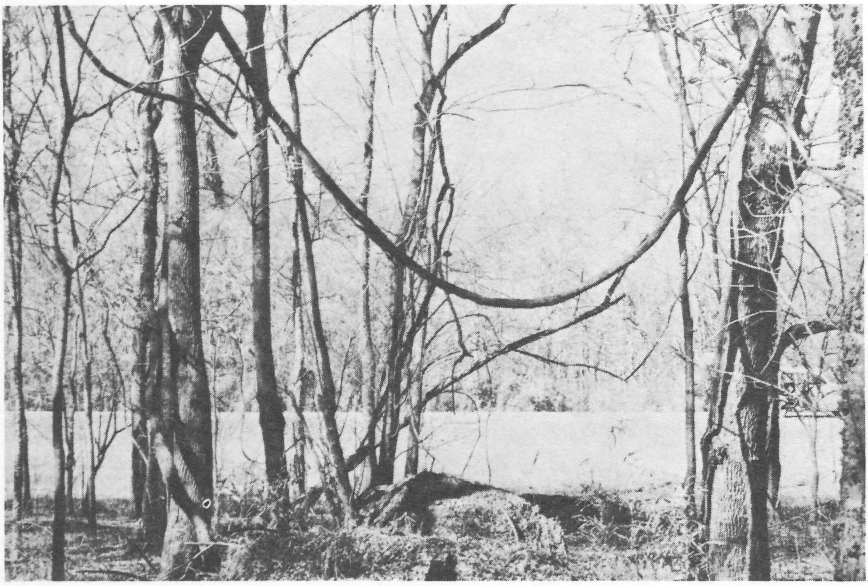


Fig. A11. A large solitary free stem

Fig. A12. A dense mass of smaller free stems

Fig. A13. This oak tree exhibits two types of branching habit: divergent above, horizontal below

Fig. A14. Detail of tree shown in fig. A13. Since it is the lower branches which will affect most military activities, it is the habit of these (horizontal) which is recorded

Fig. A15. Slash, sometimes a problem in description, and provided in this system with a special symbol

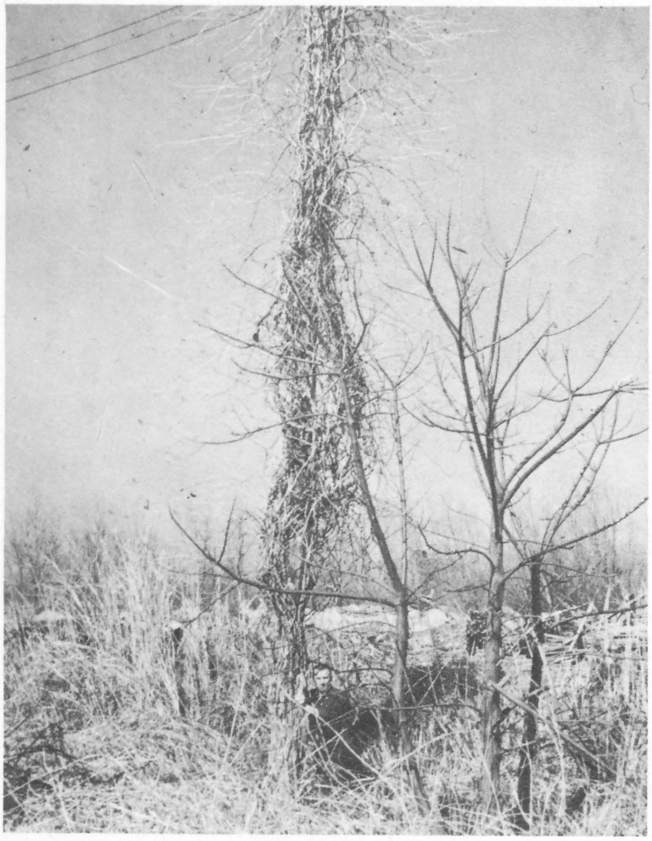


Fig. A16. A trumpet vine provides an "effective" crown for a utility pole. In an isolated example such as shown here, this is mostly a curio, but in fact could be accommodated in the symbol system (cf. fig. A17)

Fig. A17. Rank growth of honeysuckle, which en masse would be interpreted as various structural elements

THE EFFECT OF STEM SPACING ON VEHICLE PERFORMANCE

by

Eugene E. Addor[1]

No one with experience will deny that stem spacing does indeed exert some effect upon vehicle movement, at least to the extent that as the density of the stems increases, movement is increasingly hampered until at some density, movement is denied.

It is generally assumed that the effect of stem spacing (when the stems cannot be pushed over) is a function of one or more of certain characteristics of the vehicle, most commonly its width and turning radius, often its length. These assumptions are frequently stated axiomatically in the literature, but they have never been validated experimentally.

To this end a series of tests, now known as the Eagle Lake Tests, was recently conducted.* The purpose was to determine the feasibility of designing tests and data collection procedures for obtaining useful quantitative data relative to the effect of environment on the cross-country movement of vehicles.

Fig. 1 is an airphoto of the test area. The area is virtually flat, covered by an extensive stand of tall willows, and with very little understory or ground cover. Soil strength, as affected by moisture, varied from place to place due to nearly imperceptible variations in elevation. The nature of the stand was such that three test courses could be located, each with a different but relatively uniform stem density, and a different soil strength. Two of the courses (I and III) were 300 m, and one (course II) was 250 m, straight. A map of each course was prepared showing the location of every in situ element of the vegetation within 40 ft either way from the center line. Figs. 2-5 show interior views of the stand, and fig. 6 is a segment of the map of course III.

The site was deliberately chosen to be as free of slope, microrelief, understory, and other extraneous factors as was possible to find, in

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[1] Area Evaluation Section, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

* Report in preparation.

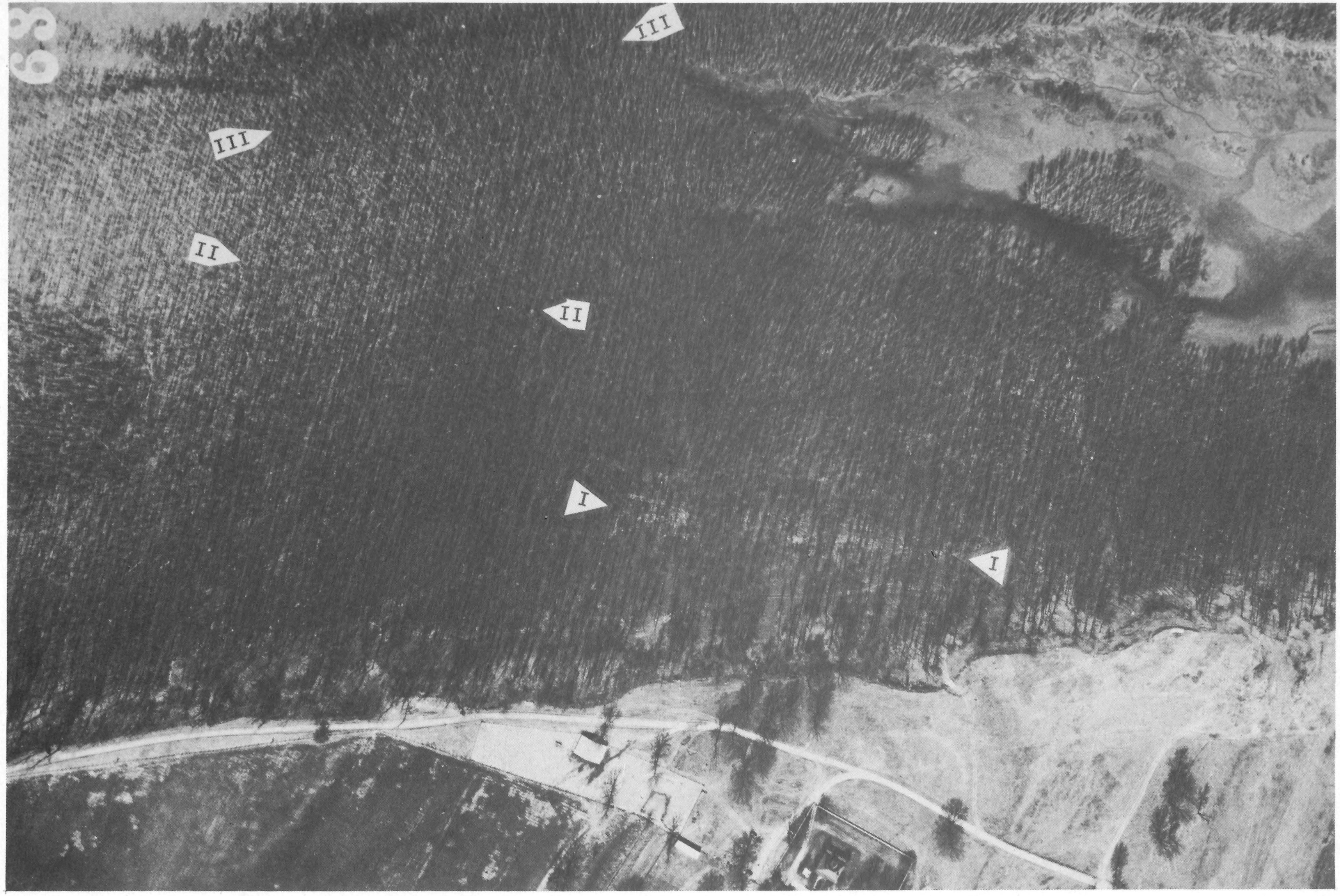

Fig. 1. The Eagle Lake test area, vertical airphoto, scale approximately 1:4000

Fig. 2. Interior view of the stand, course I

Fig. 3. Interior view of the stand, course II

Fig. 4. Interior view of the stand, course III

Fig. 5. Interior view of stand, showing a typical slash accumulation. These were only occasional in the stand, and mostly avoidable. One occurred near the end of course I

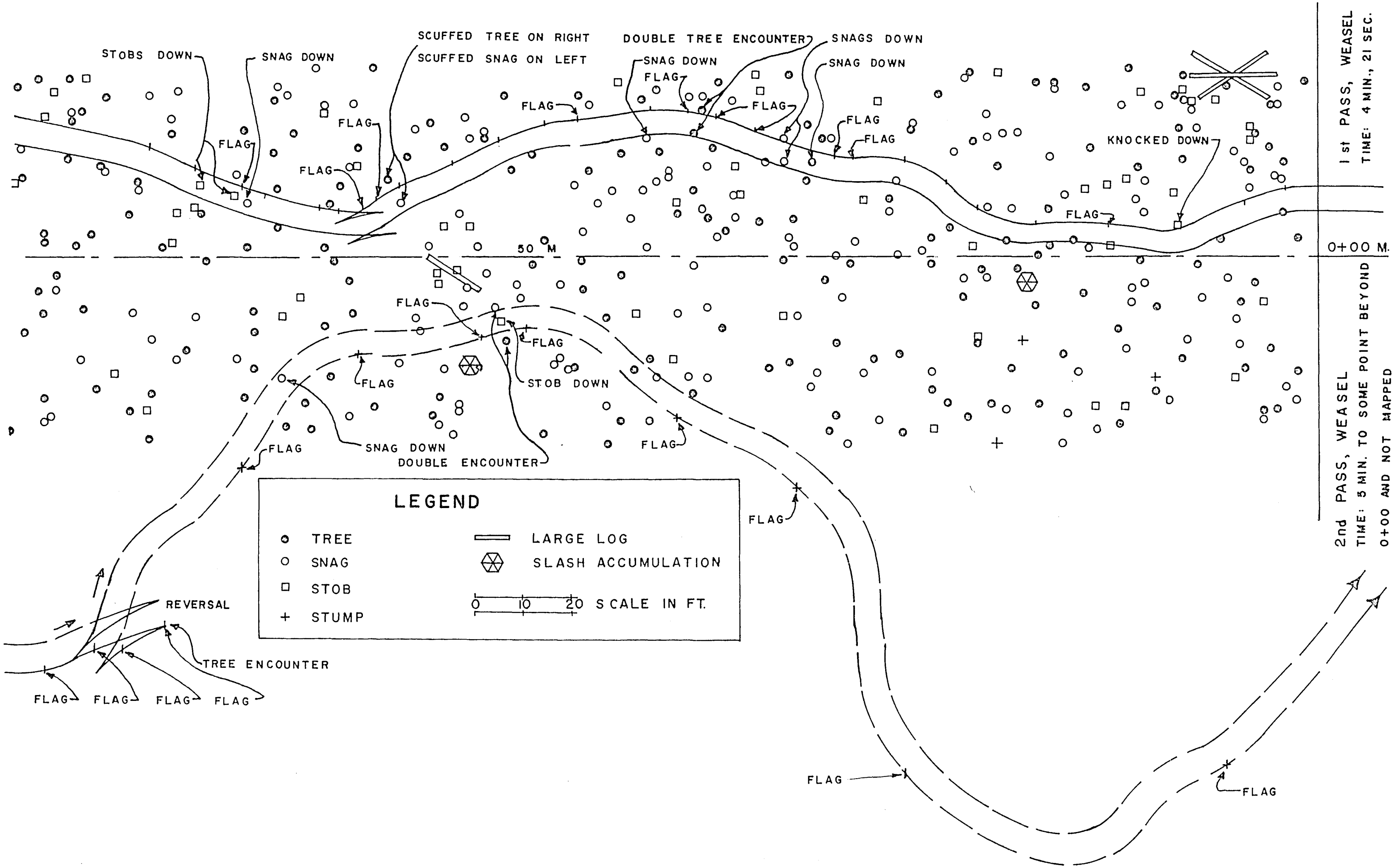

Fig. 6. Segment of the transect map, course III, with vehicle tracks plotted

anticipation that the uncomplicated data would be better suited to the development of analytical techniques. These techniques could later be refined for application to more complex data.

Stem spacing, soil strength, and time were the factors to be considered. It was intended that each of the test vehicles would make two passes over each course. All completed the requisite passes on course I, but soil strength prohibited passage of any but the weasel on courses II and III. The tracks were surveyed and plotted on the transect maps (fig. 6).

Analyses of the Eagle Lake test data are not yet completed, but a preliminary analysis suggests some interesting relations, relative to mobility, between vehicle characteristics and stem spacing. As an example of the kinds of information to be derived from such tests as these, the remainder of this paper is devoted to discussion of these relations.

To begin, perhaps it would be useful to observe that the term "spacing" is rarely defined. It is very common, for example, to find a statement to the effect that "...spacing is too close to permit passage..." with no explanation of what is meant by "spacing."

For a stand of uniform and ordered distribution (e.g. an orchard) the meaning is usually implicitly understood as the distance from one tree to the next nearest. But what of natural forests, where the distance between trees is variable and the distribution unordered?

Several somewhat related methods have been proposed for measuring the spacing of objects in random distributions.* Basically, all are expressions of nearness. The definition adopted by the Area Evaluation Section is $S = 0.6\sqrt{A/n}$, where A = area of the sample and n = number of plants in the sample.

Spacing on the Eagle Lake test courses, by this definition, was: course I, 3.29 m; course II, 2.07 m; course III, 1.60 m.

One result of the Eagle Lake tests is to force a reassessment of the usual definitions of spacing relative to mobility, as well as to cast doubt upon the supposed limiting characteristics of the vehicle.

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* The term "random" is used in this report in the casual sense, with acknowledgment that "true" randomness is rare in natural vegetation assemblages.

Quite obviously it is neither the minimum nor the average distances between obstacles which limit the passage of a vehicle. Rather it is the greatest distances between the obstacles, and the arrangement of these into unobstructed paths. That is, passage is not prohibited by the presence of limiting conditions, but by the absence of adequate conditions.

The relation becomes apparent when one considers an orchard or a vineyard in which the spacing is but very little greater than the width of a tractor, yet by following the "unobstructed paths," the farmer cultivates the field with little difficulty (fig. 7, sketch A). If, however,

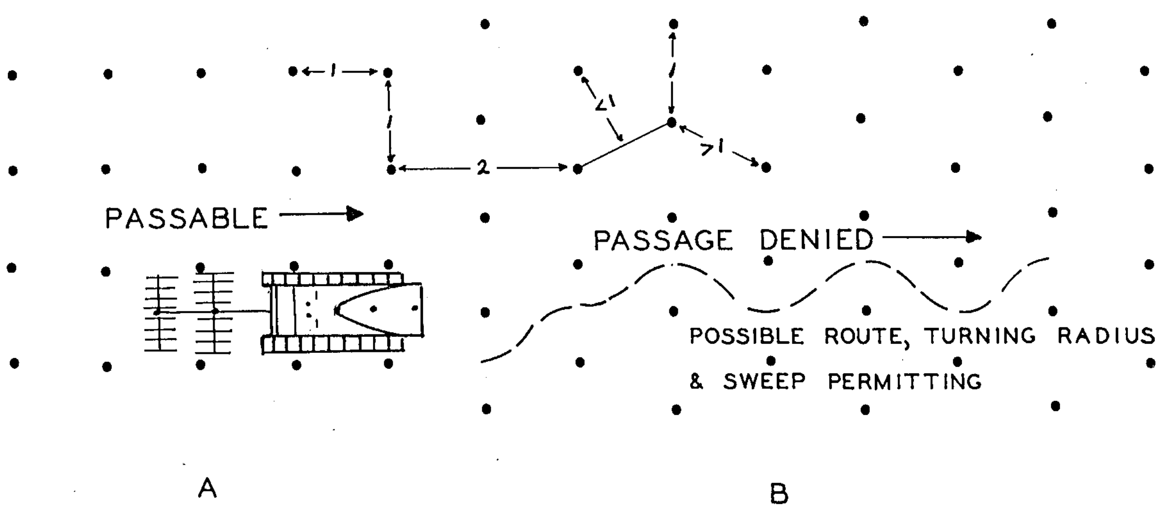

Fig. 7. Effect of rearranging obstacles, minimum spacing unchanged

alternate rows are shifted, as in B, the field can no longer be cultivated with the same equipment, even though in fact the minimum spacing has not been changed.

The one factor which has been changed is either the length or the width of the unobstructed path. This has been either reduced to two units in length, or it has been reduced in width. The original vehicle can no longer pass unless its turning radius will permit avoidance of the obstacles, and this obviously necessitates a tortuous route.

But this forced turning introduces an additional consideration. During a turn, the actual width of the vehicle is not a measure of the minimum passable distance between obstacles. Because of the sweep of the vehicle (the actual area covered by the vehicle during a turn), the width of the vehicle is increased to some effective width greater than its actual width. This value is related directly to length of the vehicle, and inversely to the radius of the turn. That is, as the length of the vehicle increases, so the sweep increases, but as the radius of the turn increases, so the sweep decreases.

It is not probable that a standard vehicle of the indicated width could negotiate the suggested route at B in fig. 7. It is probable that a vehicle capable of a full pivot could negotiate the route if, but only if, its length were such that the sweep could be accommodated.

Let us now consider the effects of increasing the spacing in a grid without changing the relative arrangement of the obstacles.

In fig. 8, the characteristics of a military 3/4-ton truck are assumed. At A, the spacing of 2.44 m (8 ft) is just 0.61 m (2 ft) greater than the width of the vehicle. The vehicle can pass in only one direction. If the spacing is increased to 3.66 m (12 ft), as at B, then a diagonal path is opened to the vehicle.

Note that a spacing which will permit a diagonal path will also permit maneuvering (turning radius 7.63 m), or conversely a spacing which will permit maneuvering will also permit a straight-line diagonal traverse (granting the probability that the sweep will be accommodated, at least for this vehicle). (There are some other subtleties which should be introduced here, and from time to time throughout this exposition, but space prohibits consideration of their ramifications.*) Note also that at both A and B in this figure, the minimum spacings are less than the length of the vehicle, though in this one it is approaching that length, 3.66 m vs 4.27 m.

Consideration of fig. 8A suggests that the relations existing between the permitted passage and the desired but denied path are similar to that existing between the legs and the hypotenuse of a right triangle, and that perhaps the distance required to get from here to there could be approximated by an application of the Pythagorean theorem.

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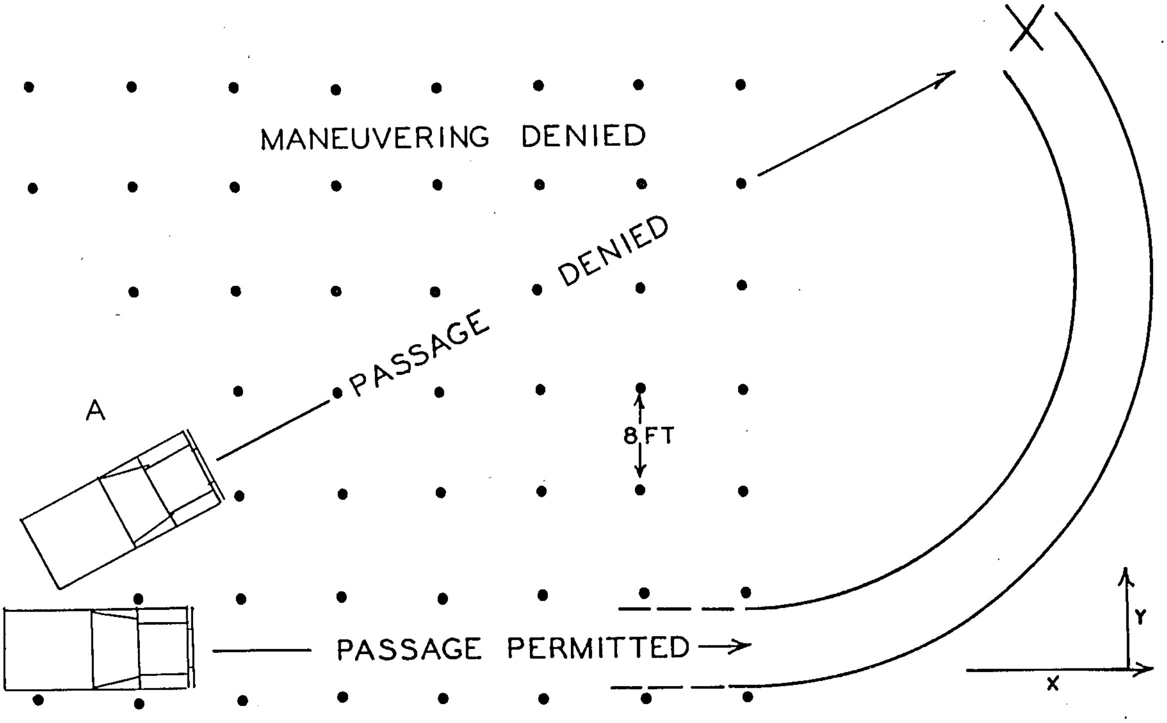
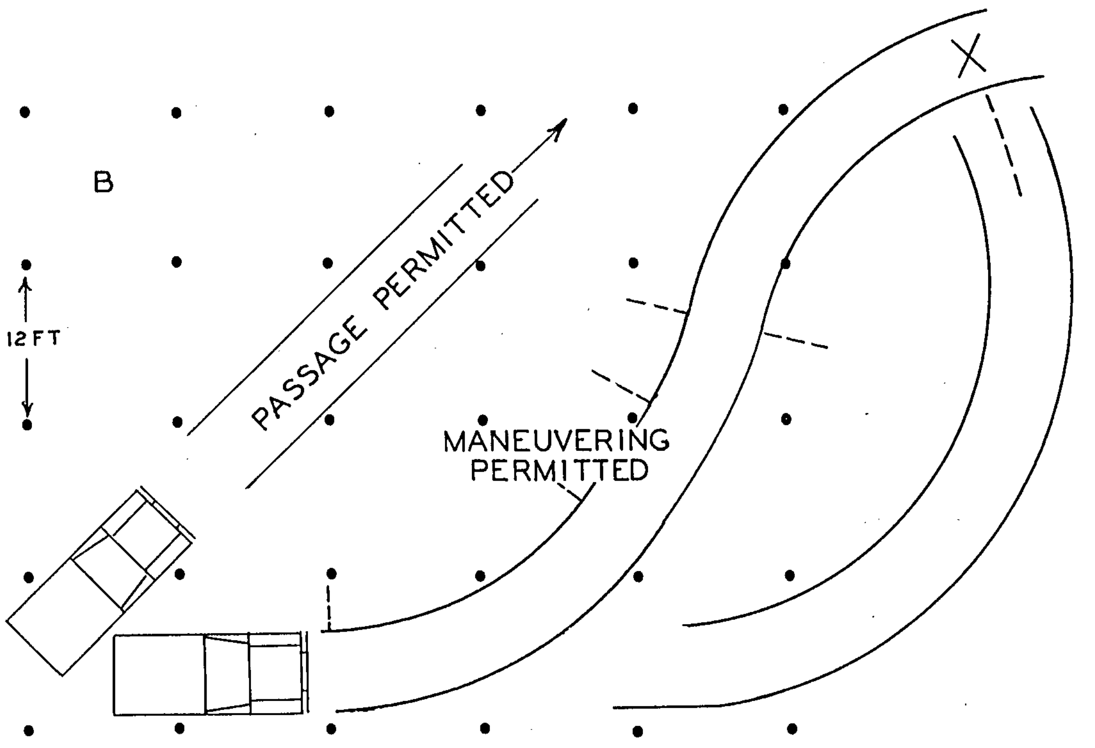
* For example, if the minimum turning radius were greater than 3.66 m, maneuvering would be denied, though passage would not be denied. Further, is there such a vehicle existing with the length and width of a 3/4-ton truck, but with greater turning radius? The next largest cross-county wheeled vehicle is the 2-1/2-ton truck, which could not move in the situation at A, and which would be denied the diagonal path at B.

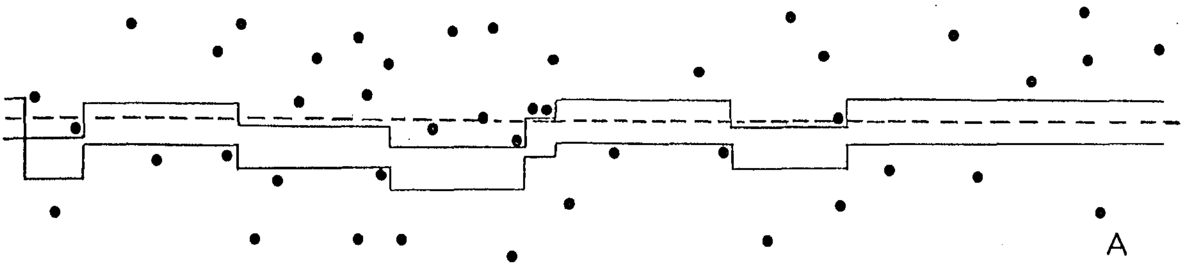


A. Spacing limits route selection

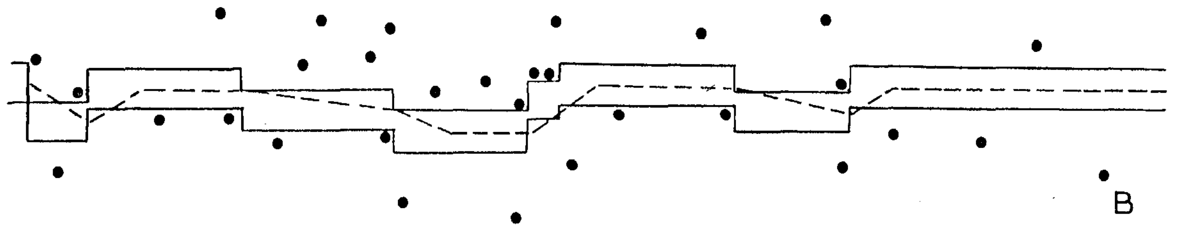


B. Spacing permits choice of paths

Fig. 8. Effect of increased spacing, arrangement unchanged



A. Desired path interrupted by obstacles



B. Approximation of path to avoid obstacles

Fig. 9. Geometric approximation of traverse distance through random distribution

If so, it remains for us to establish an application of this relation relative to natural, random distributions. Fig. 9 illustrates a proposed solution. It is assumed that a vehicle can travel in a straight line until an obstacle is encountered, whereupon it must depart laterally from its original path by as much as or less than, but never more than, one-half its width, as at A in the figure. (The obstacles are here assumed to be points, i.e., have vertical dimension only.) But since the vehicle is incapable of such abrupt lateral movement, and primarily because the driver anticipates the impending departure, the actual path acquires the aspect of a series of right triangles as at B. Then, theoretically, the total distance traveled is the sum of the hypotenuses (fig. 10).

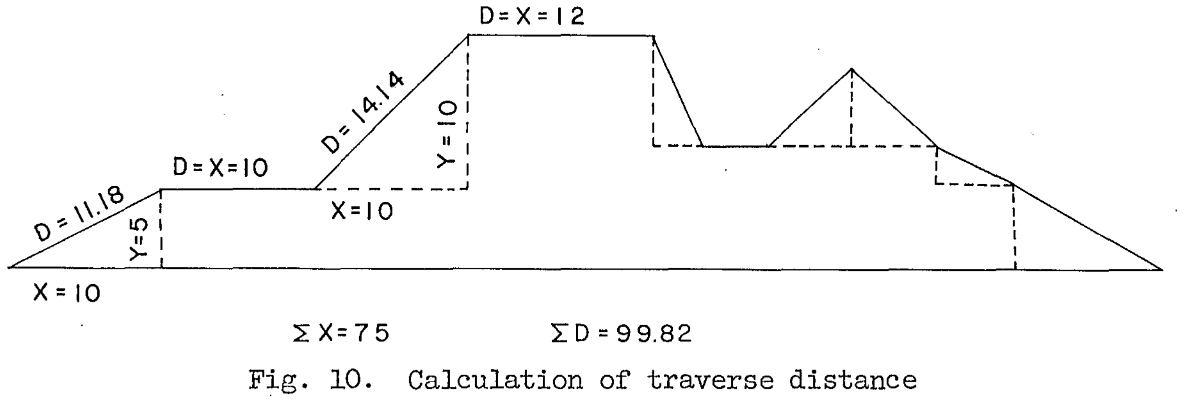
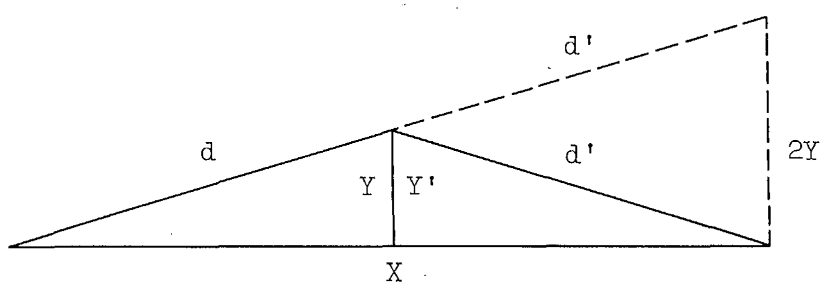


Fig. 10. Calculation of traverse distance

It has been premised that the maximum departure ever required would be one-half the width of the vehicle. It is manifest, however, that for every departure Y from the desired course, there must be an equal and opposite departure Y' to regain the desired course. Now if the distance between obstacles is averaged, and if X is set equal to this average distance, the geometry is such that the sum of d + d' is obtained by

$$d = d + d' = \sqrt{X^2 + (2Y)^2}\text{, thus:}$$



It therefore seems tentatively reasonable to let Y at each obstacle be equal to the full width rather than one-half the width of the vehicle.

Now since X has been averaged for the encounters in a given distance, and therefore all X's are equal, and since Y for each encounter has been set equal to the width of the vehicle, it follows that by extension of this geometry the actual distance D_a necessary to traverse the field is

$$D_a = \sqrt{D_s^2 + P_w^2}$$

where D_s is the straight-line distance, and P_w is the path width (the width of the vehicle).

If this concept is realistic, then it should be possible to predict the actual path length required to traverse a given distance with a given vehicle through a given obstacle field, the only remaining problem being to establish the frequency of encounters.

As a tentative measure of this factor, five straight-line paths, each scaled to represent 82 × 1.97 m (250 × 6 ft), were drawn randomly on each of the Eagle Lake transect maps. On these, all symbols for trees and snags partially or wholly within the sample paths were counted and averaged for each transect. This average number of encounters e per sample path was then multiplied by 1.97 m, the path width, to obtain a departure value Y for each transect.

Then letting $S = 82$ m , the sample path length, the distance d required to traverse the 82 m was calculated as

$$d = \sqrt{X^2 + Y^2}$$

From this value, a <u>path elongation factor</u> P_e, was calculated as

$$P_e = \frac{d}{82}$$

Now, with the straight-line length D_s of each test course known, the distance D_a actually required to traverse that distance was predicted as

$$D_a = D_s \cdot P_e$$

The results of this calculation seemed not to correlate with the actual path data, as plotted on the maps. When, however, the value e for the average number of encounters was adjusted by a factor of 0.75, and the P_e value recalculated, the predicted path lengths were found to have an interesting coincidence with the actual path lengths, as recorded on the maps (table 1).

It is interesting that in almost all cases where the actual path greatly exceeded the predicted path, alternate routes shorter than that chosen by the driver can be found on the transect maps, and the excessive elóngation can be attributed to microrelief and/or driver inexperience. The notable exception to this generalization was the weasel on the last pass.*

This coincidence of predicted and actual path lengths is especially interesting on course III, where on pass 1 the driver overran a

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* The excessive elongation of the weasel path on course III, pass 2, and the undue shortening of the 2-1/2-ton truck path on course I, pass 2, are both attributable to flagrant violation of instructions by the driver.

Table 1

Vehicle Path Length

Course	Vehicle	Pass	D_s	D_a Meas-ured	D_a Pre-dicted	Elongation $(D_a - D_s)$ Meas-ured	Elongation $(D_a - D_s)$ Pre-dicted	Differ-ences	Notes
I	3/4-ton	1	300	314.6	302.9	14.6	2.9	+11.7*	1, 2
		2	300	307.5	302.9	7.6	2.9	+4.7	1
	2-1/2-ton	1	300	306.7	307.4	6.7	7.4	-0.7**	3
		2	300	305.1	307.4	5.1	7.4	-2.3	3, 4
	Weasel	1	300	304.1	302.9	4.1	2.9	+1.2	---
		2	300	304.0	302.9	4.0	2.9	+1.1	---
II	Weasel	1	250	262.7	256.9	12.7	6.9	+5.8	5
		2	250	256.6	256.9	6.6	6.9	-0.3	---
III	Weasel	1	300	330.7	329.9	30.7	29.9	+0.8	---
		2	300	359.7	329.9	59.7	29.9	+29.8	6

Notes:
1. That the path of the 3/4-ton truck on course I was longer than necessary is evidenced by the fact that the path of the 2-1/2-ton truck is shorter.
2. 5.9 m of this elongation is attributable to microrelief and lack of experience.
3. Using $P_w = 2.44$, $e = 14.3$, therefore $P_e = 1.025$.
4. The actual path was too short, involving undue risk of damage.
5. Excessive elongation is apparently attributable only to driver inexperience.
6. The driver departed unwarrantedly from course; the figure is not a valid statistic.

* Measured value more than predicted (+).

** Measured value less than predicted (-).

considerable number of snags, and where the impression was that here the spacing was very nearly limiting, or indeed would have been limiting to a vehicle incapable of overrunning the snags. On viewing the transect map, however, it becomes obvious that other equally direct paths were open to the weasel which would not have involved overrunning of snags, and that the only reason for doing so was to extricate the vehicle from "blind alleys" of a labyrinth, in the solution of which the driver had erred.

From a consideration of the transect maps, it can be shown geometrically that the 2-1/2-ton truck could have negotiated course II (albeit, perhaps with difficulty), and that the 3/4-ton truck could have easily negotiated both II and III. Had the attempt been made and failed, that failure could have been attributed not to the geometry of the vehicle and obstacle arrangement, but solely to driver error.

Thus the assumption that mobility is a function of obstacle spacing and certain characteristics of the vehicle, while perhaps valid, seems to be improperly understood. The value at which spacing, as currently defined, imposes an absolute limitation upon movement of a vehicle is actually less than any commonly measured characteristic of that vehicle. It appears, therefore, that before spacing <u>per se</u> imposes an absolute limit to movement, driver psychology becomes more crucial than do the physical dimensions of the vehicle.* But there is evidence that this apparently complex relation between stem spacing, vehicle characteristics, and driver psychology can in fact be reduced to some intelligible and useful simplicity.

The results of these tests are by no means conclusive. Admittedly the geometric approach developed here may be entirely inadequate,** and the formula for predicting the effect of stem spacing on path elongation is at best tentative. Tenuous as these are, there are certain implications involved, which are in fact supported by at least some experimental data.

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* Note that this absence of <u>coincidence</u> does not necessarily imply a lack of <u>correlation</u>.

** For the example, the function of the 0.75 correction factor is not known; also, it is obvious in the development of the formula that all d are not necessarily equal; etc.

DATA COLLECTION PROGRAMS

by

Warren E. Grabau[1]

One of the objectives of the "Military Evaluation of Geographic Areas" (MEGA) project is to develop description and classification systems for terrain factors or factor families. These systems must be universally applicable; i.e., they must be so designed that data from any part of the world, and any climatic or cultural regime, will fit into the scheme without ambiguity. There must be a precisely defined pigeonhole for every pigeon, no matter from where that pigeon comes.

If this objective is to be attained, it follows that knowledge of all existing environmental variations must be available, to ensure that all of the pertinent attributes of the environment are incorporated. This is true because it is obviously difficult to design an all-inclusive classification system for a set of factors if one is ignorant of the presence of some of the factors.

The first step in the development of a terrain classification system is, therefore, a data collection program. Because of the necessity for making the classification systems quantitative in nature, however, a major problem immediately becomes apparent. An overwhelming proportion of existing terrain information is in qualitative terms, and these data cannot be directly translated into dependable quantitative information. Thus, most of the existing data on terrain are only marginally useful; in general, the translation from the existing qualitative descriptions to the precisely defined quantitative parameters now required is subject to such error that both the nature and magnitude of many terrain factors are uncertain. That is, neither the total ranges of variance nor the most probable values which characterize those factors are known.

The most sophisticated attempt to translate qualitative description into quantitative factor values has been applied in the desert analog study (Broughton; "Desert Terrain Analog Study," pp 43-51). First, specific

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landform is identified. Next, examples of it from various parts of the world are assembled and studied. Then the appropriate factors applicable to the landform are measured, if possible, and estimated if measurement is not possible. Unfortunately, in most cases actual measurement does, in fact, prove to be impossible; therefore, one must be content with estimates. These estimates are then summarized, and the total range of values for each factor is tabulated. Mean or most probable values cannot be obtained, because nothing approaching a valid statistical sample of the worldwide population is available. Furthermore, there is no assurance that the assigned limits are correct, because these limits were nearly always estimated rather than measured. It is upon this very shaky foundation that most of the MEGA classification systems were erected. Naturally, there are grave reservations about their validity.

The alternative to this procedure is to start with data which were measured in the field. With such data, taken directly from nature in quantitative terms, it would be possible to have a solid basis for both generalization and classification. The problem is that the collection of such data is time-consuming and expensive, and at least initially is dependent upon a high level of skill in the persons doing the measuring. As a result, the MEGA project has starved for lack of terrain data of the proper form for many years; however, this situation is beginning to change. In the last two MEGA projects, personnel have had the opportunity to collect environmental data in the field in many parts of the world. Several studies conducted for other purposes also have included data collection phases. These include the Overland Train project (Friesz; "Desert Terrain Effects on Vehicle Performance," pp 60-72), SWAMP FOX I and II (Garrett; "Mobility Studies in Humid Tropics, Panama," pp 82-95), the surface microgeometry task (Stone; "Quantitative Expression of Microgeometry," pp 9-14, and vehicle tests at Eagle Lake (Addor; "The Effect of Stem Spacing on Vehicle Performance," pp 129-142).

Additional data collection programs, all of which have yielded vital information, fall into three general classes. First, there is a group of related programs being conducted in South and Central America, in Puerto Rico, and in the United States. These are a direct result of the tropical terrain research program, which started nearly two years ago. As one response to the requirement that emphasis be placed on environmental research in the humid tropics, the Waterways Experiment Station (WES) established two overseas field detachments; one in the Panama Canal Zone (Zappi; "Tropical Terrain Studies in the Caribbean Area," pp 187-195), and the other in Puerto Rico (Benn; "Environmental Data Collection, Puerto Rico," pp 168-181). The objectives of these two detachments are to establish the nature and magnitude of environmental variations in humid tropics, to devise appropriate field sampling methods for minimum-size field parties, and to test, and if possible improve, the existing classification and description systems. As a result of these efforts, new and improved sampling methods and description systems have evolved very rapidly. A supplementary project to the tropical terrain research program is that of mapping the existing vegetation of Puerto Rico in structural terms (Anon.; "The Vegetation of Puerto Rico," pp 182-186). A great deal of effort has been placed on vegetation in the tropics, chiefly because it imposes such profound effects on many military activities and items of materiel.

There is only one example of an area in the United States resembling the humid tropics: southern Florida. This area has been studied by Marshall University (Mills; "Quantitative Environmental Studies, South Florida," pp 147-167) with three objectives in mind: to refine the descriptive system for vegetation, to develop appropriate field methods, and to collect as much quantitative data on that region as possible.

A second set of data collection programs is being done, or has been done, under contract in the United States. The primary objective of these programs is to provide a quantitative data base to use in a testing program; one major handicap to the MEGA project as a whole is the lack of precise data from properly designed tests. It is apparent that the design of tests to elucidate the quantitative relation between environmental factors and their effects on military activities must have, as a point of departure, a definitive description of the environment.

The Ranger Department has expressed a willingness to cooperate in a series of tests to determine the type and magnitude of environmental effects on small unit operations. Consequently, a program is under way to describe the environments of the Ranger Training areas at Dahlonega and Fort Benning, Georgia, and Eglin Field, Florida (McLaughlin and

Norris; "Environmental Descriptions of Ranger Training Areas," pp 196-212. It is intended further that data on the Fort Knox military reservation will also be used as the basis for a series of tests, chiefly involving visibility and vehicle relations (paper by Hoadley; "Environmental Description of Fort Knox Area," presented at conference but not available for this report).

The third type of data collection is one which was not a part of the basic MEGA research program. In the spring of 1962, the Advanced Research Projects Agency (ARPA) asked the Army to send a team of environmental and mobility specialists to southeast Asia to make a preliminary survey of those factors of the Asiatic environment that were known to affect the mobility of ground vehicles. The report of the preliminary team was to be used as the basis for the design of a long-term research study to improve the mobility of the Army in such environments, both by furnishing design criteria so that vehicles would be improved, and by developing an analytical method of predicting vehicle mobility. The WES furnished several members of the preliminary team; their achievements comprise the third type of data collection (Rula; "Mobility-Environmental Research Studies, Southeast Asia," pp 213-228).

Very substantial amounts of information from many parts of the world are already available as a result of these programs. It is proposed to continue certain of these, and extend the data collection effort to other areas as time, funds, and manpower become available. It is felt that enough environmental data of sufficient precision are finally being obtained to permit truly universally applicable descriptive and classification systems to be designed. Furthermore, there is a side benefit of no less importance; these very precise and reliable data collections will provide the information necessary to design and conduct valid experiments involving the relations of environmental factors to military activities and items of materiel. Thus, it may soon be possible to predict in quantitative terms the effects of specific environments on certain military operations.

QUANTITATIVE ENVIRONMENTAL STUDIES, SOUTH FLORIDA

by

Howard L. Mills[1]

The study reported on here has been concerned with the refinement of a descriptive system and also with methods of sampling adaptable to the quantitative analysis of the vegetation physiognomy. The structural analysis of vegetation formations is part of a comprehensive study having for its purpose the development of quantitative systems for describing and classifying soils, vegetation, and topography of tropical environments, and for predicting their effects on military operations.

The traditional classifications for vegetation are usually based upon floristic characteristics. Ecologically, it is considered that species of plants found in any geographical area will be related to their ability to grow in competition under the local conditions of edaphic significance. In such systems the individual species are the basis for ecological analysis. These systems largely overlook the fact that a vegetation association will exhibit characteristic group structure and individual life-forms which, like the flora, are expressions of the environment. In the description of tropical vegetation particularly, various workers have indicated the need for description based upon the structure and life-form rather than upon long lists of the floristic components found therein. As Dansereau has so aptly stated: "Since quantitative representation, therefore, is the important criterion in the description of vegetation, a long list of species, to say nothing of a complete enumeration of the flora, are of little value. Instead, the dominant and some other characteristic species must be recognized because of their physiognomic prominence and their indicator value."

In the traditional fields of botanical study, much attention has, in the past, been given to species analysis of vegetation formations, but as yet very little attention has been given to the analysis of the vegetation physiognomy. This seems strange inasmuch as many workers have indicated that the physiognomic basis of classification meets all the essential

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requirements for the treatment of vegetation formations. The characteristic life-forms within vegetation formations are important indicators of the environmental conditions. Thus, life-form is a major criterion of edaphic importance and studies of the vegetation physiognomy should give considerable insight into the interrelations of climatic conditions, soil structures, and the vegetation associations found. The paucity of studies may be related to the common belief that structure and life-form cannot be precisely measured and mathematically defined. The primary purpose of the present study was the quantitative analysis of the vegetation physiognomy.

An essential feature of the descriptive system used is a diagram.* This diagram is a two-dimensional representation of a three-dimensional vegetational situation. While the diagram does not depict individuals within the vegetation assemblage, it does present the organization in space of the physiognomic types. It tells what part of the cubic dimensions of the environment are occupied by each structural element** and indicates, in addition, their distribution. Uniquely, it indicates the interrelations of the structural elements. It does not presuppose any casual relations to edaphic or climatic conditions. It does not relate area, soil, seral or successional conditions. Its primary purpose is to describe and record the vegetation which exists. In order to relate the diagram to edaphic or climatic conditions it must be related to area, and to soil conditions. This must be accomplished by employment of an adequate sampling method. For the work reported here, an important aspect of sampling involves the distribution of the vegetation components in space.

Many of the methods now employed for population distribution studies are satisfactory only when random distribution of the population occurs. Many vegetation studies have emphasized that it is rare indeed for

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* These diagrams have been designated "structural diagrams" to avoid confusion with the "profile" diagrams frequently used in ecology literature, and they will be so designated henceforth in the present paper. Note that the symbol system employed in the present paper differs from that described by Addor in the paper "Vegetation Description for Military Purposes," pp 98-128. The symbol system employed here was current at the time the work was done, but is superseded by that one. This is not especially relevant to the present purpose since the symbols per se are only a means of recording data.

** For definition of "structural element," also see ibid (Editor's note).

vegetation to be distributed in a random fashion. This fact alone is sufficient to exclude from consideration the employment of a predetermined or standard size for the sampling area. Inasmuch as the distribution in space for vegetation is subject to almost limitless variation, a concept which recognizes that a continuum exists for vegetation distribution would be much more useful. Such a continuum is recognized in the "structural cell" concept of Grabau. Such a concept does not presuppose a standard structure for vegetation formations and, in practice, will require the field determination of the frequency distribution of structural elements within a vegetation assemblage. It will require the location of a common or central spatial distribution which will statistically be repeated in any contiguous extension of the area of the structural cell. Any vegetation formation will, therefore, consist of multiple structural cells, each of which will represent a single structural element. This implies that each structural element will possess some definite structural cell size. For such a concept to be practicable, some particular structural element must be chosen, and this element will then "determine" the minimum size of the sampling area required. We have designated this element as the structural cell "determinant."

While the sampling methods require the selection of structural elements, such selection is almost wholly immaterial so far as the structural diagram is concerned. Once an adequate but minimum sampling area is ascertained for a given vegetation assemblage, the diagram presumably will not change significantly with any larger sample of that assemblage, when such sample is based upon the same structural element. However, when a structural element of low frequency is depicted in a diagram based upon a single structural element of greater frequency, then the indicated coverage of the low-frequency element will be disproportionately large (i.e., the sample area would be less than the minimum for that element). For quantitative validity, the structural diagram must be based upon at least one structural element and it is quantitated for that element. It is possible to quantitate each structural element in a diagram representing any vegetation assemblage. In this sense, the structural cell determinant represents a particular combination of structural characteristics which will be directly useful in a quantitative manner.

The sampling methods employed will, therefore, have important relations to quantification of the structural diagram. One important aspect is the size and also the shape of the sampling area. It has been found during this study that square- and rectangular-shaped sampling areas are difficult to lay out with any degree of accuracy and are time-consuming. The preferred method involves a circular sampling area. In this study, it has been found that in the curve of A/N plotted over the sample radius, a "plateau" effect occurs when the size of the sampling area is increased gradually up to the area where distribution in space (mean-area-per-individual) of the structural cell determinant approaches the random situation (i.e. the sample becomes randomized). Beyond this point a linear relation exists.

In a comparison on identical study sites it was found that no similar point could be detected in the field when using a square or rectangular sample area. This basic difference seems to make the circular sample area method much to be preferred over the quadrat method inasmuch as, apparently, a statistical evaluation is possible in the field with sophisticated simplicity.

The field methods are quite simple. With the aid of an optical range finder, all individuals of the structural cell determinant are counted within a fixed radius about the center of a less-than-minimum circle. The average area occupied by each plant is determined by the simple relation of A/N , where A = area of the circle and N = number of individuals of the cell determinant. The process is repeated, with the radius increased by arbitrary amounts. Each time the radius is increased, the number of individuals is ascertained, and the total divided into the total area of the larger circle (table 1). At some point the mean area will begin to approach an approximately constant figure which, if plotted over the radius of the sample, will show a fluctuation decreasing in amplitude around a straight line with negligible slope. Beyond some point (minimum cell diameter) the relation between mean area and sample radius approaches linearity. With contiguous (clumped) populations, the fluctuation will have greater amplitude than will be found for populations approaching true randomness, but a definite tendency to "plateau" will be found in successive increments for even the most nonrandom situation. When the plateau point is

Table 1

Typical Structural Cell Size Determinations to Illustrate Changes in Area-per-Individual

Study Site Reference No.	Radius of Circular Sampling Area	Area-per-Individual	"Plateau Diameter" Calculated from Area Having Radius Indicated
BUP-6L-162-F	7.5	59.0	39.0
	10.0	52.4	36.5
	15.0	100.0	50.0
	20.0	114.0	53.8
	25.0	140.0	59.0
	30.0	141.0	60.0
	35.0	139.0	58.9
BUP-6L-162-D	5.0	39.3	31.6
	10.0	78.5	44.7
	15.0	88.5	47.5
	20.0	114.0	53.8
	25.0	109.0	52.7
	30.0	109.0	52.7
BUP-6H-70-A	5.0	7.1	13.5
	7.5	12.6	17.0
	10.0	12.1	17.5
	15.0	13.6	17.8
BUP-5L-173-A	5.0	13.1	18.3
	7.5	14.5	19.0
	10.0	14.3	18.9
BUP-5L-40-G	5.0	78.5	44.7
	8.0	50.2	43.0
	10.0	44.8	33.5
	15.0	44.2	33.6
	20.0	41.7	33.0
	25.0	41.1	32.8
	30.0	41.3	32.9
	40.0	55.9	36.0

determined, the area so outlined is designated as the structural cell.

In the fieldwork there were some instances where the plateau could not be detected. In these instances it was found that a minimum structural cell for the element selected as the determinant was not present in the area. This was particularly true for cypress sloughs, where narrow bands of vegetation in the chosen height class were not extensive enough to include sufficient individuals for the plateau effect to occur. It is also important to note that any particular structural element will plateau at various diameters when the cell is located in areas having various distributions of the individuals (e.g. within stands as contrasted to ecotones (margins of the stand)). This, however, is not believed to be a negative feature of the method; instead it may prove useful as a valid basis for comparing and evaluating in a quantitative fashion the variations in distribution between the areas.

When the number of individuals found in a sampling area of any fixed radius is plotted against the diameter of the sampling area at which the plateau occurs, a hyperbolic curve results (fig. 1). The field data upon which the curve illustrated in fig. 1 was based included structural cells having diverse cell determinants. Such a curve fits every vegetation sample obtained during this study. When this curve is plotted on log-log

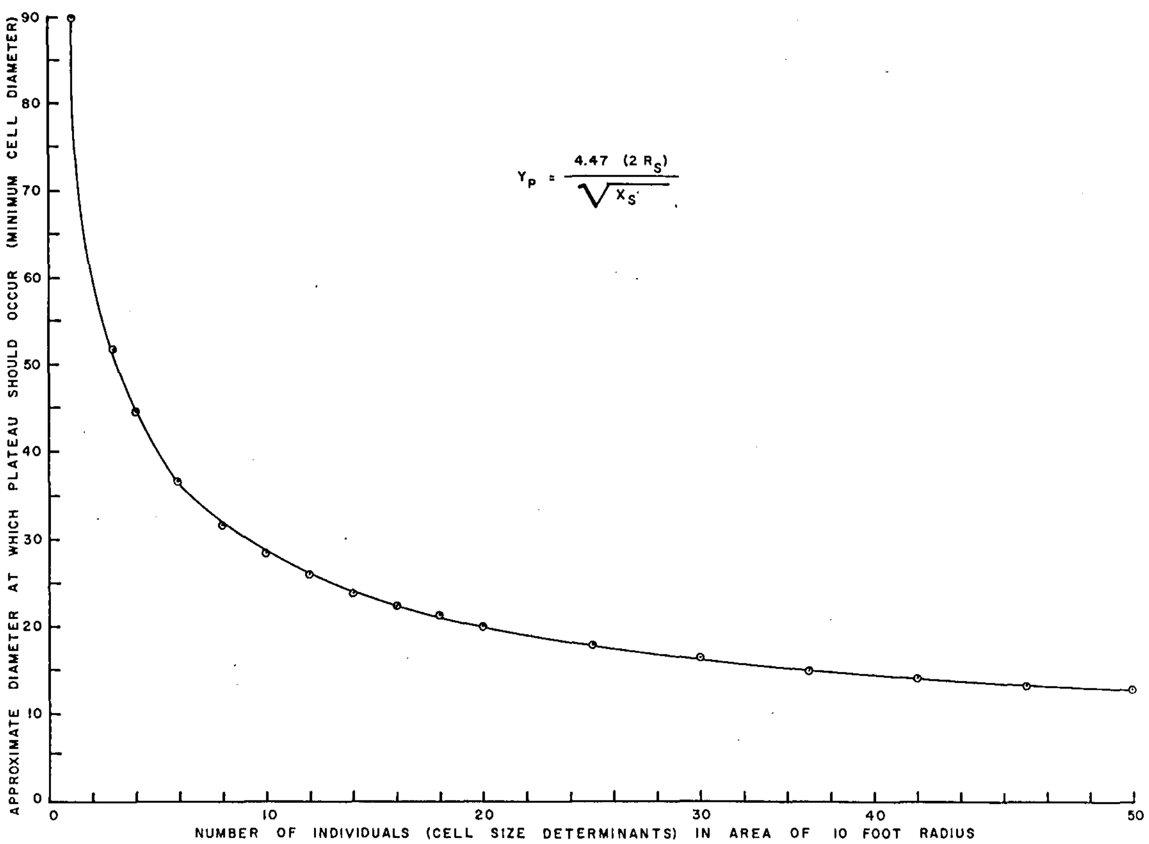


Fig. 1. Relation of minimum cell diameter and number of individuals (cell determinants) in sample plot of radius 10 ft

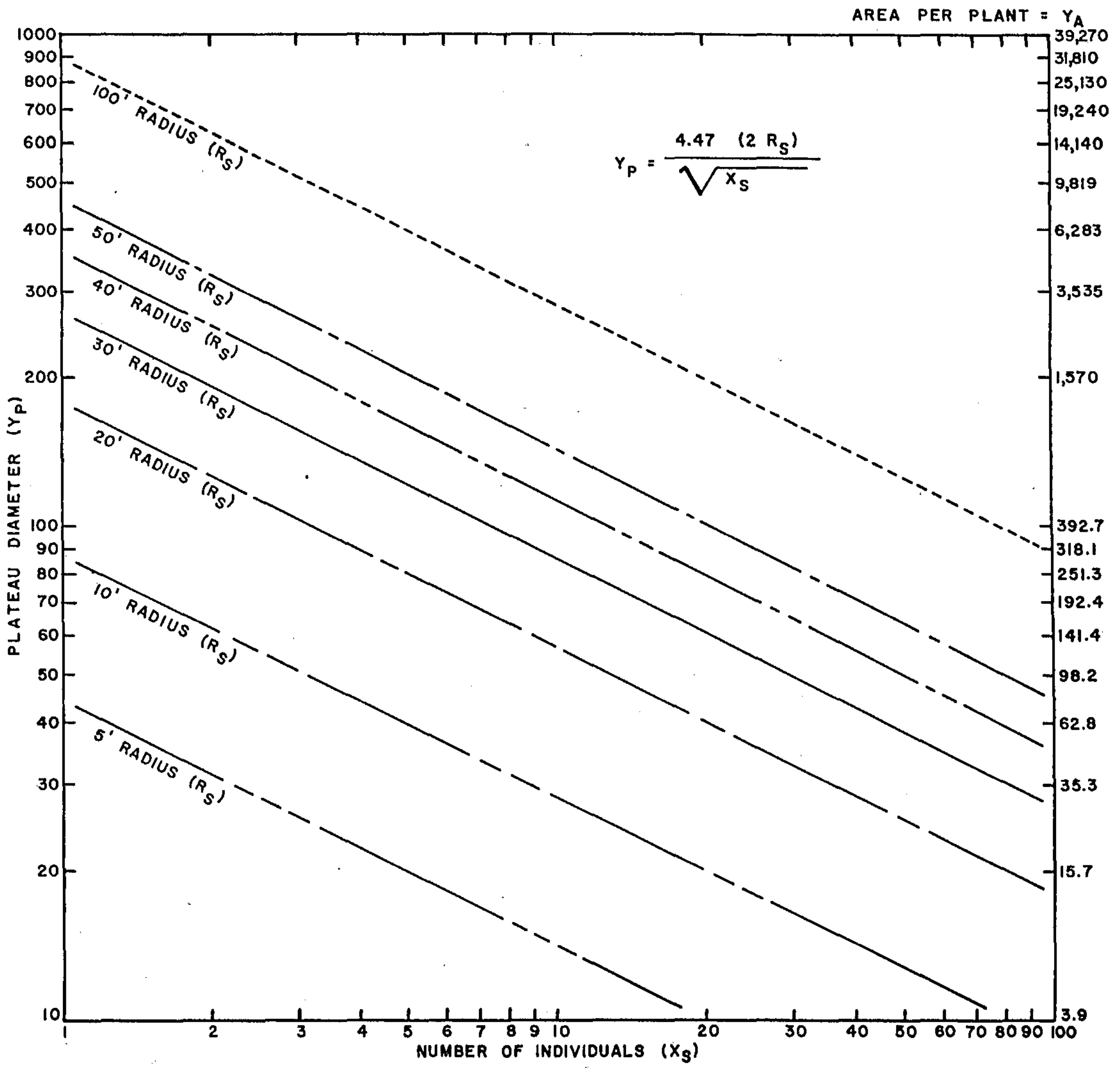
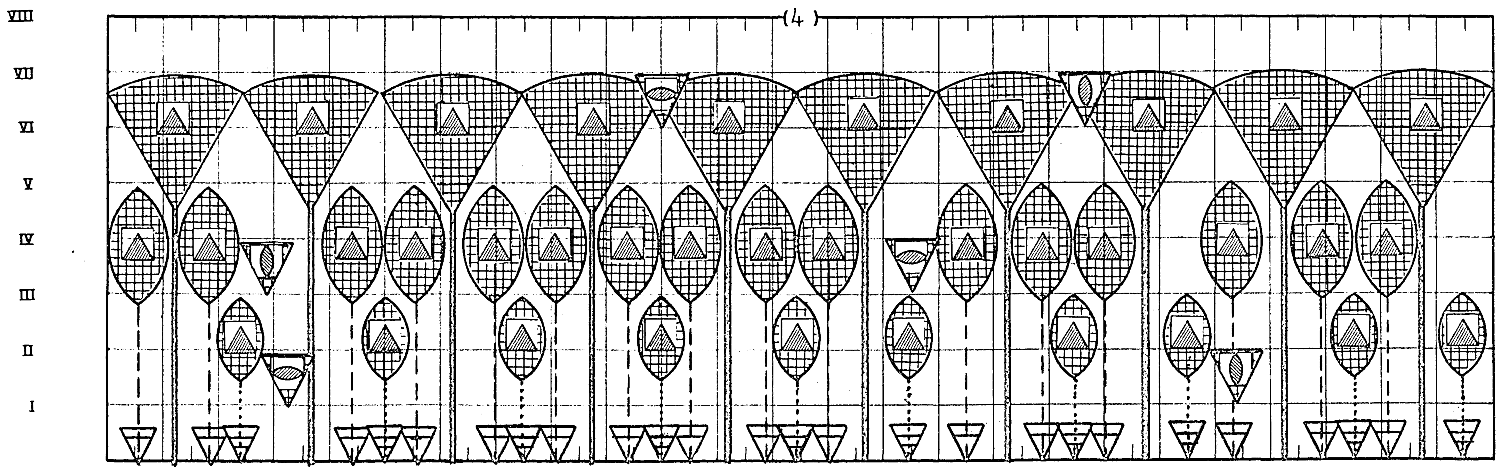


Fig. 2. Prediction of minimum cell diameter from number of individuals counted in sample plots of various radii (feet or meters)

paper a straight line results. A formula based upon this curve was derived, and apparently will calculate with predictable accuracy the minimum area required for the plateau effect to occur--for any structural element. The logarithmic relation of plateau diameter to number of individuals produces the family of curves shown in fig. 2, cell curves having the same slope but each having a displacement determined by the diameter of the sample plot. The distribution within the sample (i.e. within the structural cell) represents a mean for the distribution of any structural element (specifically the cell determinant) with given mean area in that assemblage. Analysis has revealed that the relations existing between mean area (area per

VEGETATION STRUCTURAL DIAGRAM

LOCATION BUP-4L-132-A SHEET 1 OF 2 DATE 18 July 1962



SAMPLE AREA DIAMETER 4.27 m

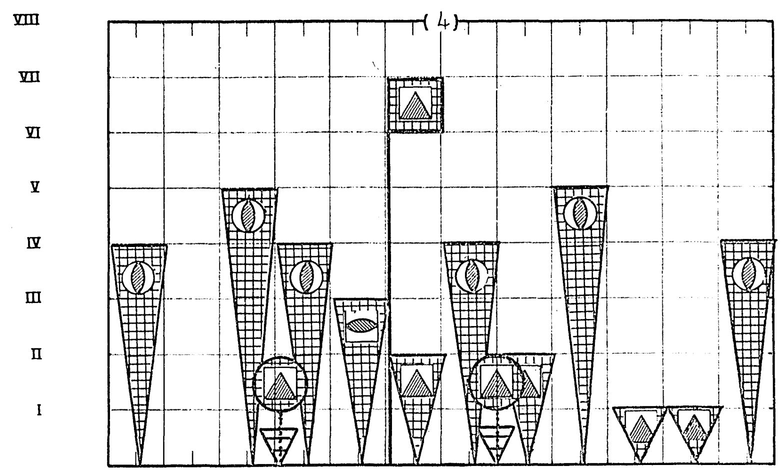


Fig. 3. Structural diagram based upon structural cell determined by plants of height class VI. The one plant of height class VII in this cell had a crown diameter equal to the structural cell diameter. It is misleadingly represented (cf. fig. 5). Note: The cell determinants, height class VI, are included in sheet 2 of 2 in the original, but not shown here

individual) and mean distances between individuals at the plateau will permit quantification of the diagram.

Quantification of the diagram is obviously dependent also upon the collection of sufficient quantitative field data for the various structural characteristics involved. In the report Quantitative Physiognomic Analysis of the Florida Everglades, methods for these purposes have been suggested.

The ultimate aim of the Everglades study was considered to be the construction of a structural diagram which would present the quantitative aspects of the vegetation assemblage. There are many aspects involving field data collection methods and diagram construction methods, which will increase or decrease ultimate quantification of the diagram. Space limitations permit discussion of only a few of the more important of these aspects.

The basic characteristic having the highest rank in the structural diagram is crown cover. In the descriptive system, cover determines the number of symbols which will represent each structural element, and coverage per symbol is a function of height class and of crown shape. Any given percent of coverage will require fewer symbols in the taller height classes than in the lower; and also, within any one height class, spindle-shaped crowns will require more symbols for any given coverage value than will other crown shapes having the same coverage value. This means that the diagram has no actual relation to the frequency of any structural element; there is no provision in the system for indicating stem frequency, either in toto or by diameter classes.

In some instances a single individual having considerable crown coverage in proportion to the size of the sample area will be represented in the diagram with multiple symbolization (fig. 3). An uninitiated observer examining such a diagram would incorrectly infer that the number of symbols indicated a dense stand of this particular structural element, when in reality there is but one individual represented, as is shown in the data sheet of fig. 4.

In this instance, it should be evident that any structural diagram depicting the coverage for this one individual was based upon a structural cell determinant other than the one in question. It is pertinent to inquire whether the structural element represented by the one individual

Structural Cell Reference Number: ________ Aerial Photograph: BUP-4L-132-A Cell Diameter: 30 feet 9.15 meters

Date: 18 JULY 62 Notes: MAHOGANY HAMMOCK
VISIBILITY — 30 ft

PLANT TYPE	HEIGHT CLASS (meters)	CROWN SHAPE	% coverage	LEAF SHAPE	LEAF TEXTURE	LEAF SIZE (sq cm.)	LEAF CONDITION	STEM DIAMETER (centimeters)	BRANCHING DIVERGE (meters)	BRANCHING HORIZ (meters)	STILT ROOTS (meters)	ENLARGED BASE (stem diam.)	ENLARGED BUTTRESS (meters)	ANNOYANCE	DISTRIBUTION	PLATEAU DIAMETER
ERECT WOODY PLANTS	VII 13 - 35 (I)	Flat X	100	B-flat X	Hard X	1 - 150 X	Lvs. green X	60 up X	2 up X							
ERECT WOODY PLANTS	VI 5 - 13 (symbol)	Spindle X	40	B-flat X	Hard X	1 - 150 X	Lvs. green X	7.5 - 15 ½; 15 - 30 ½	0 - 0.3 X						Random X	
ERECT WOODY PLANTS	V 1.5 - 5 X	Spindle X	80	B-flat X	Hard X	1 - 150 X	Lvs. green X	2.5 - 7.5 X	0.3 - 0.6 X						Random X	14
ERECT WOODY PLANTS	IV 0.7 - 1.5 X	Spindle X	53	B-flat X	Hard X	1 - 150 X	Lvs. green X	0 - 2.5 X	0 - 0.3 X						Random X	
ERECT WOODY PLANTS	III 0.3 - 0.7 X	Spindle X	30	B-flat X	Hard X	1 - 150 X	Lvs. green X	0 - 2.5 X	0 - 0.3 X						Random X	
ERECT WOODY PLANTS	II 0.1 - 0.3 X	Round X	10	B-flat X	Hard X	1 - 150 X	Lvs. green X	0 - 2.5 X	0 - 0.3 X						Random X	
STEM ONLY																
ERECT NON-WOODY PLANTS	V 1.5 - 5 X		10	L-flat X	Hard X	150 up X	Lvs. green X								Random X	
ERECT NON-WOODY PLANTS	IV 0.7 - 1.5 X		16	L-flat X	Hard X	150 up X	Lvs. green X								Random X	
ERECT NON-WOODY PLANTS	III 0.3 - 0.7 X		4	Needle X	Hard X	1 - 150 X	Lvs. green X								Random X	
ERECT NON-WOODY PLANTS	II 0.1 - 0.3 X		10	B-flat X	Hard X	1 - 150 X	Lvs. green X								Random X	
ERECT NON-WOODY PLANTS	I 0 - 0.1 X		10	B-flat X	Hard X	1 - 150 X	Lvs. green X								Random X	
CLIMBING	I–VII: N N N N N N N	Lianas woody gr. X	4	B-flat X	Hard X	1 - 150 X	Lvs. green X	7.5 - 15 X							Random X	
AIR	II N; IV N; VII N		4	Needle X	Hard X	1 - 150 X	Lvs. green X								Random X	
AIR	II N; IV N; VII N		4	L-flat X	Hard X	1 - 150 X	Lvs. green X								Random X	
SPRAWLING																

Height classes: I 0 - 0.1; II 0.1 - 0.3; III 0.3 - 0.7; IV 0.7 - 1.5; V 1.5 - 5; VI 5 - 13; VII 13 - 35; VIII 35 - 100. Crown shape: Round, Flat, Pointed, Spindle, Tabular (woody / non-woody; Lianas gr. epi.; Vine gr. epi.). Leaf shape: Needle, L-flat, B-flat. Texture: Filmy, Papery, Hard, Succul. Size: 0 - 1, 1 - 150, 150 up. Condition: Absent, Dead-clinging, Lvs. green, Twig gn-no lv., Fungi. Stem diameter: 0 - 2.5, 2.5 - 7.5, 7.5 - 15, 15 - 30, 30 - 60, 60 up. Diverge: 0 - 0.3, 0.3 - 0.6, 0.6 - 2, 2 up. Horiz: 0 - 0.5, 0.5 - 1.5, 1.5 - 3.0, 3 up. Stilt roots: 0 - 0.3, 0.3 - 0.6, 0.6 - 2.0, 2 up. Base: 0 - 2X, 2 - 4X, 4X up. Buttress: 0 - 1, 1 - 2, 2 - 4, 4 up. Annoyance: Multiple, Spines, Stinging, Cutting, Poisons. Distribution: Random, Clumps, Patches, Grid, Rows, Strips.

TO CALCULATE DIAMETER OF A STATISTICALLY-PROBABLE-MINIMUM CIRCULAR SAMPLING AREA (PLATEAU DIAMETER) FOR ANY DESIRED VEGETATION TYPE USE THE FORMULA:

$$\text{PLATEAU DIAMETER} = \frac{4.47\ (\text{DIAMETER OF AREA SAMPLED})}{\sqrt{\text{NUMBER OF INDIVIDUALS OF TYPE CHOSEN WITHIN AREA SAMPLED}}}$$

THE PROBABLE SAMPLING ERROR (95% CONFIDENCE LIMITS) WILL BE:

LESS THAN 20% - IF THE NUMBER OF INDIVIDUALS IN AREA SAMPLED EXCEEDS EIGHT;

LESS THAN 10% - IF THE NUMBER OF INDIVIDUALS IN AREA SAMPLED EXCEEDS FIFTEEN;

LESS THAN 5% - IF THE NUMBER OF INDIVIDUALS IN AREA SAMPLED EXCEEDS TWENTY.

MARSHALL UNIVERSITY EVERGLADES PROJECT FIELD DATA SHEET - REVISED: 14 NOV 62

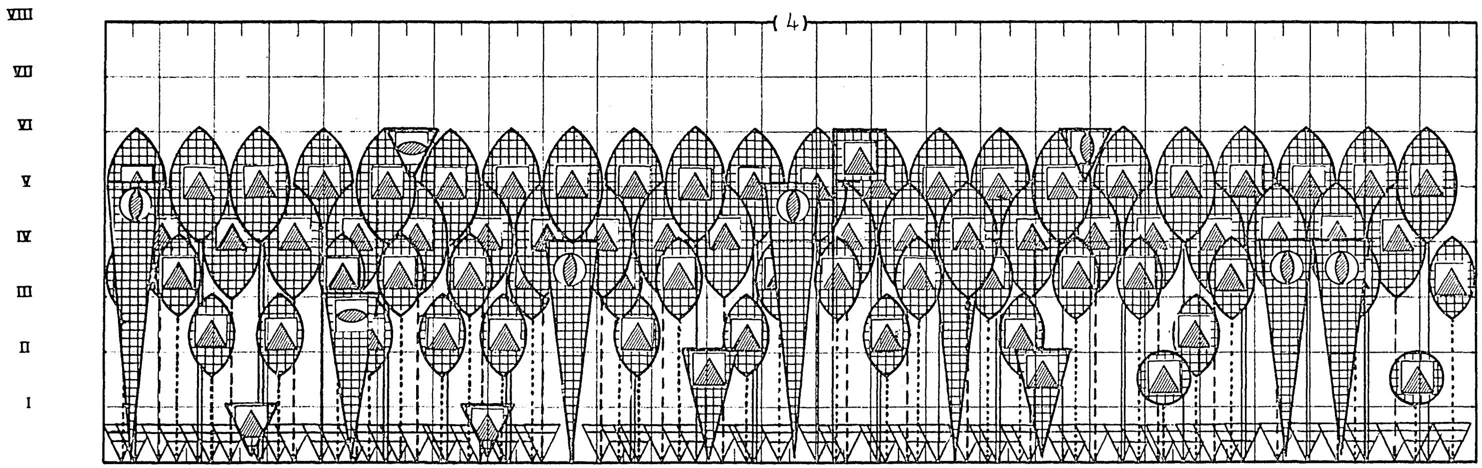
Fig. 4. Data sheet with data upon which was based the structural diagram shown as fig. 3

should have been used as the structural cell determinant. This element certainly represents a less frequent element in the vegetation assemblage and must be more widely spaced than is the one chosen as the cell determinant. Usually the selection of such an infrequent structural element would mean that the area of the sample would become very large and the analysis of the vegetation much more complicated and time-consuming.

In the Florida studies, it was found that even if the less frequent element was used as the determinant, the structural diagram did not differ materially from that based upon a more frequently occurring element. The one item which was markedly different was the cover percentage assigned to the one individual; this was always grossly overrated in the smaller sampling area. It should be clearly understood that the solution of the problem does not lie in the elimination of such an individual from consideration as a possible structural cell determinant. This individual and its coverage must always be depicted in the diagram. When considered separately, the basic problem involves the manner in which cover for such an individual is to be considered. While this may be approached in several ways, the method finally selected must not prevent quantification of the individual in the diagram. Neither should the depiction of this element convey the false impression that its frequency is such that it is in fact the structural cell determinant for the sampling area indicated on the diagram. Because the diagram accords high rank to cover, the minimum sampling area should have a relation to individual crown cover, but must of necessity be based on a structural element of sufficient frequency for statistical validity and for precise diagram interpretation. The diagram of fig. 3 has been reconstructed in fig. 5 with the single individual of height class VII included in the mean-area determination. In this sense it is not strictly a structural cell determinant since the cell has been determined by height class VI plants; but its frequency has now been quantitated in proper relation to the determinants. Note that it is now shown in the supplementary diagram. There is now no doubt that this individual is not the structural cell determinant. The impression that there exists a forest of such individuals could not be conveyed to the most uninitiated observer. Its frequency relation to that of the structural cell determinant can now be quantitated.

VEGETATION STRUCTURAL DIAGRAM

LOCATION BUP-4L-132-A DATE 18 July 1962



SAMPLE AREA DIAMETER 4.27 m

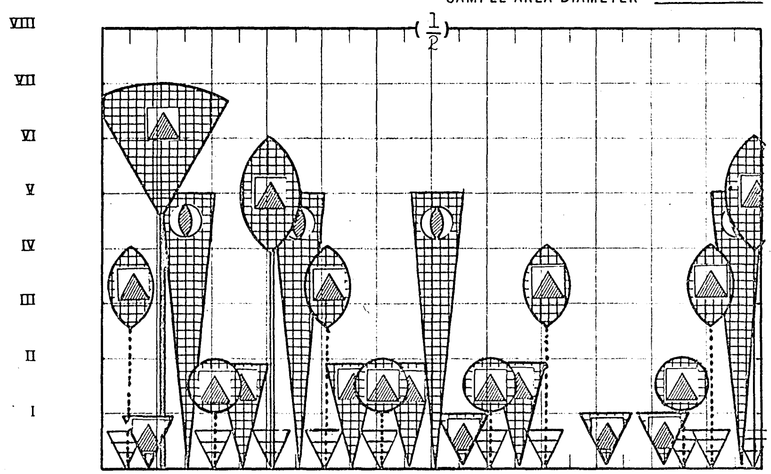


Fig. 5. Structural diagram of fig. 3 reconstructed, with plant of height class VII included in mean area determination

An alternative method of handling the above problem would be to calculate the probable area of a structural cell based upon the infrequent element. The coverage percentage so determined would then be used to depict the one individual in the diagram based upon and indicating the cell diameter for the structural cell determinant having suitable frequency. With this method, also, the number of stems should be quantitated in terms of the structural cell determinant.

The calculations which relate stem diameter frequency to cover are summarized as follows:

a. Total stem count shown on data sheet divided into the number of stems for each diameter class (× 100) equals the percentage of stems for each diameter class.

b. Total cover for the height class divided by the coverage-per-crown symbol for the structural element equals number of symbols to be depicted on the diagram.

c. Number of crown symbols to be depicted on the diagram multiplied by the percentage of stems for each diameter class equals the number of crown symbols to be depicted with a stem diameter symbol.

The method outlined permits quantification of the diagram for the number of individuals involved in the symbolization shown. It simplifies field collection of data since it is not necessary to make separate horizontal-line entries on the data sheet for each stem diameter class. The infrequent structural element, by being included in the total coverage of the symbolization which is quantitated, has been assigned a correct stem and stem diameter frequency. While its coverage in relation to the actual sampling area has been reduced drastically, it more nearly reflects what its percentage cover would be if a minimum sampling area based on it had been studied.

In a minimum cell, find for the cell determinants the ratio of the number of symbols having a given stem diameter class to the total number of symbols for a given crown shape and height class multiplied by 20 equals the number of individuals with the given stem diameter in the area of the structural cell. Any variable plant characteristic may be handled in much the same manner and will permit quantification of the diagram for this characteristic. Similarly, the diagram may be interpreted by dividing the total number of crown symbols of the cell determinant into the number of

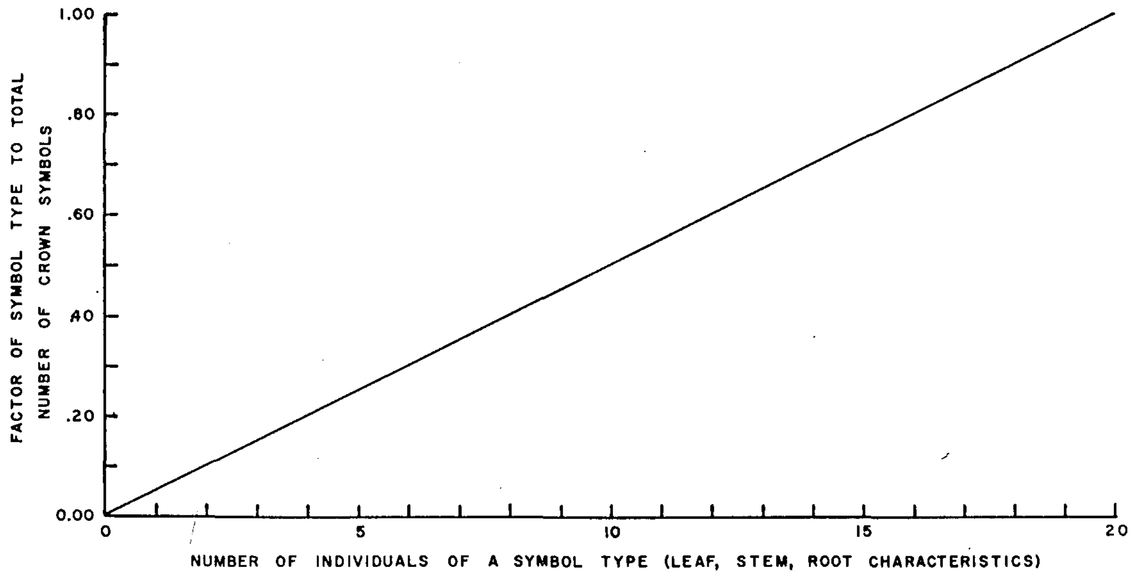


Fig. 6. Frequency of any given plant characteristic to number of crown symbols within a height class (coverage-frequency correlation)

crown symbols with a particular stem diameter class (or any other characteristic). The figure obtained equals the factor shown on the Y axis of fig. 6. The number of individuals for the factor is determined by the intersect of the graph (factor $\times$ 20).

The system as now envisaged employs a structural diagram which is divided into 25 horizontal divisions. This horizontal dimension is a measure of the area of coverage of the structural elements classified by the descriptive system. As such, it is understood that the total coverage possible for any structural element (without overlap) will be 100 percent for any height class. The basic value of one horizontal unit will then be equal to 4 percent coverage. The coverage value for any structural element in the study site is related to the space occupied by the crown symbol representing this element in the diagram. As the height of the woody vegetation decreases, the crown symbol becomes smaller, both vertically and horizontally (i.e. will represent less cover per symbol). Within any height class there are varying horizontal dimensions among the symbols for the different crown types. The total coverage value found for a particular structural element and recorded on the data sheet must be converted into the appropriate crown symbol (type) of the proper size for the height class involved. It is a common occurrence that the total coverage when divided by the cover-per-crown-symbol-value will involve fractional symbolization. If the fractional symbol exceeds one-half symbol this may be represented at the diagram margin (i.e. one-half symbol being shown). However, it also is a common occurrence to have fractional symbols for many structural elements and height classes. This means that the margin of the diagram is likely to become excessively cluttered with fractional symbols.

This problem has been overcome through the use of a supplementary diagram which may be assigned any coverage value for a grid unit. In this way, the fractional symbols having less than one-half total symbol in the main diagram can be shown on the supplementary diagram as whole symbols, or multiples of whole symbols. The coverage value for the supplementary diagram must, of course, be indicated if the information presented there is to be related properly to the principal diagram.

In the transfer of field data, it is a common occurrence to have differing fractions of symbols among the various structural elements which must be diagrammed on the one supplementary diagram having but one coverage value per grid unit. The decision as to what coverage value will most nearly represent the coverage (in terms of symbols) for each individual structural element having fractional symbols involves some time-consuming calculations, and in many instances a suitable decision is extremely difficult. The graph shown as fig. 7 has been designed to indicate not only what scale on the supplementary diagram will be required to diagram the fractional symbol as a complete symbol, but also to permit a rapid decision as to the proper scale value when several symbol types with varying fractional percentages are to be included on the supplementary diagram. This graph is also useful in relating the symbolization of the supplementary diagram to the main diagram whenever quantitative interpretation is desired.

Another problem merits considerable attention. When the coverage value is determined separately for each crown shape within a height class, it is oftentimes found that there is the problem of symbolization of all these shapes at the individual values for cover determined in the field. This problem is encountered whenever the sum total obtained for the combined coverage of the various structural elements within the height class exceeds 100 percent. For small percentages above 100 percent the necessary overlap does not present a serious diagram interpretation problem. However,

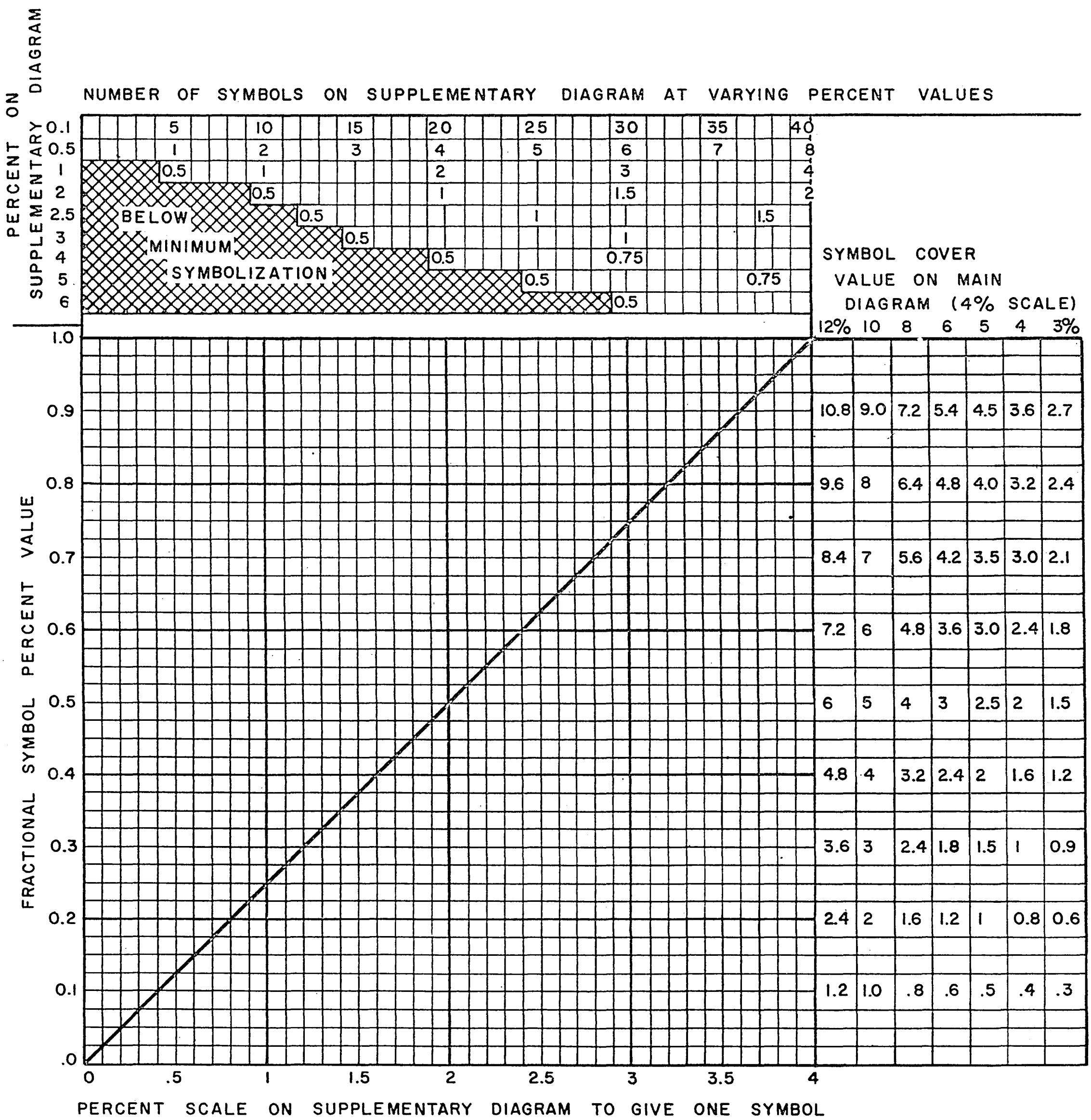


Fig. 7. Supplementary diagram symbolization values for fractional symbols of main diagram

with increasing percentage above 100 percent cover, the problem of diagram interpretation becomes acute inasmuch as subordinate characteristics included within the crown symbol, and also stem characteristics, may be obscured by excessive overlap. In many instances the problem may be solved by zigzagging the various symbol types so that some of each type will be visible in sufficient degree to show these interior symbolizations and stem characteristics. However, for many tropical situations having many structural elements within a height class, there may be low percentage values per structural element, but excessive total coverage (much above 100 percent). In such instances an overlapping pattern of symbols, as outlined above, may not be satisfactory.

A possible solution to this problem would be to prohibit symbolization above 100 percent for any height class. This seems to be a reasonable approach, inasmuch as the method involved in mapping vegetation cover always excludes overlap. Also, inasmuch as the diagram does not depict any actual individuals in the vegetation complex, the assignment of prorated coverage values to the various structural elements within a height class is sufficient for quantitative purposes.

For the quantitative interpretation of the structural diagram the following information must be either presented on the diagram or must be deduced from it:

<u>a</u>. The "Sample Area Diameter" indicated must be that of the minimum cell diameter (i.e. plateau diameter).

<u>b</u>. The structural cell determinant must either be indicated in some manner on the diagram or should be obvious by visual examination of the diagram.

It would be entirely satisfactory to indicate on the diagram any sample plot diameter in excess of the minimum structural cell, inasmuch as the minimum represents the threshold where size of the sampling area is linearly related to the number of individuals, mean-area, and to mean distance between individuals. These in turn are related to all other characteristics. However, this is not desirable for two reasons:

<u>a</u>. Once the minimum plateau diameter is exceeded, the diagram cannot be easily compared with another so as to evaluate differences between study sites. Diagrams indicating arbitrarily chosen diameters must be quantitated on the basis of values more difficult to derive, and having less reliability.

<u>b</u>. Whenever the indicated sampling area exceeds the minimum plateau diameter, the relations found at the plateau will vary in degree for each diagram. This will necessitate including considerably more quantitative information on the diagram.

For the vegetation studied in the Everglades, it is apparent from the field data that the plateau occurs when approximately 20 individuals of the structural element selected as the structural cell determinant have been included in the sampling area. We believe that the plateau occurs precisely with 20 individuals, but the field data, which are based usually on radii increments of 2.5 to 5 ft, do not permit precise determination of the number. However, the equation which was derived from field data tends to indicate that this is the situation since when the number of individuals in the sampling area equals 20, the plateau equation becomes (fig. 1)

$$\text{plateau diameter} = \frac{4.47\ (d_s)}{\sqrt{20}} = \frac{4.47\ d_s}{4.47}$$

where d_s is the diameter of the sample and, at this point, the plateau diameter equals the sampling area diameter. Therefore the number of individuals of the cell determinant depicted in the diagram should equal 20. Furthermore the coverage value found for this structural element, and represented by the diagram symbolization, irrespective of the percent coverage values and the number of symbols depicted, is that of 20 individuals. This relation is then correlated to all other symbolizations when the "Sample Area Diameter" indicated on the structural diagram is that of the minimum cell diameter. All structural elements may be equally quantitated by counting 20 individuals and determining the area which includes these individuals. They may also be quantitated on a height class basis so that all symbolizations of any diagram for the height class would include 20 individuals. This method would lower the precision somewhat but, in most instances, it would be sufficiently valid for most purposes.

At the plateau there exist mathematical relations between area-per-individual and mean distance between individuals which very closely approximate actual field measurements for these relations. The linear relation of minimum plateau diameter to distance between individuals is shown as fig. 8. The logarithmic relation of area-per-individual and mean distance between individuals is shown as fig. 9.

The relations indicated above are based upon circular sampling areas, and they differ from those based upon square and rectangular areas. The relations indicated by Braun-Blanquet for mean distance between individuals and area-per-individual show that mean distance is equal to the square root of the area-per-individual. It is evident that the difference is related to the geometry involved. In field studies attempting to compare the circular sampling method with rectangular methods, it was found that for each

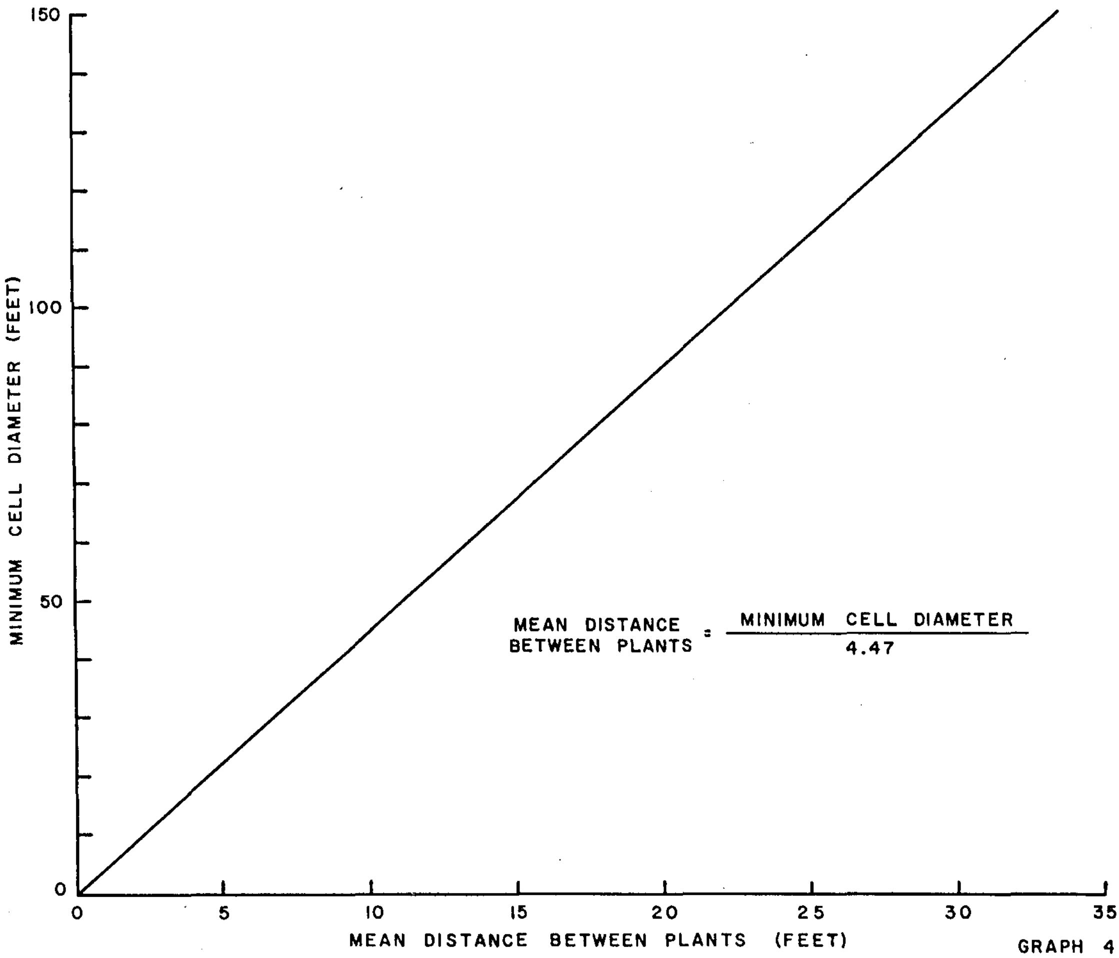


Fig. 8. Relation of cell diameter to mean distance between plants

individual counted in the circular method there was approximately 1.5 individuals counted in a quadrat having an area equal to the circular area for the same study site and identical distribution in space of the individuals. Thus, the mean-area-per-individual in our circular area multiplied by 0.67 (i.e. 1/1.5) would approximate the mean-area-per-individual found for the quadrat. Published data based on quadrats agree closely with our findings upon conversion of the data (mean-area for quadrat multiplied by 1.5 equals approximately the mean-area for our circular sampling area).

Cottam and Curtis have found for hexagonal distribution that the mean distance between individuals will be equal to 1.075 the square root of the mean-area. Also, Cottam, Curtis, and Hale have found that distances between closest individuals in a random population bear a constant relation to the square root of the mean-area. Calculations, based upon plots of

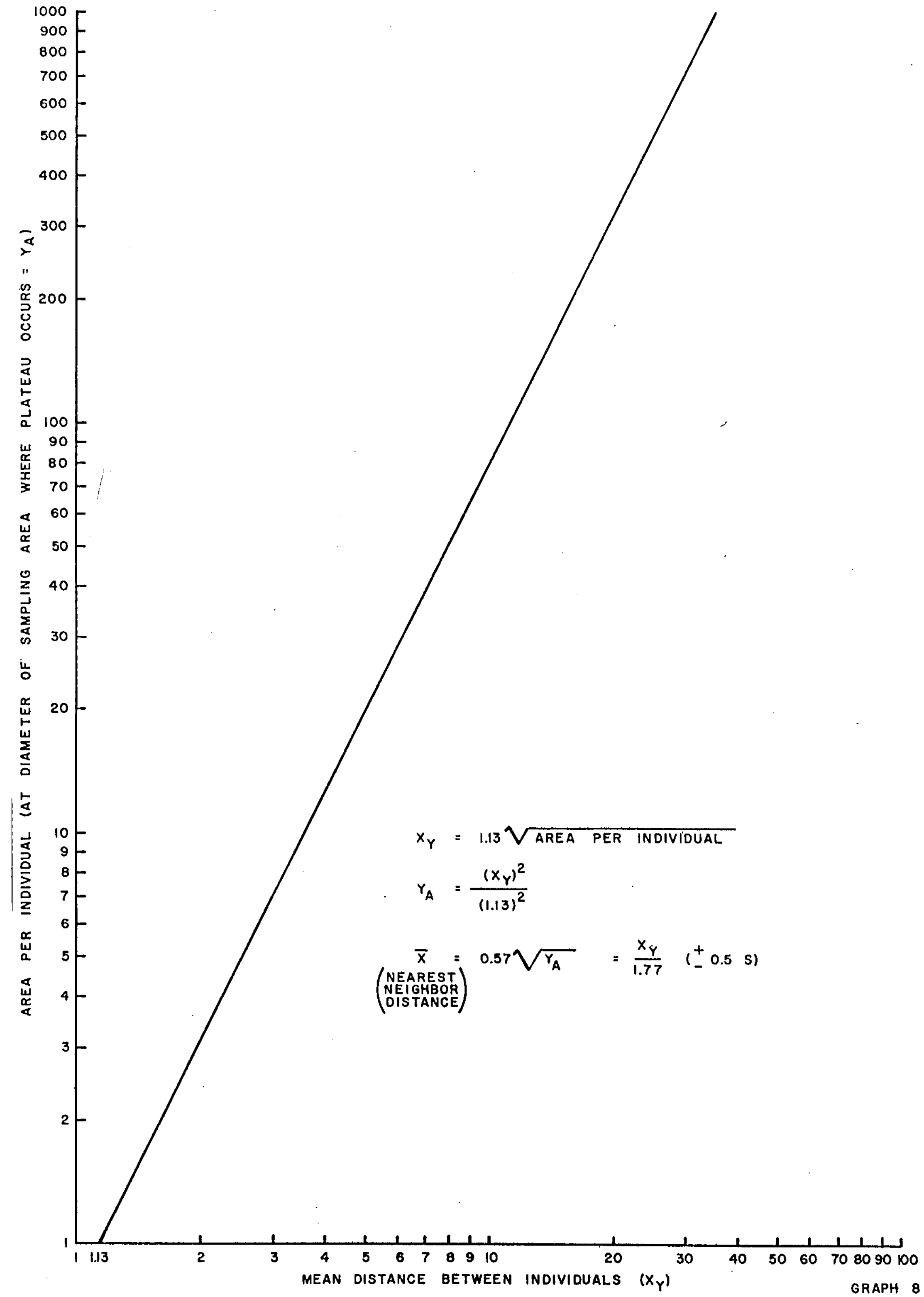


Fig. 9. Relation of area per individual to mean distance between individuals, in a sample of minimum (plateau) diameter

vegetation assemblages which included several height classes, indicate that a rather precise relation exists between area-per-individual and mean-distance-to-nearest-neighbor. Mean-distance-to-nearest-neighbor equals 0.57 the square root of mean-area and is also equal to mean distance between individuals divided by 1.77. These relations, for our field data, are precise to within plus or minus one-half standard deviation of field determinations for mean distance between nearest neighbor. Grabau has stated that in any array of randomly distributed points the most probable distance from one point to its nearest neighbor closely approximates 0.6 the square root of the mean-area per point. Our 0.57 the square root of the mean-area per individual, from field data, is remarkably close to that for Grabau's random population.

Stem diameter classes and other stem, leaf, root characteristics are quantitated in the diagram by a simple ratio between crown type and the characteristic under consideration. For example, if there are eight crown symbols for a cell determinant and three of these are depicted with stem diameter symbol for 30-60 cm, then, in the area of the minimum cell indicated there will be 3/8 of 20 individuals having this diameter class. The plateau diameter for the stem diameter class may be calculated from the plateau formula or estimated from graph of plateau curves (fig. 1) by locating 7.5 individuals on the X axis and, for curve equal to one-half of the diameter shown on the diagram, the probable plateau situation is read on the Y axis. The plateau diameter is then related to mean-distance-between-plants. The mean-distance-between-plants is then related to area-per-individual. For the example given, the area-per-individual calculated will be within plus or minus 20 percent of the mean-area obtained in the field. The mean-distance-between-individuals calculated in this fashion will be approximately plus or minus 10 percent of the field determinations.

ENVIRONMENTAL DATA COLLECTION, PUERTO RICO

by

Bob O. Benn[1]

Introduction

The Area Evaluation Section (AES) of the Waterways Experiment Station (WES), in carrying out environmental research to describe and compare areas in terms of the impacts of their climatic and terrain characteristics upon military activities, has divided the total environment into factor families. These families include surface macrogeometry, surface microgeometry, hydrologic geometry, surface composition, and vegetation. The mission of the Tropical Terrain Research Detachment (TTRD) is to collect basic environmental data for the development of quantitative terrain descriptive systems for microgeometry, surface composition, and vegetation, as outlined in Plan of Tests; Tropical Soil Studies in Panama and Puerto Rico, WES, 1962.

The scope of this report will be limited to a discussion of the surface composition (soils) and vegetation data being collected. Microgeometry data are excluded because these measurements have been temporarily suspended in Puerto Rico.

Soils Data

Soils data are being collected in Puerto Rico and other tropical areas to accumulate basic knowledge of in situ physical and environmental characteristics that will have a direct military application, as well as being useful in studies associated with predicting the trafficability of soils. The field program was devised to provide soil, weather, and other environmental data that could be used in two studies related to trafficability prediction: (a) a study to develop a method for predicting moisture content and soil strength of the surface soils in tropical climates, and (b) a study to develop a trafficability classification scheme for tropical soils.

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[1] Project Engineer, WES Tropical Terrain Research Detachment, San Juan, Puerto Rico.

Soil-moisture prediction method

A soil-moisture prediction method has been developed for soils in the temperate climates--specifically for soils in the United States. The method is tentative and the relations used therein are being refined as additional data become available. Use of the prediction method permits one to make fairly accurate estimates of the moisture content of the 0- to 15-cm (0- to 6-in.) and 15- to 30-cm (6- to 12-in.) layers of soil on a day-to-day basis. If the moisture content of the soil is known the strength can be predicted, and if the strength is known the trafficability of the soil can be predicted. Thus, if the vagaries of weather and the characteristics of the soil are known or can be estimated, one can predict the trafficability of the soil for any period of time.

Prior to the current studies in Puerto Rico and Panama, data had been collected in Puerto Rico in 1955 and 1956 and in Panama in 1955 for the purpose of determining whether the prediction system as developed for soils in temperate climates could be also applied to soils in tropical climates. From the results of these earlier studies it was concluded that the techniques of the prediction method were applicable to tropical soils. However, it was recommended that additional research be conducted on additional soil types and environmental conditions to determine valid basis for the development of reliable prediction factors. The large amount of data currently being collected from sites in Puerto Rico, Panama, Costa Rica, and Colombia, and that recently collected from sites in Hawaii should provide this information.

Soil trafficability classification

A trafficability classification scheme has been developed for soils in humid-temperate climates, specifically for those soils in the United States. The study involved a statistical analysis of wet-season strength for each soil type (classified in the Unified Soil Classification System (USCS) and U. S. Department of Agriculture (USDA) textural terms) for soils located on high and low topographic positions, respectively. From the data one can estimate the probability of "go" for any military vehicle on any soil during or several days after rain. A similar analysis will be conducted for soils located in the humid-tropical climates and a classification scheme will be developed similar to the one presently available for soils in humid-temperate climates. Periodic data collected during the year at sites established for moisture-prediction purposes as well as data collected once during the study period will be used in this study. Analysis of these data will be made by the Army Mobility Research Center (AMRC), WES.

Selection of prediction-development and satellite sites

Both studies required the establishment of sites for the continued and detailed collection of soil moisture and soil strength data; these sites are called either "prediction-development" (PD) sites or "satellite" sites, depending on the detail of the data taken. The selection of a location for installing a PD or satellite site was made after considering a number of factors including accessibility of the area, soil type, topography, and climatic type. Soil type was given considerable weight in the selection of sites as the Soil Conservation Service is in the process of remapping the soils of Puerto Rico and is in a position to have very good first-hand knowledge of soil types that could be classed as problem soils.* Consideration of the topography location was made to avoid duplication of test sites and to ensure that a high percentage of the test locations would be in problem soils. Sites were located in as many climatic types as possible ranging from the very wettest locations (El Yunque) to the driest (Lajas Valley).

Vegetation Data

Measurements of vegetation structure are being made to develop a quantitative descriptive system of the vegetation mass on the earth's surface. In the final form this system must include all constituents of the vegetation structure that will produce an identifiable effect on a military activity. The techniques being used to measure the vegetation structure at the present time are an extension of a system proposed by Dr. Pierre Dansereau.** Analysis of these data will be made by the AES and their contractors.

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* Problem soils for this phase of the study are defined as soils that would vary from a "go" to a "no go" condition with changing climatic conditions.

** Assistant Director of the New York Botanical Garden. He is at present under contract with WES to map the vegetation of Puerto Rico.

In the initial stages of the program it was planned to establish a few PD sites and several satellite sites, and to collect all data on all sites. After detailed reconnaissance of the island, it became apparent that separation of the data collection scheme into two separate parts (soils and vegetation) would be advantageous and necessary if an economical means of measuring the variations in the vegetation structure were to be attempted. This was due to the fact that a small change in topographic position caused a significant change in soil type; also the agricultural practices in Puerto Rico did not allow much variety in the land use of a specific soil type.

The selection of the first 18 vegetation sites was made on the recommendation of Mr. Roy Woodbury, Staff Botanist, Insular Experiment Station, Rio Piedras. They were selected to encompass the broad structural variations in the natural uncultivated vegetation in climatic areas ranging from wet to dry. The next 16 sites were selected from apparent textural changes appearing on aerial photographs flown in 1951. The next 32 sites were selected by Dr. Dansereau. Selection of at least some additional sites will be made on the basis of studies of recent large-scale aerial photographs--scale 1:2,500 or 1:5,000.

Data Collected from Study Sites

In addition to the PD, satellite, and vegetation sites, there are two types of "special purpose" sites. These are called Puerto Rico Comparative Soil Study Sites and Puerto Rico Soil Stabilization Sites.

Prediction-development sites

The PD site is laid out in a rectangular plot 21 ft wide and 36 ft long (fig. 1). It is then subdivided into 3-ft squares. Three of these squares, preselected randomly, are sampled at each visit. The data collected daily, periodically, and one-time are given in table 1.

Table 1

Field Data Collected on Prediction-Development Sites

Type Collection	Type Data
Daily	Rainfall
	Depth to water table

(Continued)

Table 1 (Concluded)

Type Collection	Type Data
Daily (Continued)	Fiberglas electrical-resistance unit readings Pertinent notes
Periodic	Cone index; 3-in. increments to 18 in. Remolding index; 6- to 12-in. depth Moisture content; 3-in. increments to 18 in. Soil density; 3-in. increments to 18 in. Vegetation
One-time	Site description Bulk samples; 6-in. increments to 18 in., for laboratory testing San Dimas cores, for determining moisture content at saturation and at 60-cm water tension

Fig. 1. A prediction-development site located in the western part of the island, approximately 5 miles north of Mayagüez

Satellite sites

The satellite site is circular with a radius depending on the vegetation growing on the site (this will be explained in more detail under vegetation sites). The data collected periodically and one-time for these sites are given in table 2.

Table 2

Field Data Collected on Satellite Sites

Type Collection	Type Data
Periodic	Cone index; 3-in. intervals to 18 in. Remolding index; 12-in. depth Moisture content; 3-in. increments to 12 in. Soil density; 3-in. increments to 12 in. Depth to water table Water table max-min gauge reading Vegetation Pertinent notes
One-time	Site description Bulk samples at 6-in. increments to 12 in., for laboratory testing San Dimas cores, for determining moisture content at saturation and at 60-cm water tension

The soil data are collected from two plots selected at random within the text plot.

Puerto Rico comparative soil study sites

These sites were selected to provide basic data for a comparative study of trafficability and other engineering soil properties determined by laboratory tests in order to compare and evaluate the magnitude and range of physical characteristics of the selected tropical and temperate soils. Four main groups will be compared: red clays from basic rock, red clays from acidic rock, black clay soils from water deposits, and silty soils from one or more geographic locations of both climates having, as far as possible, similar soil class, parent material, topography, and plasticity. Data collected are given in table 3.

Table 3

Field Data Collected on Puerto Rico Comparative Study Sites

Type Collection	Type Data
One-time	Site description Cone index at 20 locations at 3-in. intervals to 18 in.

(Continued)

Table 3 (Concluded)

Type Collection	Type Data
One-time (Continued)	Remolding index at 20 locations at 6- to 12-in. depth
	Moisture content, 6- to 9-in. and 9- to 12-in. depths
	Soil density, 6- to 9-in. and 9- to 12-in. depths
	Bulk samples, 6- to 12-in. depth, for laboratory testing

Puerto Rico soil stabilization sites

Undisturbed and disturbed samples were taken from three locations on the island to provide material upon which research on the stabilization of soils in tropical environments will be conducted. The Massachusetts Institute of Technology has contracted with WES to do this research. Samples collected on these sites are as follows:

a. One cubic foot undisturbed soil sample, 3- to 15-in. depth

b. One hundred pounds disturbed soil sample, 3- to 15-in. depth

Vegetation sites

The techniques and equipment used to record the vegetation measurements taken on these sites are in part unique with the Puerto Rico detachment. It should be pointed out that most of the effort has been devoted to gathering the field data and only a small portion has been expended in the presentation of data. Much emphasis has been given to detail and accuracy of the data taken within the specified limits. To this end each plant in the dominant height classes was considered separately, given a type number, and mapped on the plan sheet. These data can then be carried to the office and the necessary computations made to convert this information to the structural diagram. The examples below will demonstrate how the size of sample cell is selected, how the data are collected, and how the data are presented on the structural diagram.

Sample cell size determination. The size of the structural cell is determined as follows:

a. A typical or common structural type is selected that occurs frequently enough to have considerable significance in the vegetation population, but does not occur so frequently that it would yield so small a cell diameter that other individuals in the population having considerable significance would not be properly represented in the cell diameter.

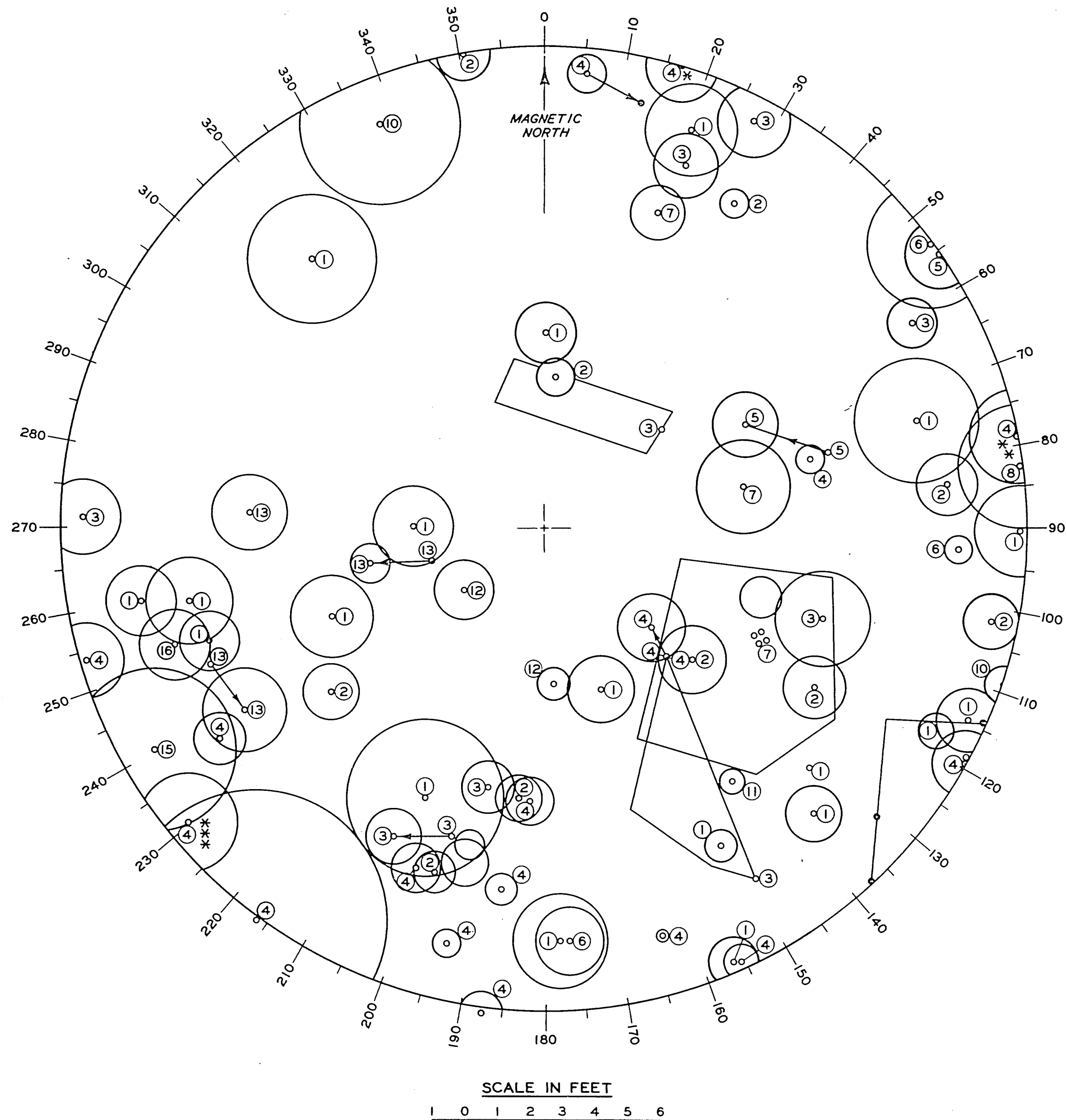
b. At least eight individuals in a given radius are counted and the structural cell diameter is predicted using a prediction of minimum cell diameter graph (Mills; "Quantitative Environmental Studies, South Florida," fig. 2, p 153).

c. The predicted cell diameter is checked to ensure that 20 individuals are included in the predicted cell diameter; if not, the cell diameter is increased to include 20 individuals.

Mapping of the plant type. After the cell diameter has been determined the plane table is set up in the center of the test plot and oriented on magnetic North (fig. 2). Starting with the lowest mappable height class and using the alidade and range finder, the location of the stem of each plant is plotted on the plan data sheet (fig. 3), the type number is recorded near the point where the stem is plotted, and then the outline of the crown is plotted on the plan sheet. If the plant crown is nearly circular, the maximum and minimum diameter is averaged and is plotted on the plan sheet as a circle. If the plant crown is irregular, it is mapped by plotting points projected vertically downward along the periphery of the crown; these points are then connected with straight lines.

Fig. 2. Vegetation sample being taken in a mangrove forest area in North Central Puerto Rico

At the same time the plant location is plotted on the plan sheet its structural description is recorded by type number on the structural data sheet (fig. 4). This data sheet is adapted from the one devised by



LEGEND

* 7 STEMS (4)

* 9 STEMS (1)

** 6 STEMS (4)

*** 10 STEMS (4)

SITE NO. V-23

DATE 7 FEB 63

TECHNICIAN SANCHEZ. LEBRON. AND PIVULL

H. C. NO. 5

Fig. 3. Vegetation data sheet

STRUCTURAL CELL REFERENCE NUMBER: V-23 AERIAL PHOTOGRAPH: ______ CELL DIAMETER: 9.9 METERS (30 ft.)

DATE: 15 MAR 63 NOTES: DATA TAKEN FROM FIELD DATA SHEET DATED 7 FEB 63

HEIGHT CLASS

TYPE	RANGE VALUE / MEASURE STD DIA	I < 0.1 M. / NONE	II 0.1-0.3M. / GROUND LEVEL	III 0.3-0.7M. / 0.1 M.	IV 0.7-1.8M. / 0.3 M.	V 1.8-5 M. / 1.0 M.	VI 5-13 M. / 1.5 M.	VII 13-35 M. / 1.5 M.	VIII > 35 M. / 1.5 M.
1						X			
2						X			
3						X			
4						X			
5						X			
6						X			
7						X			
8						X			
9						X			
10						X			
11						X			
12						X			
13						X			
14						X			
15						X			
16						X			
1					X				
2					X				
3					X				
4					X				
5					X				
6					X				
7					X				
8					X				
9					X				
10					X				
1				X					
2				X					

CROWN SHAPE

TYPE	ROUND	FLAT	LANCEOLATE	SPINDLE	IRREGULAR	MASK	CROWNLESS	% COVERAGE
1				X				20
2				X				30
3				X				5.5
4				X				8.7
5				X				.70
6	X							.93
7		X						1.0
8	X							.88
9				X				.59
10				X				2.4
11				X				.06
12				X				.42
13				X				1.9
14				X				2.2
15		X						2.2
16				X				.44
1				X				2.4
2				X				2.8
3				X				.35
4				X				.36
5				X				1.1
6				X				.50
7				X				1.8
8				X				2.3
9				X				—
10				X				.44
1		X						16
2		X						4

LEAF CHARACTERISTIC

TYPE	SHAPE: BROAD AND FLAT	LONG AND FLAT	AWL	THREADLIKE	TEXTURE: FILMY	MEMBRANEOUS	HARD	SUCCULENT	SIZE: < 1 SQ. CM.	1 - 150 SQ. CM.	> 150 SQ. CM.	ACT'Y: LEAVES LIVING	LEAVES DEAD
1	X						X			X		X	
2	X						X			X		X	
3	X					X			X			X	
4	X						X			X		X	
5	X					X			X			X	
6	X					X				X		X	
7	X					X				X		X	
8	X						X		X			X	
9	X						X			X		X	
10	X						X			X		X	
11	X						X		X			X	
12	X					X				X		X	
13	X					X			X			X	
14	X						X			X		X	
15	X						X			X		X	
16	X						X		X			X	
1	X					X			X			X	
2	X						X		X			X	
3	X						X			X		X	
4	X						X		X			X	
5	X						X			X		X	
6	X					X				X		X	
7	X						X			X		X	
8		X					X		X			X	
9	X						X		X			X	
10	X					X				X		X	
1		X				X				X		X	
2		X				X			X			X	

STEM

TYPE	DIAMETER: < 2.5 CM.	2.5 - 7.5 CM.	7.5 - 15 CM.	15 - 30 CM.	30 - 60 CM.	> 60 CM.	HABITS: ERECT	DECUMBENT	TWINING	FREE	HDNS.: HARD, WOODY	SOFT, NONWOODY	SUCC.: NOT SUCCULENT	SUCCULENT-GREEN	FUNGI
1		X					X				X				
2	X						X				X				
3		X					X				X				
4	X						X				X				
5	X						X				X				
6		X					X				X				
7		X					X				X				
8		X					X				X				
9	X						X				X				
10		X					X				X				
11	X						X				X				
12	X						X				X				
13		X					X				X				
14			X				X				X				
15			X				X				X				
16	X						X				X				
1	X						X				X				
2	X						X				X				
3		X					X				X				
4	X						X				X				
5	X						X				X				
6	X						X				X				
7	X						X				X				
8	X						X				X				
9	X						X				X				
10	X						X				X				
1	X						X					X			
2	X						X					X			

BRANCHING

TYPE	TYPE: HORIZONTAL	DIVERGENT	HEIGHT: < 0.5 M.	0.5 - 1.0 M.	1.0 - 2.0 M.	2.0 - 3.0 M.	> 3.0 M.
1		X	X				
2		X	X				
3		X	X				
4		X			X		
5		X			X		
6		X	X				
7		X	X				
8		X	X				
9		X	X				
10		X			X		
11		X			X		
12		X			X		
13		X			X		
14		X	X				
15		X	X				
16		X	X				
1		X	X				
2		X	X				
3		X	X				
4		X	X				
5		X	X				
6		X			X		
7		X			X		
8		X	X				
9		X			X		
10		X	X				
1		X	X				
2		X	X				

ROOTS, ARMATURE, DISTRIBUTION

TYPE	STRUCT.: STILT OR PROP ROOTS	ENLARGE BASE	PLANK BUTRESSES	EMERG.: < 0.3 M.	0.3 - 0.6 M.	0.6 - 2.0 M.	> 2.0 M.	SPREAD: < 2 X STEM DIAM.	2-5 X STEM DIAM.	5-15 X STEM DIAM.	15-45 X STEM DIAM.	> 45 X STEM DIAM.	ARMATURE: SPINES > 5 MM. LONG	SPINES < 5 MM. LONG	CUTTING EDGES	POISONS	STINGING ORGANS	DISTRIBUTION: RANDOM	CLUSTERS	CLUMPS	GRID	ROW	STRIPS
1																							
2													X	LY		X							
3														X	ST								
4																							
5														X	ST								
6																							
7														X	ST								
8																							
9																							
10																							
11																							
12																							
13														X	ST								
14																							
15																							
16																							
1														X	ST								
2													X	LV									
3																							
4																							
5																							
6																							
7																							
8																							
9																							
10																							
1																							
2																							

WES REVISED: 11 FEB. 63

Fig. 4. Structural data sheet

Marshall University (Mills; "Quantitative Environmental Studies, South Florida," fig. 4, p 156), modified to conform with the recently modified symbol system (Addor; "Vegetation Description for Military Purposes," pp 98-128). This procedure is repeated for all plants in the lowest height class before starting on the next larger height class. The height classes are handled separately to avoid confusion when reducing the data to plot on the structural diagram.

Data reduction. The problem now becomes an office exercise. Measured field data are available for a number of studies of natural populations; however, this discussion will be confined to plotting of the structural diagram retaining as much detail as possible in the process.

The very simple case of two plants mapped with overlapping circular crown is considered first. The area covered for each plant, by disregarding the portion of overlap, is computed by the relation

$$\frac{d^2 \pi}{4}$$

where d = diameter of the plant. Naturally, when the summation of the individual plant areas is computed, this procedure would give considerably more total areal coverage for the two plants than if the areas of the plants were adjusted to exclude the area of overlap. Assuming that absolute values of overlap are unimportant, the correct areas covered and not covered can be computed on the basis of weight.

A copy of the plan data sheet (fig. 3) is trimmed along the circumference of the test plot. Next, the areas that designate crown coverage are cut out and then weighed on analytical balances. Finally, the remaining bits of paper are weighed to determine the weight of the area that has no crown coverage. The percent of areas covered and not covered can then be computed by the process shown in the following subparagraph d.

In plotting the structural diagram, base the number of symbols used on the total plant area of each plant, but use for plotting only that percentage of the diagram computed by the relation: (total area) - (area not covered) = (area covered). The symbols are plotted in the same relation as they appear on the plan sheet. Thus the diagram indicates a more correct coverage value and an indication of plant interrelations. This procedure is demonstrated with the data collected on vegetation site V-23 located in a scrub forest area on the side of a hill in the Susua forest near Sabana Grande, Puerto Rico, as follows:

a. Determine the diameter of each plant mapped, or area covered if not plotted as a circle; tabulate this information. The information on the two types of height class (H.C.) is illustrated in fig. 5.

b. Determine percent coverage of each plant type and record on the structural data sheet (fig. 4).

c. Determine the coverage that can be symbolically represented and adjust the percentage accordingly. It is possible to represent very small percentages on the diagram by the use of inserts (fig. 6).

d. Compute the area that can be used on the structural diagram by weight (wt).

H.C. 5 - wt of area covered = 2.31 g

wt of area not covered = 3.52 g

5.83 g

$$\text{Area of area not covered} = \frac{3.52}{5.83} = 60.4\%$$

$$\text{Area to be used} = 100\% - 60.4\% = 39.6\%$$

e. Study the plan sheet and determine which types should be shown as overlapping, touching, or separate.

f. Study the tabulation (fig. 5) and determine the size of symbols to use for each plant.

g. Plot in the outline of the plant symbols.

h. Review, adjust, and proceed with the final drawing (fig. 6).

In addition to the above-discussed data, slope measurements, site description notes, soil notes, and stereopair photographs are taken on each site. Also all sites are located accurately on military quad sheets and aerial photographs.

TABULATION OF AREA COVERED BY PLANTS ON V-23 - H.C. 5

CIRCULAR AREAS

Type	Diameter (ft)	Area (ft^2)	% Total
1	1.75	2.41	
	1.75	2.41	
	3.00	7.07	
	1.25	1.23	
	1.00	0.79	
	4.00	12.57	
	2.00	3.14	
	1.00	0.79	
	1.75	2.41	
	1.00	0.79	
	1.50	1.77	
	2.00	3.14	
	3.00	7.07	
	5.00	19.63	
	2.50	4.90	
	1.75	2.41	
	2.75	5.94	
	2.25	3.98	
	2.25	3.98	
	4.00	12.57	
		99.00	20.41
2	0.6	0.28	
	1.25	1.23	
	1.00	0.79	
	2.00	3.14	
	1.75	2.41	
	1.25	1.23	
	2.00	3.14	
	2.00	3.14	
	1.50	1.77	
	1.25	1.23	
	1.50	1.77	
		20.13	3.02

IRREGULAR AREAS

Areas Measured with Planimeter

Type 1:

$$5.00 \text{ in.}^2 + 0.60 \text{ in.}^2 + 1.65 \text{ in.}^2 = 7.25 \text{ in.}^2$$

Scale of Plan Sheet 1 in. = 2.5 ft

$$7.25 \text{ in.}^2 \times \frac{6.25 \text{ ft}^2}{1 \text{ in.}^2} = 45.31 \text{ ft}^2$$

$$\frac{45.31 + 99.00}{706.9} = 20.41\%$$

(706.9 = Total area of plot, ft^2)

Type 2:

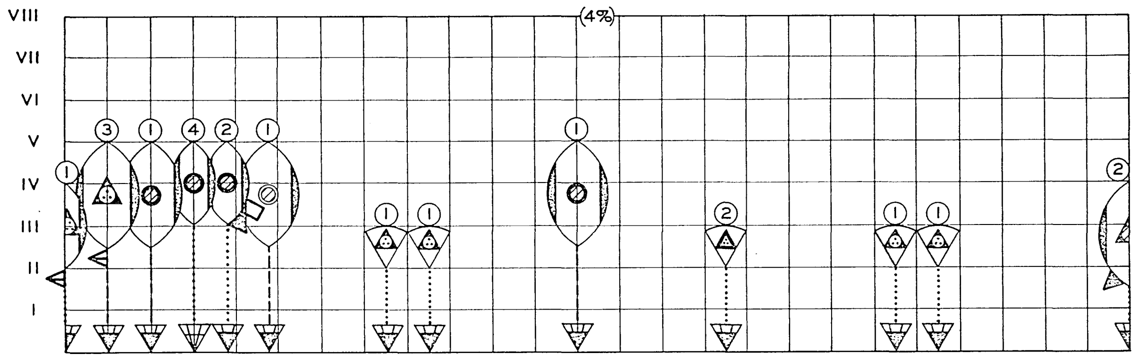
$$0.2 \text{ in.}^2 \times \frac{6.25 \text{ ft}^2}{1 \text{ in.}^2} = 1.25 \text{ ft}^2$$

$$\frac{20.13 + 1.25}{706.9} = 3.02\%$$

Fig. 5

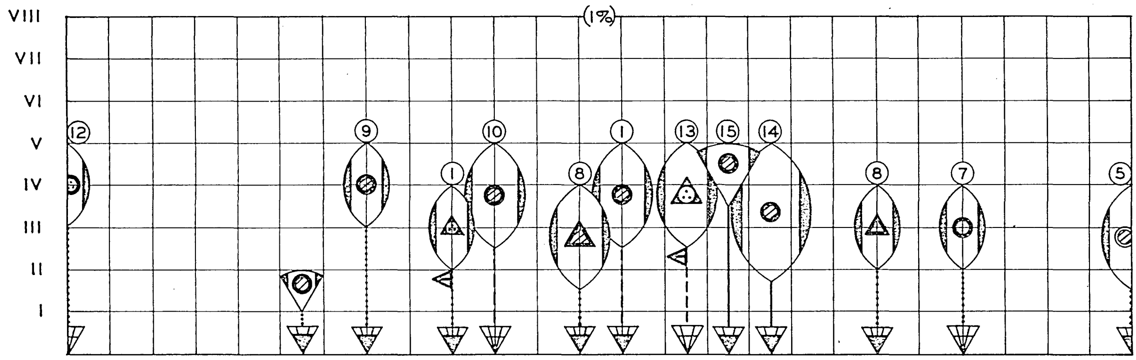
LOCATION SUSUA FORESTS - MARICAO, P. R.   DATE 13 FEB. 1963

V-23



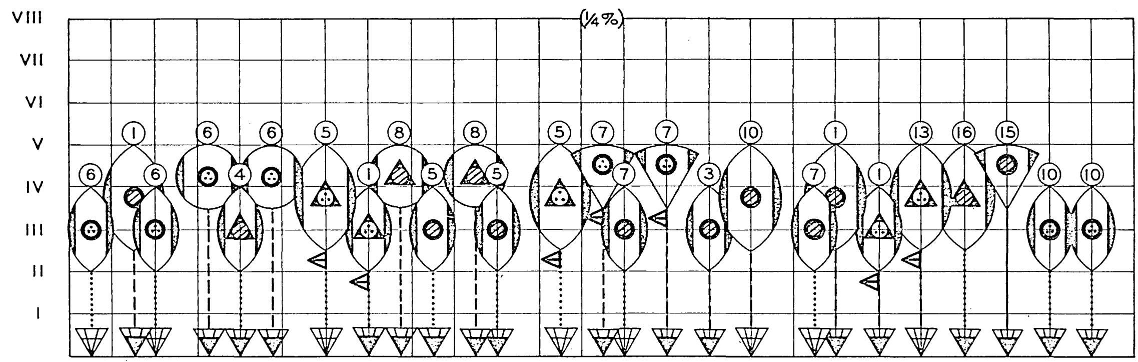
H. C. 5

MAIN DIAGRAM = 27.0 %
INSERT "A" = 8.25
INSERT "B" = 4.5
TOTAL 39.75 %



H. C. 5

INSERT "A" = 8.25 %



H. C. 5   SAMPLE AREA DIAMETER 30 FEET

INSERT "B" = 4.5 %

Fig. 6. Vegetation structural diagram

THE VEGETATION OF PUERTO RICO

The New York Botanical Garden has undertaken the task of mapping the existing vegetation of the island of Puerto Rico, hopefully at a scale of 1:25,000. While it will probably be impracticable to achieve this level of detail for the entire island, the intention remains to map two, or perhaps three, north-south strips across the island at that scale, and to map the entire island at some as yet unspecified smaller scale.

Data on structural variations of the vegetation of the island are currently being gathered by the Tropical Terrain Research Detachment (TTRD), which is a field team of the Waterways Experiment Station (WES). Up to the present time, 67 vegetation sites (fig. 1) have been sampled in accordance with the WES methodology (Benn; "Environmental Data Collection, Puerto Rico," pp 168-181). In addition, Dr. Pierre Dansereau of the New York Botanical Garden, assisted by Mr. Peter Buell, has examined the island in some detail and collected taxonomic, ecological, and structural information.

While the mapping program has not progressed to the point where firm conclusions can be drawn, certain very tentative relations can be advanced on the basis of data furnished by Dr. Dansereau. These relations are presented in table 1. A very general and still largely hypothetical map of gross distributions of natural vegetation structural types is illustrated by fig. 2. There is little doubt that this map will be greatly modified as additional data become available, and it is possible that new information will force basic revision of the entire scheme.

In view of the very tentative nature of the present hypotheses concerning both the physical nature and the dynamics of Puerto Rican vegetation, the data and interpretations presented herein should be regarded with considerable reserve. This report should be interpreted as only a very preliminary progress report, and no more.

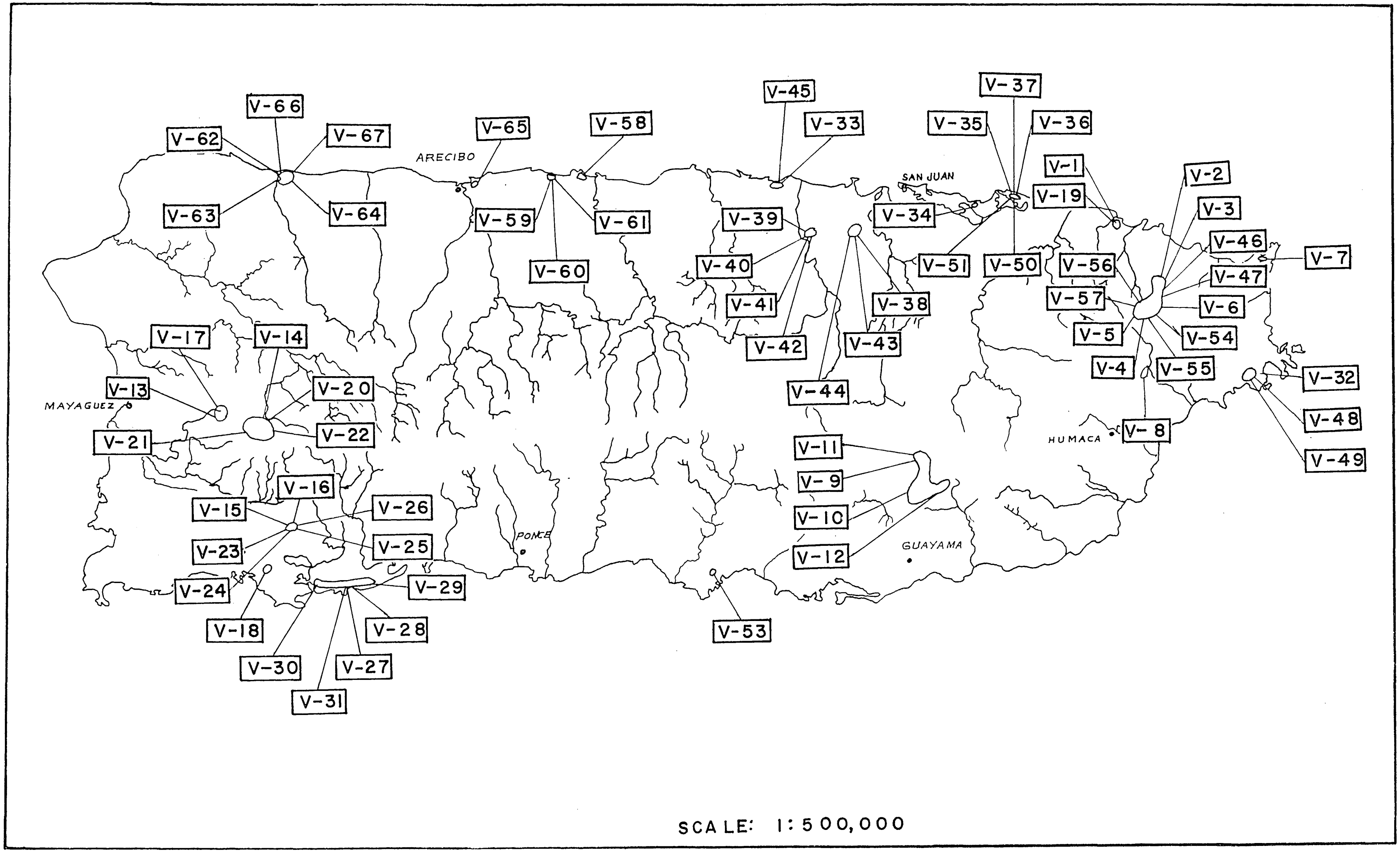


Fig. 1. Location map of vegetation sites in Puerto Rico

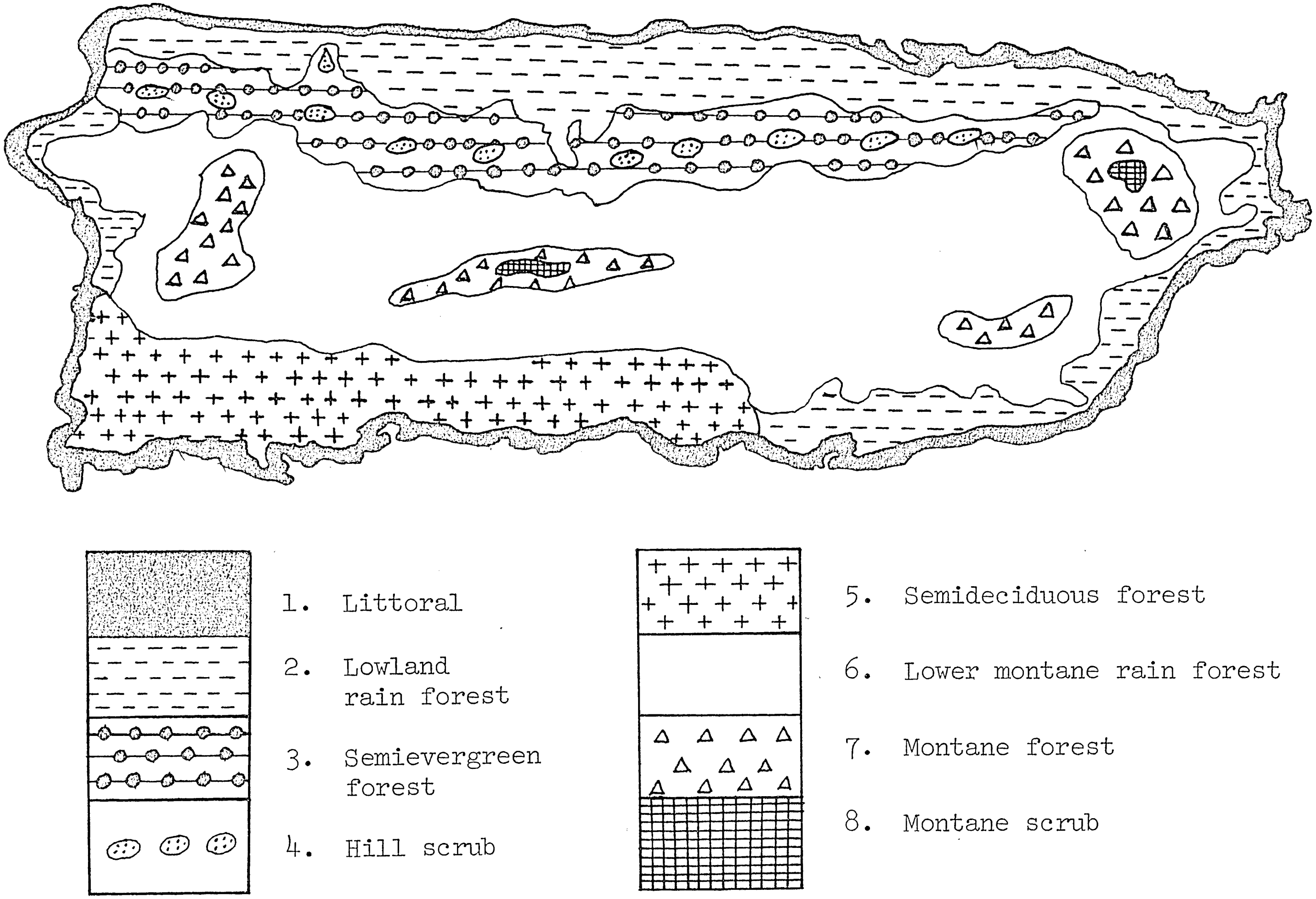


Fig. 2. Vegetation zones of Puerto Rico

Table 1

Vegetation Zones of Puerto Rico

(After Dansereau)

Zone	Landform	Plant Community	Formation-Type	Principal Species
Littoral	Open water	Seaweed prairie	Prairie, meadow	Algae
	Lagoon	Seaweed tangle	Prairie, meadow	Algae
	Shallows	Turtle-grass sward	Meadow	Thalasia testudinum
	Reef	Mangrove	Scrub	Avicennia nitida
	Intertidal belt:			
	Rocky	Fucoid crust	Crust	Fucus sp. Turbinaria turbinata
		Mangrove	Scrub forest	Rhizophora mangle Avicennia nitida Laguncularia racemosa
	Sandy	Sterile		
		Mangrove		Rhizophora mangle Avicennia nitida Laguncularia racemosa
	Silty	Mangrove		Rhizophora mangle Avicennia nitida Laguncularia racemosa
	Supratidal belt:			
	Rocky	Flat sedge and spurge tufts	Steppe	Fimbristylis spadicea Euphorbia buxifolia
		Flat sedge mat	Meadow	Fimbristylis spadicea
		Salt scrub	Scrub	Conocarpus erecta Suriana maritima
		Cactus bush	Scrub	Cephalocereus royenii Opuntia rubescens
	Sandy beach	Beach grass	Prairie	Spartina patens Sporobolus virginicus
		Beach vine	Meadow	Ipomoea pes-caprae
	Beach ridge	Sea-grape bush	Scrub	Coccoloba uvifera
		Maray-maray bush	Scrub	Dalbergia ecastophyllum
		Coconut grove	Forest	Cocos nucifera
	Dune	Beach grass	Prairie	Spartina patens
		Sea-grape bush	Scrub	Coccoloba uvifera
	Estuary:			
	River and lake	Water-hyacinth mat	Meadow	Eichhornia crassipes
		Water-lettuce mat	Meadow	Pistia stratiotes
		Watergrass mat	Prairie	Panicum purpurascens
	Swamp	Pterocarpus swamp	Forest	Pterocarpus officinalis
		Pond-apple swamp	Forest, woodland	Annona glabra Conocarpus erecta
	Marsh	Spikerush marsh	Prairie	Eleocharis spp.
		Icaco scrub	Scrub	Chrysobalanus icaco
Lowland rain forest	Open water	Water-hyacinth mat	Meadow	Eichhornia crassipes
		Watergrass mat	Prairie	Panicum purpurascens
	Flooded land	Cattail marsh	Prairie	Typha angustifolia
		Reed marsh	Prairie	Phragmites communis
		Rivercane brake	Prairie	Gynerium sagittatum
	Upland	Mixed hygrophytic rain forest	Forest	Diospyros ebenaster Mammea americana
		Trumpet-wood forest	Forest	Cecropia peltata
		Jungle	Scrub, forest	Abrus praecotorius Ipomoea spp. Piper aduncum Casearia guianensis
		Scrubland	Scrub	Psidium guava Croton spp.
		Savana	Savana	Spathodea, Randia, Didymopanax, etc.

(Continued)

Table 1 (Concluded)

Zone	Landform	Plant Community	Formation-Type	Principal Species
Lowland rain forest (Continued)	Upland (Continued)	Grassland	Prairie, steppe, meadow	Andropogon, Eragrostis, etc.
		Pasture	Steppe, meadow	Gramineae
		Canefield	Prairie	Saccharum officinarum
		Pineapple plantation	Prairie	Ananas sativa
		Orchard	Savana	Mangifera indica, etc.
		Garden	Scrub, meadow, steppe	(Various)
Semievergreen forest	Ravine	Mixed hygrophytic forest	Forest	Diospyros ebenaster Mammea americana
	Slope	Glateado forest	Forest	Coccoloba laurifolia
Semievergreen	Summit or spur	Gumbo-limbo--Palm scrub	Scrub	Bursera simaruba Gaussia attenuata
	Cliff	Balsamfig--Anthurium cliff	Scrub	Clusia rosea Anthurium acaule
Semideciduous forest and scrub	Rocky hillsides	Bucaro forest	Forest	Bucida buceras
		Gumbo-limbo savana	Savana	Bursera simaruba
		Sebucan--Tachuelo thornscrub	Scrub	Cephalocereus royenii Pictetia aculeata
		Uniola prairie	Prairie	Uniola virgata
	Sand and silt flats	Mesquite savana	Savana	Prosopis juliflora Parkinsonia aculeata
Lower montane forest	Slopes and plateaus	Tabanuco forest	Forest	Dacryodes excelsa
		Trumpet-wood forest	Forest	Cecropia peltata
		Inga--Coffee forest	Forest	Inga vera Cyathea arborea Inga laurifolia Coffea arabica
		Tree-fern scrub	Scrub	Cyathea arborea Hemitelia horrida
		Pepper scrub	Scrub	Piper aduncum
		Rose-apple scrub	Scrub, forest	Eugenia jambos
		Pasture	Steppe, meadow	Gramineae
		Andropogon prairie	Prairie	Andropogon bicorne
		Plantain and banana plantations	Prairie	Musa spp.
		Tobacco fields	Prairie	Nicotiana tabacum
	Cliffs	Algal crusts	Crust	Algae Myxomycetes
		Balsamfig--Anthurium cliff	Scrub	Clusia rosea Anthurium acaule
		Fern savana	Savana	Cyathea arborea Gleichenia spp.
	Lakes and ponds	Lemna crust	Crust	Lemna perpusilla
	Marshes	Aroid--Sedge belt	Prairie	Colocasia antiquorum Cyperus sp.
	Riverbeds	Yerba de clavo strip	Prairie	Jussiaea repens
Montane forest	Hillsides	Sierra palm forest	Forest	Euterpe globosa
		Sierra palm and broadleaf forest	Forest	Euterpe globosa Calycogonium squamulosum Clusia minor
		Moss forest	Forest	Tabebuia rigida Podocarpus coriacea
Montane scrub	Hillsides	Elfin forest	Scrub	Micropholis garcinifolia Podocarpus coriacea
	Plateau	Bog scrub	Scrub	Nepsera aquatica Sphagnum spp.
	Outcrop	Evergreen low scrub	Scrub	Eugenia borinquensis Tabebuia rigida

TROPICAL TERRAIN STUDIES IN THE CARIBBEAN AREA

by

Marcos A. Zappi[1]

In the summer of 1961, the U. S. Army Engineer Waterways Experiment Station (WES) initiated preparations to conduct a tropical terrain studies program in selected countries of the Caribbean area. The program was undertaken as a joint venture of the Area Evaluation Section (AES), and the Army Mobility Research Center (AMRC). A program was developed to collect environmental data, including information on soils, vegetation, and surface geometry, in the field in Panama, Colombia, Costa Rica, Nicaragua, and Guatemala for one continuous seasonal cycle.

The soils aspect of the program is concerned primarily with the collection in situ, at certain selected sites, of data pertaining to the strength of tropical soils and to those environmental conditions, such as climate and vegetation, that would affect the strength of these soils. These data will be used to develop a system for predicting moisture-strength relations of surface soils in the tropics and to develop a trafficability classification scheme for tropical soils.

The vegetation and surface geometry aspects of the program have three principal objectives: first, to observe and record changes in the vegetation and microrelief of these areas as evidenced during a complete seasonal cycle; second, to test and evaluate a system, based on parametric symbols, for mapping the physical characteristics of tropical vegetation associations; and third, to develop and apply field techniques for mapping surface microgeometry features in tropical areas. The data will be used to develop a method for establishing analogous areas in different geographic regions, and as the basis for the evaluation of environmental conditions for military purposes in tropical areas.

Administrative and logistical support for the program is furnished by the Inter-American Geodetic Survey (IAGS). In Colombia WES is

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collaborating with the Instituto Geografico "Agustin Codazzi" of Bogota, and in Costa Rica with the Instituto Costarricense de Electricidad (ICE). The participation of these three organizations in this program, as well as the assistance rendered by various U. S. Government and other agencies, has been of great assistance. Although government agencies in Nicaragua and Guatemala had indicated their willingness to collaborate in the program, circumstances made it necessary to postpone the proposed studies in these countries.

A project office was established at Fort Clayton, Canal Zone, in late October 1961. Initially, this office was staffed by the project engineer and two technicians from WES. Additional people were obtained locally to assist in the field program.

The topography of the Canal Zone is largely the result of stream erosion and weathering. The region is characterized by many conically shaped hills, which are spaced irregularly and give a chaotic appearance to the terrain. Landforms are controlled primarily by the relative resistance to erosion of the rocks in any given area. Geological structure apparently has played a relatively minor role in the configuration of the landscape, especially on the Pacific side.

The geology of the Canal Zone is varied and complex. Formations change their lithological character both laterally and vertically. Generally speaking, igneous rocks (mostly volcanics) and related sediments are found in the Pacific side of the Zone. In the Atlantic side, sedimentary rocks predominate. Sedimentary and igneous rocks interfinger and/or overlap in a southerly direction. Metamorphic rocks are virtually unknown in the Canal Zone.

The climate of the Canal Zone is characterized by moderately high temperatures and humidity throughout the year. Rainfall is abundant, but violent general storms such as hurricanes are unknown.

There is a distinct dry season on both the Atlantic and Pacific sides, but the dry season is better defined on the Pacific side. The dry season generally covers a four-month period, from about January to April. The Atlantic coast receives almost twice as much rainfall as the Pacific coast, the rainfall diminishing progressively toward the Pacific side. Cristobal, on the Atlantic coast, has a yearly mean rainfall of about 325 cm. Balboa, on the Pacific coast, has a yearly mean rainfall of about 175 cm.

Oddly enough, rainfall data obtained by the WES team and the U. S. Army Electronics Research and Development Meteorology Team, Canal Zone, seem to indicate that areas east of the Canal received more rain during the past year than those west of the Canal. It is not known whether this is a normal situation, or whether it is entirely fortuitous.

During November and early December 1961, the WES team selected five locations for the establishment of "prediction-development" (PD) sites on the Pacific side (fig. 1). A PD site (fig. 2) is one which is employed to

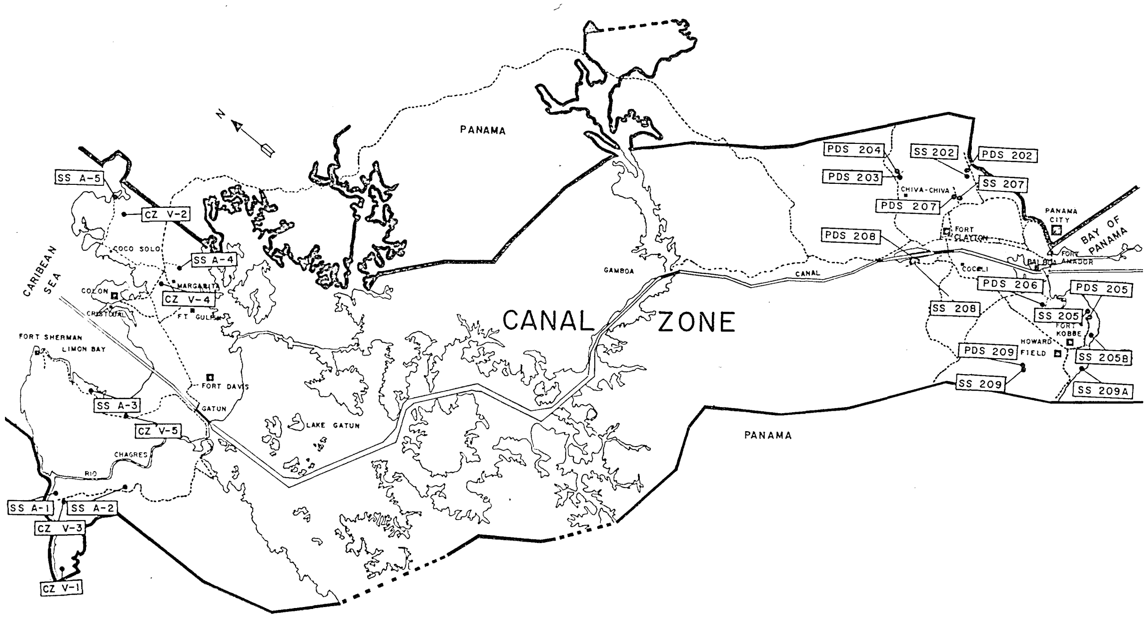

Fig. 1. Location map of tropical terrain research sites

provide data for establishing the quantitative relation between rainfall, soil moisture, and soil strength. In Panama, they were laid out as 6.2- by 10.3-m rectangles. Fiberglas electrical resistance units were installed so that soil moisture could be readily determined. Standard brass rain gages and groundwater wells were installed at each location. Daily collection of data was started on 12 December 1961.

Shortly after daily visits to these sites commenced, a rash of vandalism began. Brass rain gages were stolen at several sites, Fiberglas units and water wells were tampered with, and even the "Do Not Disturb" signs were stolen. To assure a continuous flow of data and to avoid vandalism, three new PD sites were established in areas less exposed to normal

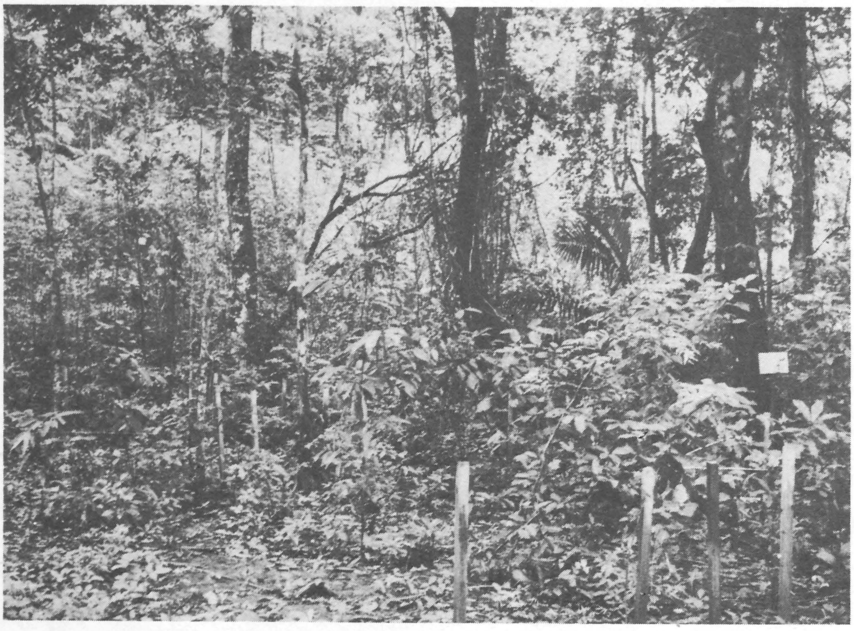

Fig. 2. PD site located approximately 4 airline miles north of Panama City

traffic. These sites were laid out as 14- by 28-m rectangles to provide a larger area for daily soil sampling, should this become necessary. Daily collection of trafficability data was started at these sites in May 1962.

Five of the PD sites were located in relatively flat areas which lie among randomly oriented hills. Lateritic residual clays predominate at these sites; these clays are rather friable, especially during the dry season, and exhibit a fairly good internal drainage. When field moisture contents are low, they fracture in hexagonal patterns. When dry, sampling of these soils becomes very difficult even with a drive-type sampler. The fracturing of the soils also hinders the use of the cone penetrometer, which frequently tends to follow the fissures. The fractures are better developed in areas which lack the protective cover of vegetation or fallen leaves.

One of the PD sites was located in a coastal swamp which was, at one time, used as a dredge tailing pond; however, this site now has a well-developed soil profile. The soil consists of a silty clay loam which in places changes to a very plastic clay. It is a saline soil with pH values in the 5.0 to 5.5 range.

Another PD site was located in a flat area on the west bank of Miraflores Lake. This site is believed to be on an alluvial terrace of the Old San Juan River which, prior to the construction of the Canal, flowed south into Panama Bay.

Still another PD site lies on the east flank of an alluvial coastal plain. This area is being used as a firing range, which led to problems now and then. When the site was chosen, the area looked very much like a tropical savanna. Recently, large areas in it have been cleared and graded for use as a parachute landing area.

Microgeometry and vegetation sampling cells were established in areas adjacent to all but three of the PD sites. Two satellite sites were established in the general vicinity of their corresponding PD sites. One of them is located in a mangrove swamp which is marginal to the Pacific Ocean. The other satellite site is located in an unusually dry coastal area. The soil is very sandy; it is probably an abandoned coastal sandbar. Large trees and tall coconut palm trees are found there. During the dry season, there is little underbrush and ground level visibility is good. At this time, the site assumes a semiarid appearance, large clumps of cacti being found in several places. With the return of the wet season, the vegetation cover becomes more profuse and the cacti are less evident.

Daily visits to the first five PD sites were terminated on 28 February 1963. Visits to these sites will be continued on an intermittent basis, at which times pertinent vegetation, microgeometry, and trafficability data will be obtained.

Because of a higher yearly rainfall, a less pronounced dry season, and the existence of relatively undisturbed large forests, it was decided to establish five sites on the Atlantic side of the Zone in June 1962. These sites were selected primarily for the collection of vegetation and microgeometry data, although pertinent trafficability and weather data are also obtained. They are visited weekly.

Three of the Atlantic sites are located in coastal lowlands, one is in an inland lowland and the fifth is in the highlands. In the coastal lowlands, the surface horizon of loam or clay loam is underlain by silty clays, except in the mangrove swamp; here the soil is a highly organic muck. In the highlands, the soil is predominantly a residual lateric clay.

A major consideration in the selection of the Atlantic side sites was difference in vegetation structure. For example, one site is located in a lowland adjacent to Limon Bay; here the trees are tall and tend to have buttress roots, with little underbrush growing under the canopy.

This area is frequently flooded during the wet season. At the site selected in the mangrove swamp, the trees have well-developed stilt roots. Different varieties of mangrove are found intermixed here.

In January of this year, five "vegetation sites" were established on the Atlantic side. One of the sites is shown in fig. 3. They were selected to represent vegetation structural types which differed from the cells already established. Microgeometry, vegetation, and trafficability data are being obtained at these sites to record extreme changes caused by the wet and dry seasons.

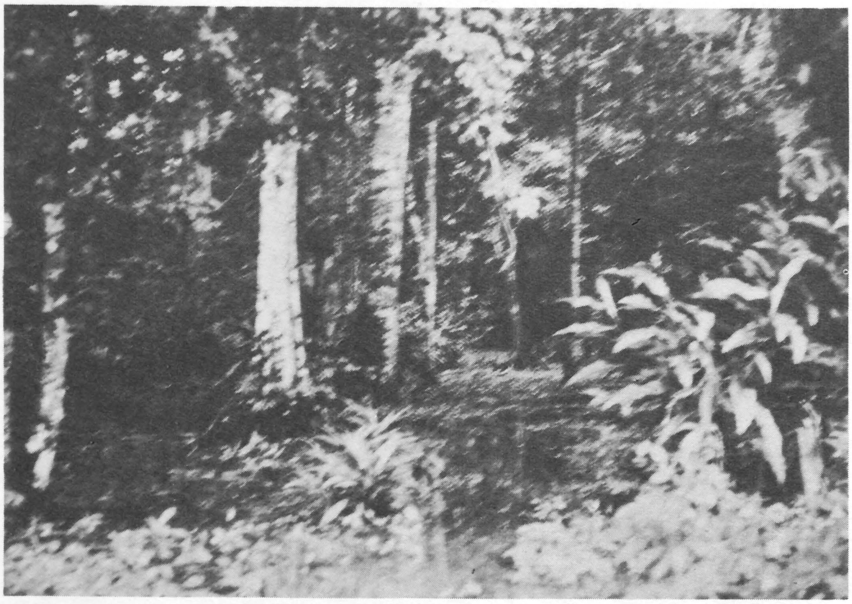

Fig. 3. Vegetation site about 3 miles south of Fort Sherman on the Atlantic side of the Canal Zone

Until recently, field activities had been limited to areas within the Canal Zone. Early this year a reconnaissance trip was made along the Pan-American highway to select possible areas of interest for "one-shot" collection of data.

The coastal area east of Panama City is a region of extensive lowlands. While most of the area is trafficable during the dry season, it becomes a trafficability problem area during the wet season. Trafficability and vegetation data have been obtained at six locations in this area (fig. 1). Additional field trips of this type are planned, but their extent will depend on the manpower and time available.

After several months of unexpected delays, a "Working Arrangement" was signed on 25 June 1962 between IAGS, acting in behalf of WES, and the Instituto Geografico "Agustin Codazzi" of Bogota, an autonomous agency of the Colombian Government. The arrangement established the basis for terrain studies to be conducted in the Sabana of Bogota.

The climate of the Sabana is, because of its proximity to the Equator, essentially without seasons. The temperature is relatively constant; the mean yearly temperature ranges between 12 to 14 C (53.6 to 57.2 F). However, rainfall at a given locality may vary from year to year; the deviation from the yearly mean can be as high as 40 percent. Generally, rainfall is lower in the center of the Sabana and increases toward the surrounding mountain fronts. At Usaquen, near the eastern mountain front, the yearly mean is 1119 mm (44.7 in.); at the Techo airport in the central part of the Sabana and near Bogota, the yearly mean rainfall is 518 mm (20.7 in.), while at El Rosal on the western limits of the Sabana the yearly mean precipitation is 1017 mm (40.7 in.).

The extensive agricultural development of the Sabana and the large construction programs in areas adjoining Bogota limited the selection of sites for trafficability studies.

During late June and early July 1962, four PD sites and five satellite sites were established in areas north and west of Bogota. Fig. 4 is an illustration of one of the PD sites. All sites are located within a 16-km radius from the Instituto. Because Fiberglas units are not being used in Colombia, the PD sites were laid out as 14- by 28-m rectangles to provide sufficient area for the collection of daily moisture samples. Standard brass rain gages and groundwater wells were installed at each location. Field collection

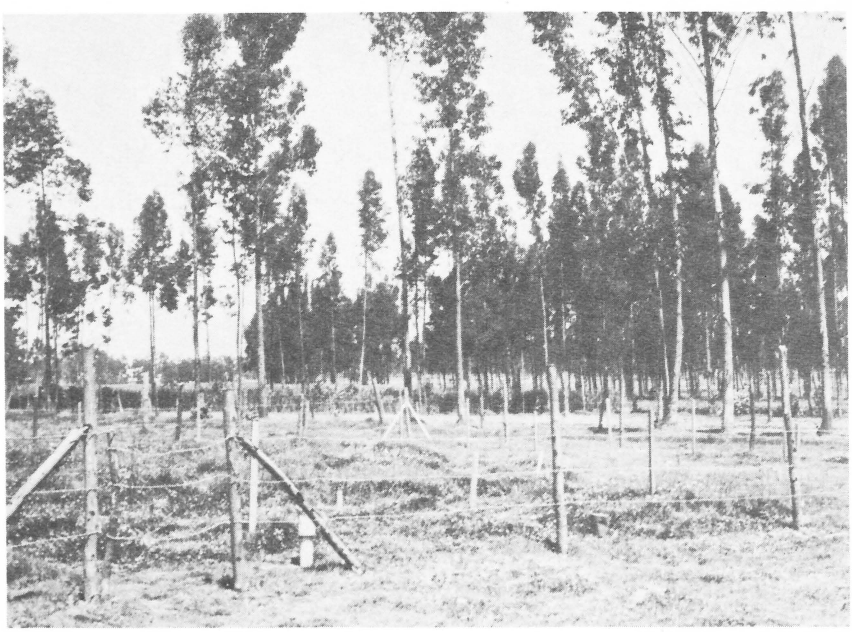

Fig. 4. PD site near Bogota, Colombia

of data was started at these sites on 16 July 1962.

Two of the sites are in the Techo soil series, one of the principal soil series in the Sabana. At this location the soil profile is as follows: 0 to 23 cm, silt loam; 23 to 61 cm, clay hardpan; 61 to 122 cm, grey clay. Because of the clay hardpan, drainage at the sites is poor.

Another pair of sites are in the Bogota soil series. The soil profile is as follows: 0 to 30 cm, clay, heavy, brownish-grey; 30 to 127 cm, clay, heavy, grey, very plastic when wet. In November 1962, the "vegetation sites" were established in a nearby swamp. Vegetation, microgeometry, and trafficability data are being obtained at these sites.

Two sites were also placed in the Tibaitata soil series, the most important series in the Sabana. Both sites are located in a pasture; natural drainage at the sites is fair. At this location the soil profile is as follows: 0 to 53 cm, silt loam, dark grey to black, contains organic matter; 53 to 127 cm, silt loam, light coffee in color when dry, contains very little organic matter.

Two additional sites have been located near the town of Usaquen in an unidentified soil series on the eastern limits of the Sabana. Both sites are in pasturelands; drainage is poor with frequent flooding during the wet seasons. The soil profile is as follows: 0 to 58 cm, clay loam, black when wet, slightly plastic, contains organic matter; 58 to 92 cm, clay loam, black when wet, very plastic, less organic matter; 92 to 130 cm, clay, greyish brown, very plastic.

A single area evaluation site is located in a eucalyptus grove in the Tibaitata soil series. Pertinent trafficability data are also being obtained at this site. Drainage at the site is fair. The soil profile is as follows: 0 to 46 cm, silt loam, dark brown, contains little organic matter; 46 to 86 cm, silt loam, yellowish-brown, contains little organic matter; 86 to 130 cm, clay loam, yellowish-brown, slightly plastic when wet.

On 14 November 1962, a "Working Arrangement" was signed between IAGS, acting in behalf of WES, and ICE, an autonomous agency of the Costa Rican Government, for the purpose of conducting tropical terrain studies in that country. The area selected for these studies is in the vicinity of Turrialba, a town about 30 air miles east of San José. The five PD sites established in this area are all on the grounds of the Inter-American Institute of Agricultural Sciences, an agency of the Organization of American States, at an elevation of about 590 m above sea level. No satellite sites were established since, as of this date, no vegetation or surface geometry studies have been programmed for this area. Three of the sites are located in pasturelands, one is in a coffee and banana grove, and the last lies in a marshy area which is used for pasture during dry periods.

The yearly mean temperature at Turrialba is 22.6 C (72.7 F). A 16-year record at Turrialba shows a yearly mean precipitation of 257 cm; March, with a mean precipitation of 6.6 cm is the driest month; December, with 34.3 cm, is the wettest.

In addition to the PD sites, several locations have been visited in the Turrialba area for "one-shot" collection of data. Additional trips are planned in and outside the Turrialba area to collect more of this type of data.

ENVIRONMENTAL DESCRIPTIONS OF RANGER TRAINING AREAS

by

R. E. McLaughlin[1] and F. H. Norris[2]

U. S. Army Ranger training is conducted at Ft. Benning, Georgia; Eglin Field, Florida; and in a mountainous area located in north Georgia. The last-named area lies southeast of Blue Ridge, Fannin County; southwest of Blairsville, Union County; and northwest of Dahlonega, Lumpkin County; the latter serves as a useful reference point for locating purposes. Environmental aspects of this area, which was selected for the initial investigation, are discussed in this presentation insofar as time and the completeness of our study will permit.

The area is almost completely within the Blue Ridge Province, but includes a part of the inner edge of the Piedmont Province in the form of the Dahlonega Plateau impinging from the south. The latter represents less than 4 sq miles of a total of 97 sq miles covered by the study area. A belt of higher hills rising from the general piedmont surface and projecting spurs from the Blue Ridge make provincial boundaries arbitrary in places. Even so, the high, sinuous, south-facing escarpment of the Blue Ridge, extending east to west across the southern portion of the area, slopes abruptly from a crest above 3000 ft to altitudes of 1900 ft or less, and produces the most prominent topographic feature of the region. Including the escarpment, approximately 50 percent of the study area lies above 2500 ft in elevation. Maximum relief is 2182 ft.

From south to north, the area can be divided into four physiographic sectors: (a) piedmont, (b) escarpment belt, (c) interior basin, and (d) north ridge section. The latter, extending from Wilscot Mountain across Duncan Ridge to Akin Mountain, forms a sinuous drainage divide with a north-facing slope. Due to its relation with the Nottely basin on the north, the north ridge section has some characteristics, though less pronounced, which resemble those of the Blue Ridge escarpment to the south. High relief along the eastern and western margins of the area, coupled with

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the transverse ridges of the escarpment belt and the north ridge section, makes the central interior basin a distinctive feature. Except for a wide gap to the northwest, the basin is closed and the main drainage pattern is centripetal. The central basin is further characterized by numerous, more or less rounded knobs at different coincident elevations, and by the main floodplain development of the Toccoa River and its tributaries. The genetic relation of landforms within this upland basin was tested by comparing the elevations of 73 topographic highs with corresponding local relief measurements. A 55 percent correlation justified the use of the regression equation (fig. 1). The regression line is fitted to highs

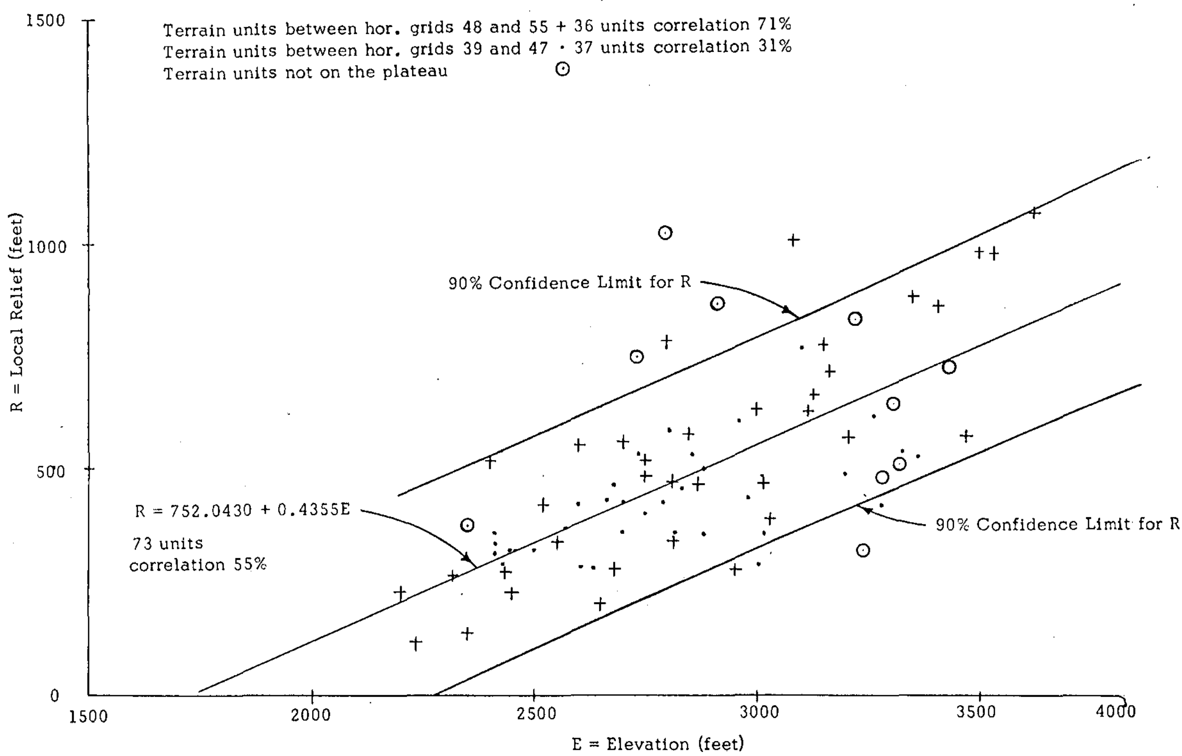


Fig. 1. Regression of local relief R on the respective terrain unit highs, elevation E , for the plateau portion of the U. S. Army Ranger training area northwest of Dahlonega, Georgia

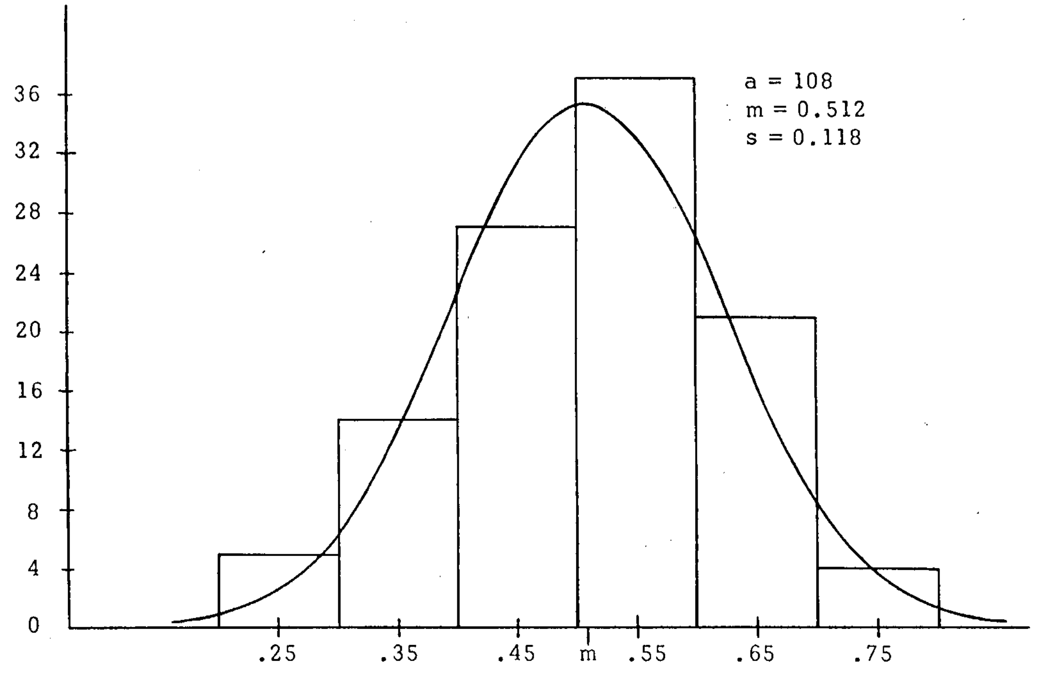
(crosses and dots) located in the central section. The other highs (circled dots) are sites on the northern slopes of the escarpment belt, the physiographic sector to the south of the basin. A physiographically distinct collection of related monadnocks or inselbergs is suggested.

The study area is underlain chiefly by crystalline rocks, referred to in the earlier reports as Carolina and Roan series, which are metasedimentary in origin for the most part with numerous intrusives adding to the complexity of the area. Several types of gneisses and schists covering a wide range of mineralogy are the characteristic rocks, with pegmatite dikes occurring in abundance. Deep chemical weathering of these ancient rocks is widespread and thick saprolite regoliths are a striking feature in some of the sectors, particularly to the north and northeast. Relatively resistant massive gneisses hold up the high ridges as in the escarpment belt to the south. Landform profiles and small-scale features are related to rock type and weathering phenomena. The high order of dissection, strikingly coincident topographic levels, and complexity of drainage patterns attest to a history of several geomorphic cycles in the area.

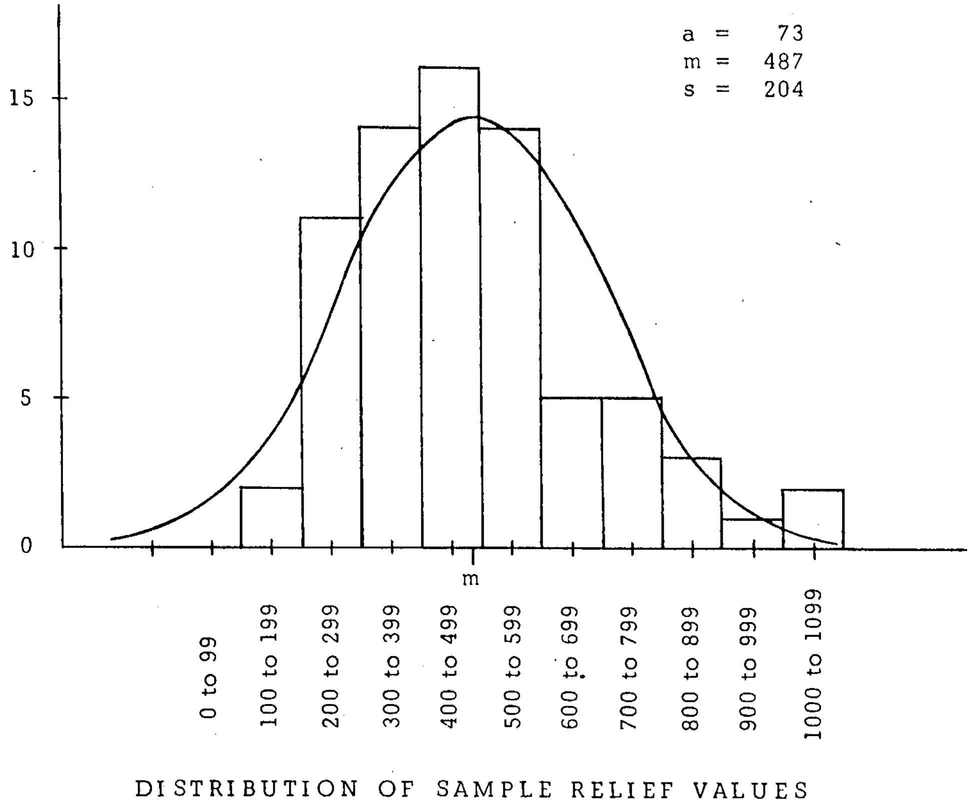
Five environmental components are being considered in the area: surface macrogeometry, surface microgeometry, surface composition, vegetation, and hydraulic geometry. The degree of emphasis placed on each of these components was determined by Waterways Experiment Station project supervisors. Particular consideration is being given macrogeometric terrain analysis and physiognomic description of vegetation, with resulting data plotted on areal maps on a scale of 1:25,000. Other environmental factors involving surface materials, hydrology, and microgeometry are being treated to the extent that they can be adequately assessed within the time limitations imposed upon this phase of the project, and to the degree deemed relevant to the type of military operation involved.

Surface Macrogeometry

The macrogeometric system based on elongation number, profile area, peakedness index, relief, and dissection parameters as developed by the Vanderbilt group at Fort Knox, Kentucky (Application of Terrain Descriptive Techniques to Fort Knox, Kentucky, 1962, as modified), has been used. Terrain units have been centered on topographic highs. Comparison of terrain unit patterns to distribution of actual relief in selected portions of the area shows fair correspondence. For the elongation number and relief parameters, random samples of the values display normal distribution (fig. 2). Again examining the elongation number parameter, it can be



DISTRIBUTION OF SAMPLE ELONGATION NUMBERS



DISTRIBUTION OF SAMPLE RELIEF VALUES

Fig. 2

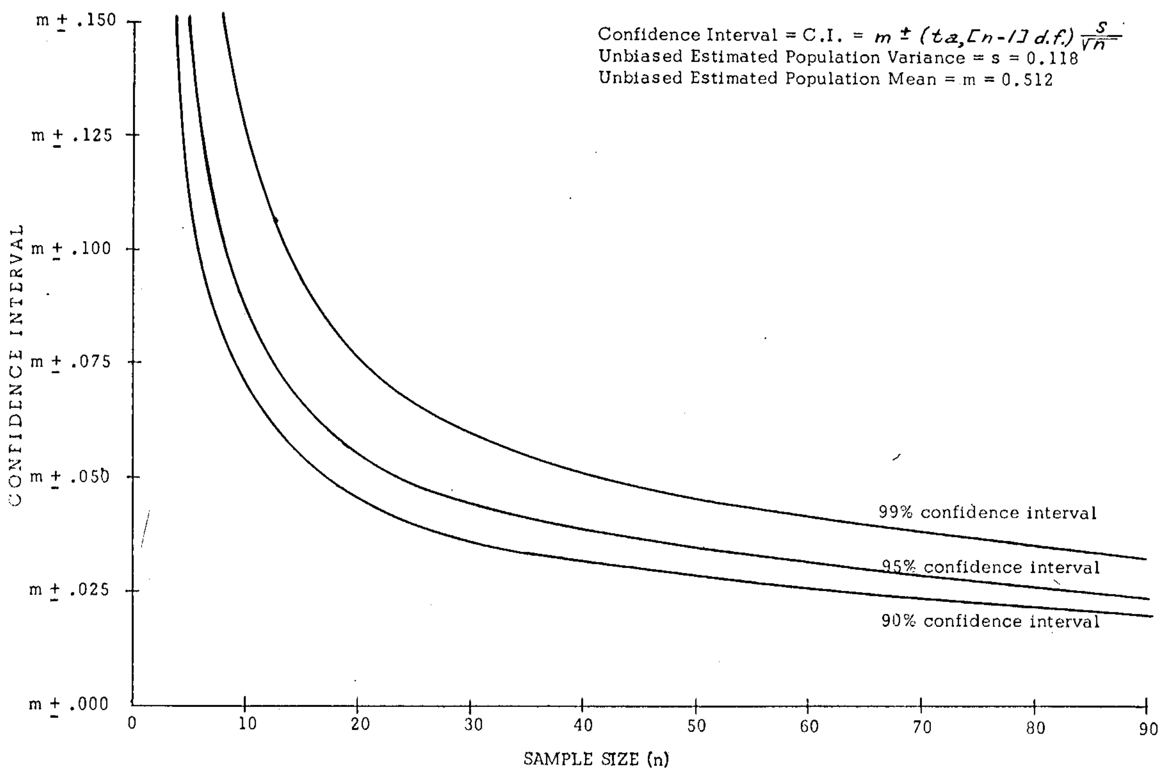


Fig. 3. Confidence intervals for sample means where s = 0.118 and m = 0.512

statistically demonstrated that, by comparing confidence intervals for sample means of elongation numbers with size of sample, a sample size between 60 and 100 is significant at 99, 95, and 90 percent levels of confidence regardless of the size of the population from which the sample is drawn (fig. 3). Similar analyses of other parameters are being conducted. Correspondence between profile area and elevation is being examined, and parallelism numbers and boundaries for elongation numbers are being computed.

Surface Composition

For descriptive purposes, a system to classify the wide variety of surface materials present in the area is being developed. Response to weathering and relative movement are characteristics in common which cut across complex mineralogic and petrologic differences and provide a genetic basis for classification. Features such as degree of consolidation, structure, texture, color, soil development, and special weathering characteristics utilized in the system require minimal technological qualification. In generalized application, the system appears to possess geographic and topographic significance in the study area. The system is summarized and illustrated as follows:

a. Hard rock surface. Divided on basis of massive versus bedded (foliated) structure. Includes gneissic exposures characteristic of escarpment belt above 2500 ft and elsewhere, and schistose exposures, typically angular and ledgy, often folded and faulted, each with pedological distinctiveness.

b. Loose rock surface. Divided on basis of implied degree and agency of transport, but can be topographically differentiated in practice. Includes gap and slope colluvium, stream alluvium, and rock residuum (saprolite). Unconsolidated except for occasional resistant fragments, cobbles, pebbles, and remnant dike stringers. Found in gaps in linear ridges of the escarpment sector, along stream courses and near bases of slopes at lower elevations, and in deeply weathered northeastern and northwestern portions of the area, occasionally elsewhere.

c. Combination surface. Consists of mixtures of a and b categories above with percentage limitations. Produced by differential and extensive weathering of a types but to a lesser degree than any of the b types. Highly variable within short distances. Characteristic of intermediate elevations along outer margin of central basin sector.

Hydrologic Geometry and Surface Microgeometry

Hydrologic, pedologic, and microgeometric data have been collected as deemed useful for descriptive purposes or judged militarily significant. Much of the data on microgeometry was collected at vegetation sites and recorded in percentages. The data were plotted on 8-rayed circular plots in some instances, and along upslope and cross-slope transects where other methods were impractical. Important microgeometric features in the area include streams and drainage ditches, dead logs, and rock outcrops. Hydrologic data include cross-section and basin area measurements, and bottom conditions and surface velocity observations. Drainage basin characteristics, drainage density, and hypsometric function computations are being considered for possible inclusion among the hydrologic data. In addition to gross observations used in surface material descriptions, some soils information was collected at vegetation sites.

Vegetation

The area under consideration is in the Chattahoochee National Forest and actually is at least 85 percent covered by mixed oak and pine forest in a mosaic of varying stages of development and of condition. Cultivated and pasture lands are limited to relatively narrow areas along the principal streams and one national highway, and where the land has been left untended it is being invaded by woody species and is rapidly reverting to thicket and eventually forest. Logging operations, both recent and current, add their own peculiar effects to the natural variety of cover types characteristic of the southern Blue Ridge Mountains.

The late Dr. Royal E. Shanks participated actively in early organizational planning and contributed much to the training of our field crew.

Aerial photographs of the area were not immediately available for study. Hence, the field party went out at first to obtain vegetation data by sampling in areas already known to differ (1958 TVA Forest Inventory Study) and in areas fully expected to differ because of variation in ecological factors. In particular, efforts were made to sample the vegetation at several different elevations on both north-facing and south-facing slopes, as well as from the valley bottoms and the ridgetops, and from locations illustrating man's use of the forest.

Sixty-nine circular sample plots of nested variable radius type were eventually selected, and detailed observations were recorded in the field. Distribution of plot diameter sizes is shown in fig. 4.

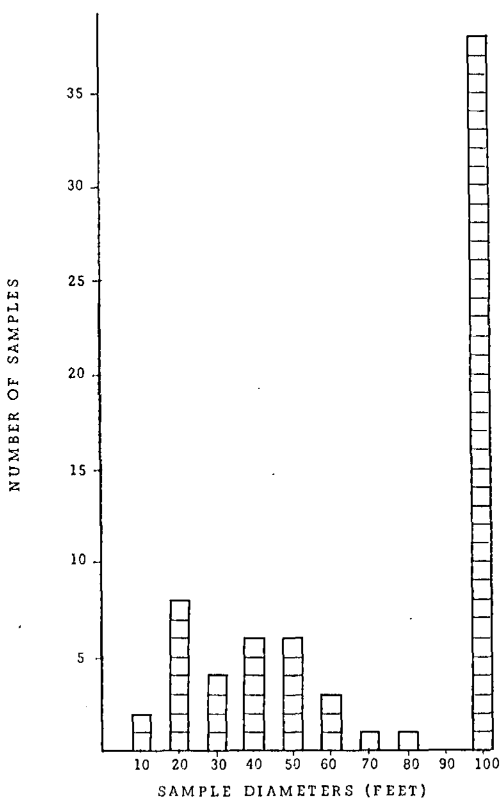


Fig. 4. Distribution of sample plot diameters

The 10- and 20-ft-diameter samples were of low old field and thicket vegetation. The considerable number of 100-ft samples, mainly of forests, accumulated early in the work, and were the result of ease of sampling procedure coupled with high confidence that the 100-ft size ordinarily is quite adequate for the usual sampling of forests of the region.

Vegetation diagrams were constructed using the WES system and the sampling data and diagrams were examined from several points of view. Variation in degree of complexity of the vegetation is implicit in fig. 6 where it may be seen that the extreme range in number of structural elements per sample extends from 5 to 30. The median is at 14, and 75 percent of the samples have from 10 to 20 elements each. Thus, some plots are several times as complicated as others.

The somewhat irregular outline of the curve of fig. 5 results from the facts that (a) different kinds of vegetation owe their differences in part to the number and degree of development of the component structural elements, and (b) uneven numbers of plots within given vegetation types were used for sampling. In fig. 3 the individual samples of the previous figure have been designated as they belong to a simple series of vegetation "mapping types." Although few samples were collected in thicket and park-woodland, the very fact that their cover occurs in a restricted number of height classes would appear to be compatible with their lower number of structural elements as observed in the field. Old field vegetation is more complicated, and while its range in elements is nearly that of the range of forest elements, its median is clearly lower. The name slash is here applied to stands in which relatively recent cutting has opened conspicuous areas in the overstory and notable amounts of tops and limbs in undecayed condition litter the forest floor. This is clearly a complex type, although its range of elements in these samples is narrower than that of the forest, or of the forest with thicket.

Forest varies widely in most of its characteristics. Figs. 7 and 8 are diagrams of samples taken approximately a stone's throw apart, and illustrate differences as those due to local site.* The plot with the more dense cover was from a deciduous stand in a steep, "moist and protected" ravine while the other was from an oak-pine stand on a much less steep but

* Leaves were present as indicated by the size, shape, and texture symbols, although the crosshatching is absent from these and other vegetation diagrams in this paper.

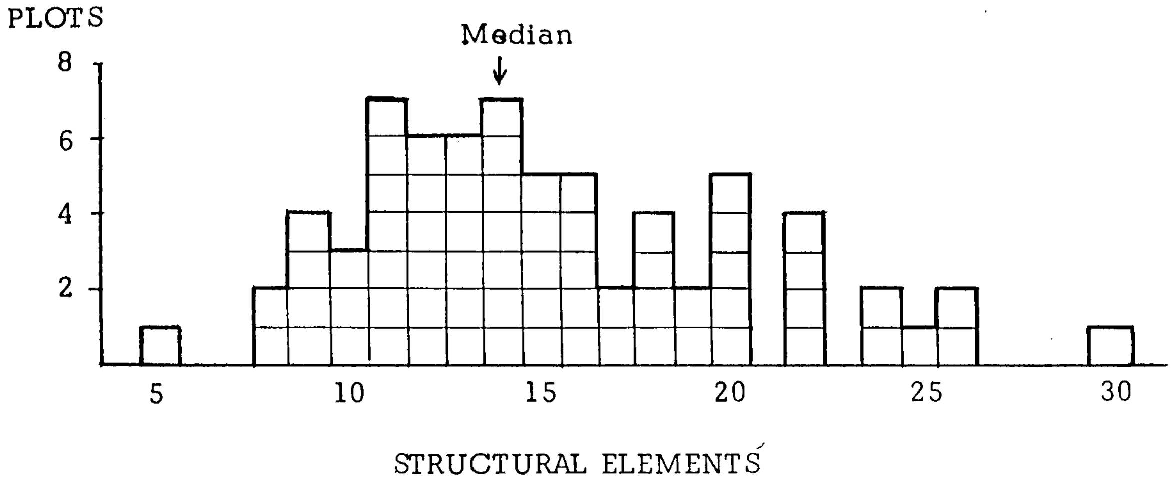


Fig. 5. Distribution of samples in terms of total number of structural elements present per sample

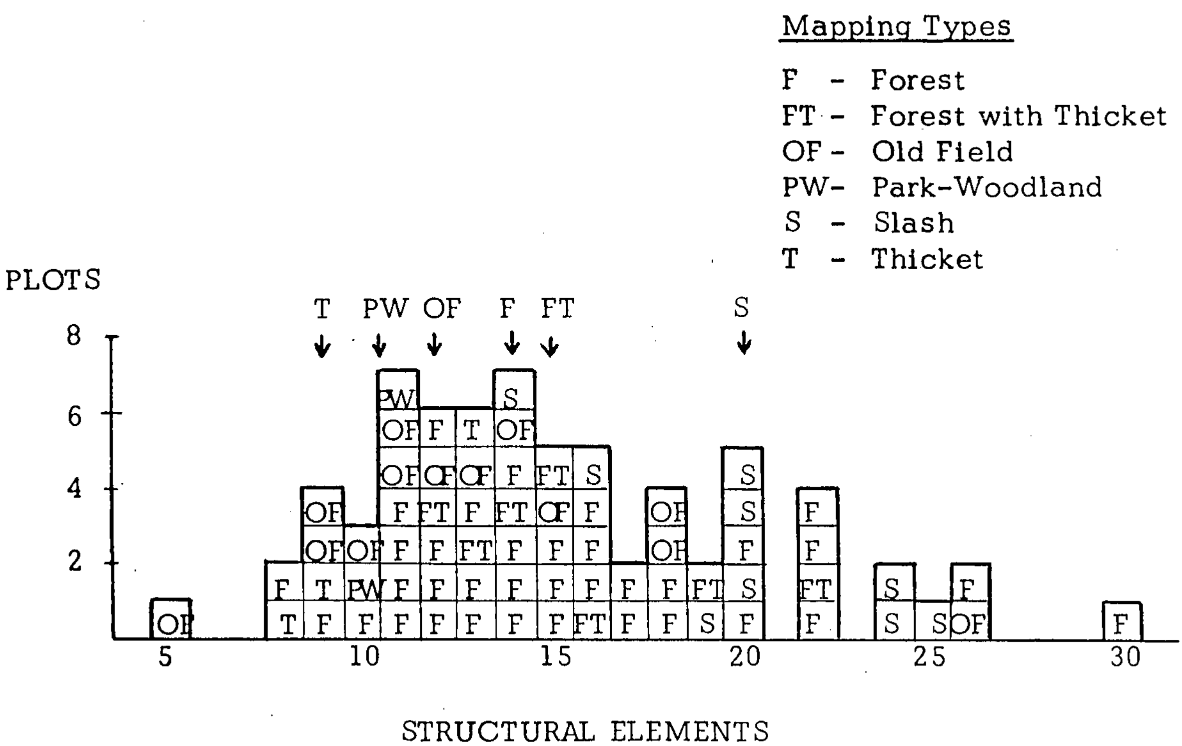
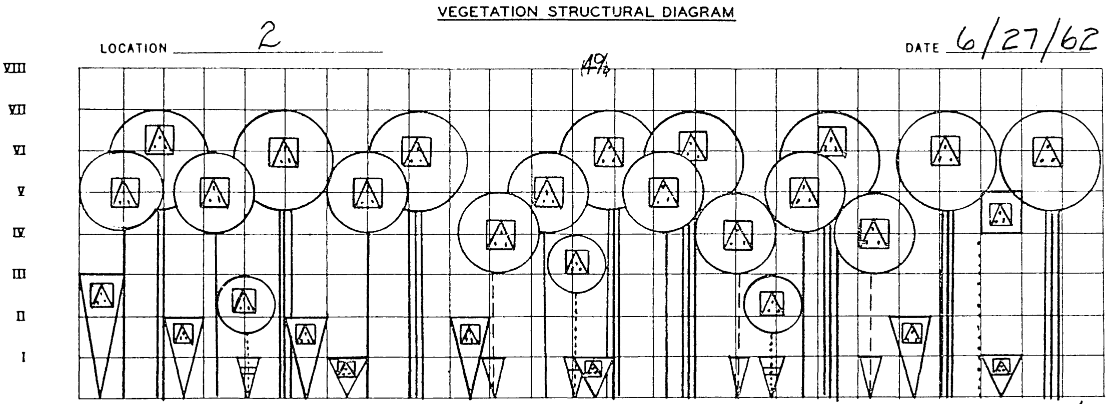


Fig. 6. Distribution of samples, structural elements present per sample, and vegetation mapping types


VEGETATION STRUCTURAL DIAGRAM
LOCATION 2
DATE 6/27/62
VIII
VII
VI
V
IV
III
II
I
4%

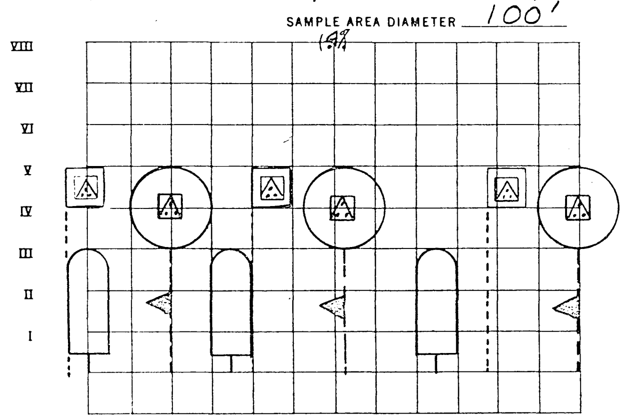
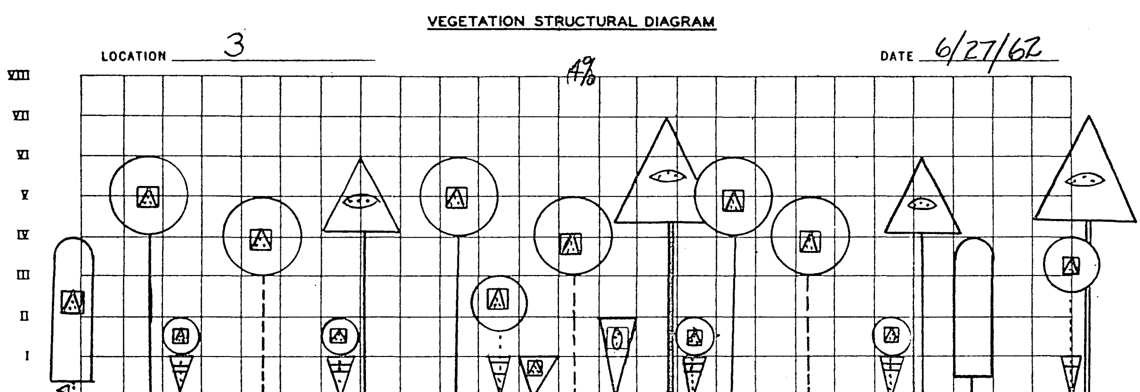

SAMPLE AREA DIAMETER 100'
VIII
VII
VI
V
IV
III
II
I

Fig. 7


VEGETATION STRUCTURAL DIAGRAM
LOCATION 3
DATE 6/27/62
VIII
VII
VI
V
IV
III
II
I
4%

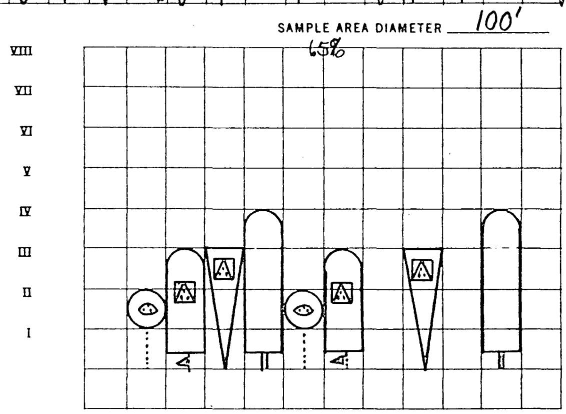
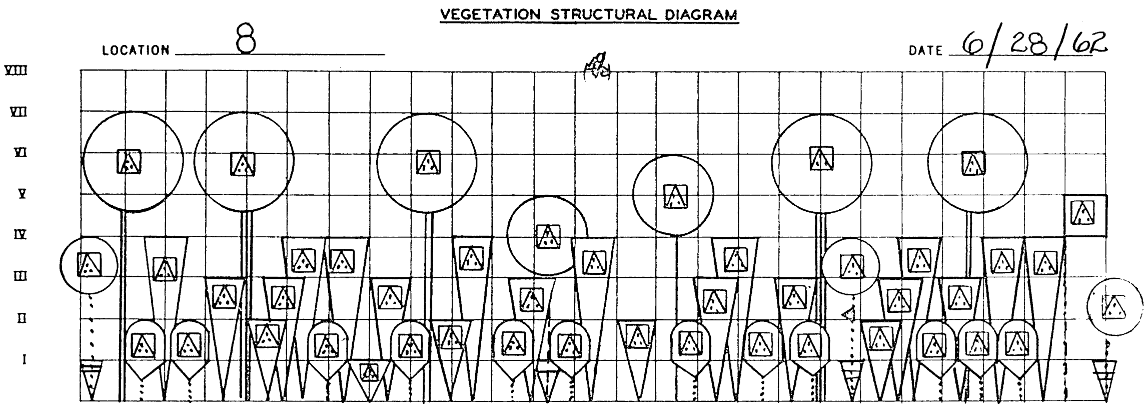

SAMPLE AREA DIAMETER 100'
VIII
VII
VI
V
IV
III
II
I

Fig. 8



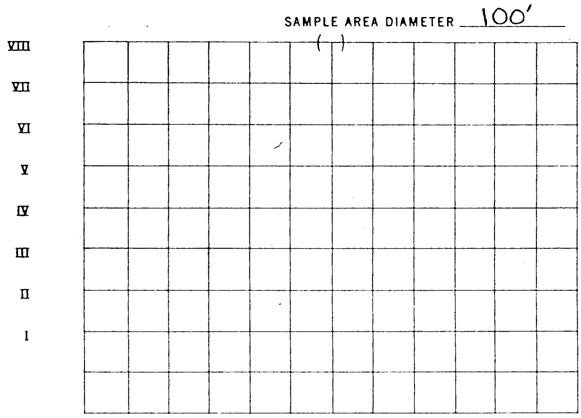
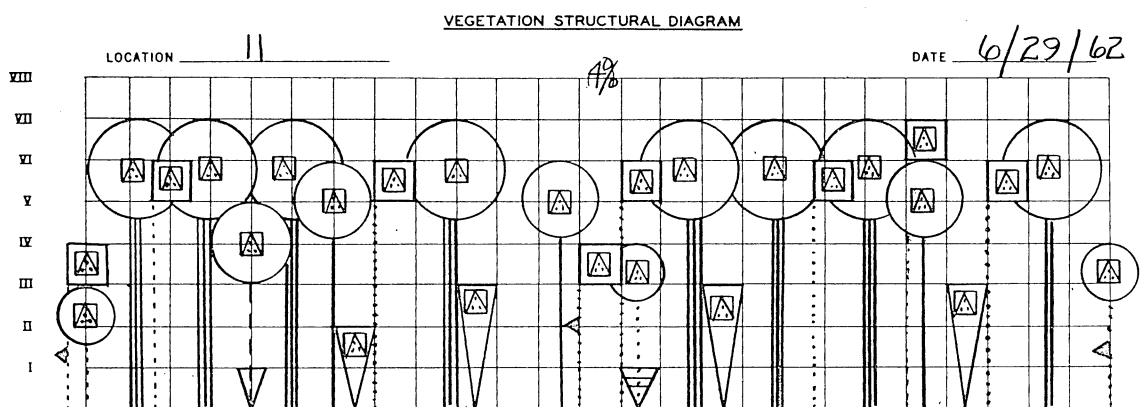


Fig. 9



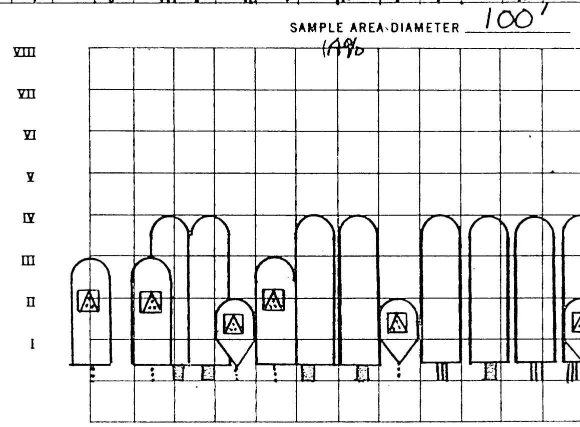


Fig. 10

1% POISON IVY COVER
LOCATION NOT RECORDED

"dry and exposed" lead. Both were at approximately midaltitude on the south-facing slope of a major ridge (Conner Mountain).

Figs. 9 and 10 are illustrative of the forests along the undulating crest of the same major ridge mentioned above. Both are relatively free of woody elements in lower height classes, but the overstories differ widely in cover and in number and size of their supporting stems.

Fig. 11 illustrates a well-stocked forest stand as it occurs at mid-slope elevation with north-facing exposure on the north-facing side of the same ridge. It is likely that reduced moisture stress (as compared with that at a comparable elevation on the south-facing slope) is playing an important role in the support of this stand.

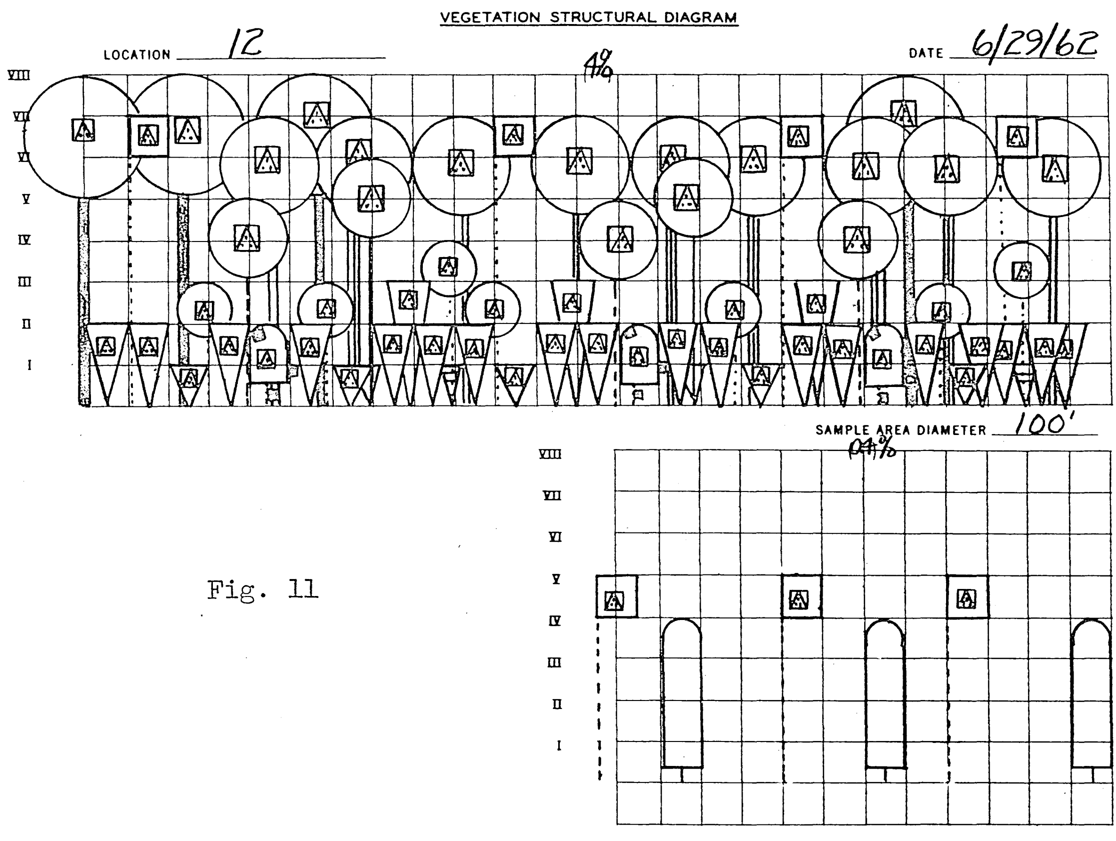


Fig. 11

It is not always easy to determine the cutting history or the burning record, but signs of cutting within recent years were not present in these samples. The ranger training area, however, does include much land in private ownership, and no known strictly virgin stands of timber have been seen by us. Selective cutting, some of it severe, has been widely

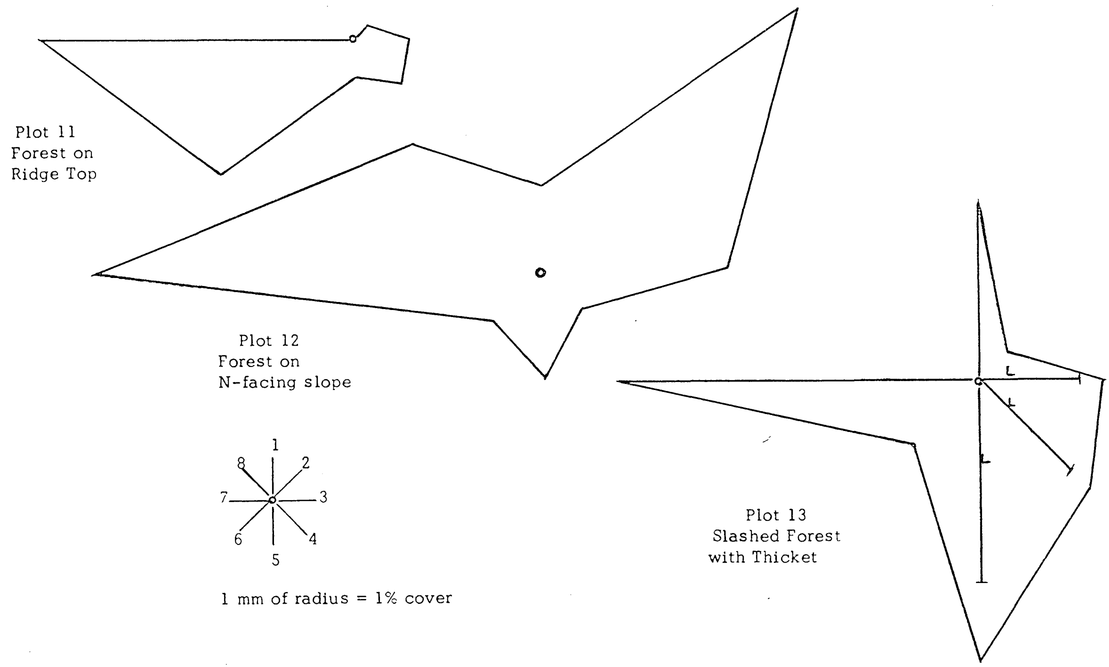


Fig. 12

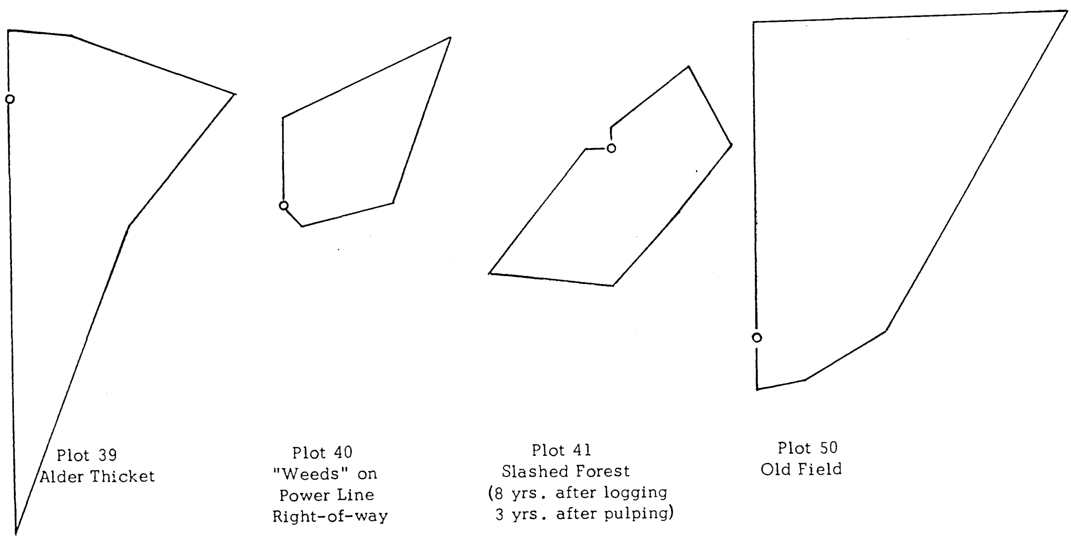


Fig. 13

practiced, and the condition of a forest stand seems often more clearly related to its previous use by man than to the processes of natural regeneration. High percentages of cover can occur in almost any height class, as seen in the star diagrams of fig. 12. Here eight radii correspond to the eight height classes and one percent cover equals 1 mm length along a radius. Fig. 13 shows the distribution of cover by height classes in a

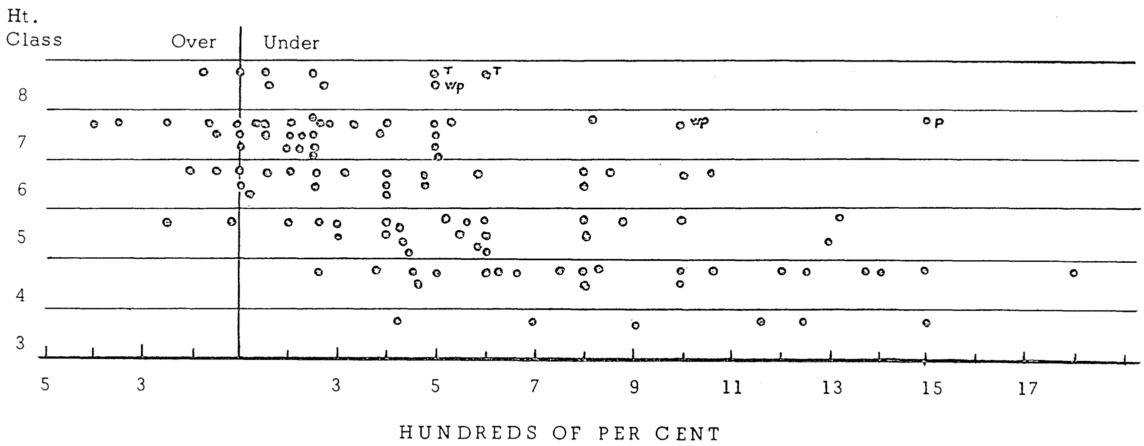


Fig. 14. Diagram representation of stem frequency

cutover forest, a thicket, under a power line, and in a weedy old field.

One problem in adequately portraying a sample of vegetation by the diagram system is that of stem frequency. In our area, at least, and as shown in fig. 14, the diagrams with their fixed ratio of stem number to crown cover percentage tend to underrepresent the actual number of stems observed in the field. Especially is this notable in the lower height classes where the factor of difference is not a few times but regularly several to many times.

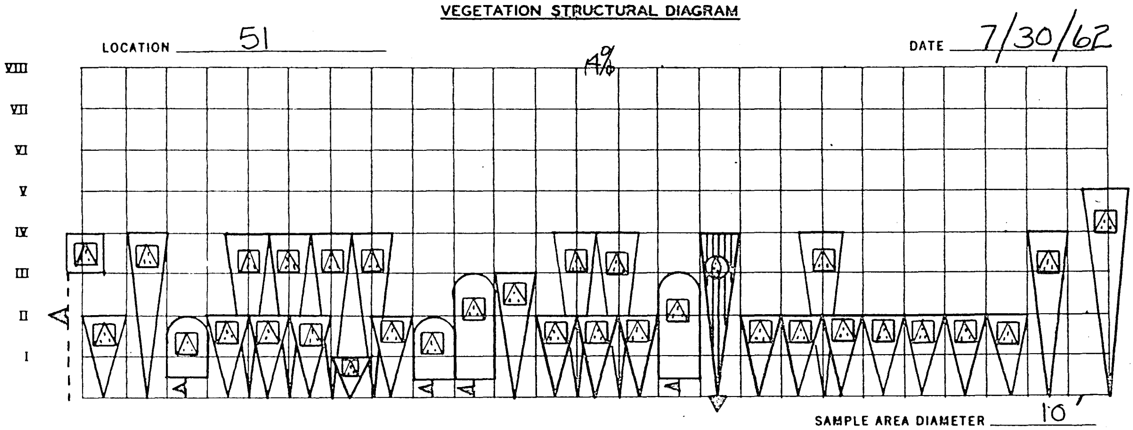
A more serious difficulty is that of extrapolating from limited amounts of detailed sampling data in order to construct a vegetation map. Some very large differences between forest vegetation samples (structural cells) are not separable by us on our aerial photos at 1:15,000 and 1:20,000 scales. No natural system of "classes of forest vegetation plots" based on multiple characteristics seems evident.

Accordingly, on the basis of data available and with respect to characteristics implicit in activities which include the foot soldier (chiefly cover and movement), a series of mapping units has been devised and used as follows:

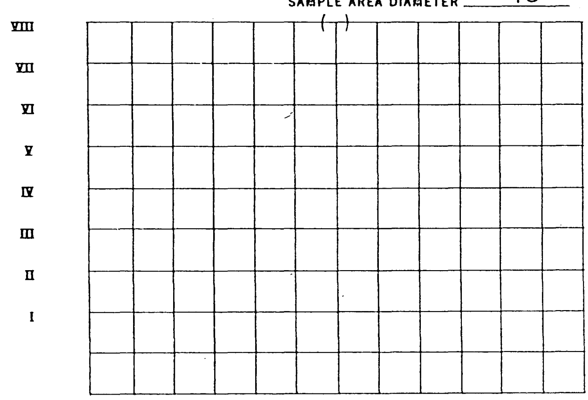
a. Cultured areas, including buildings, farmyards, fields in crops, clear pastures, roads and rights-of-way. Cover is highly variable. Travel unimpeded.

b. Old fields, weedy areas with scattered woody plants. No closed cover layers above 5 ft, tangled and sometimes thorny underfootage. (Example is shown in fig. 15.)

c. Thicket-woody stems in high density, essentially closed

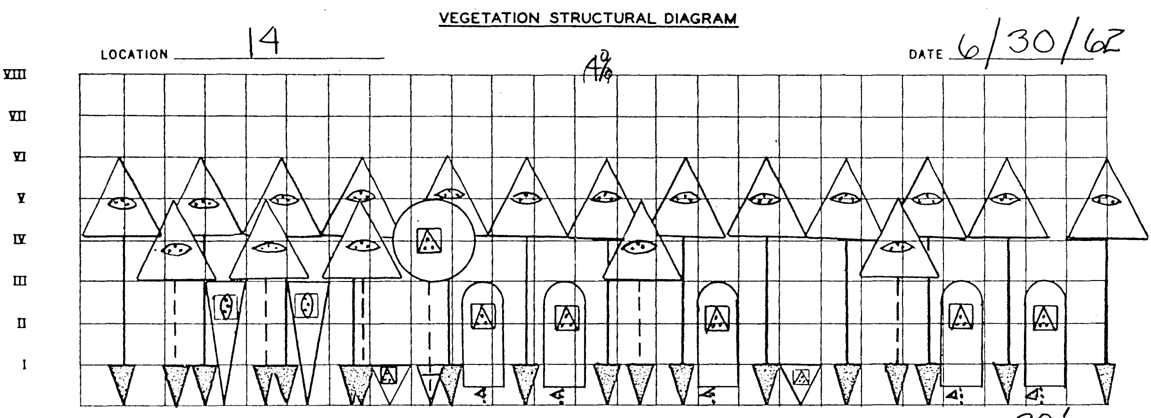


VEGETATION STRUCTURAL DIAGRAM
LOCATION 51
DATE 7/30/62
VIII
VII
VI
V
IV
III
II
I
SAMPLE AREA DIAMETER 10'

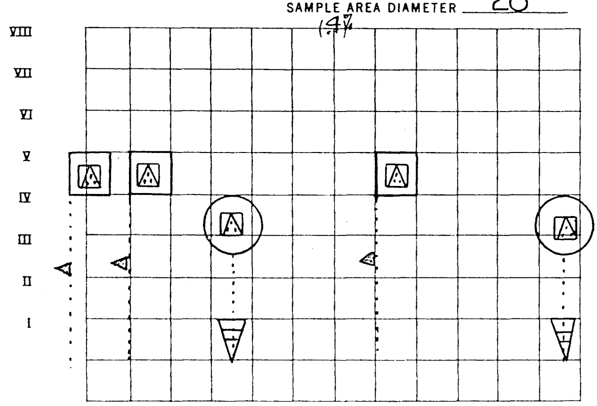


VIII
VII
VI
V
IV
III
II
I

Fig. 15



VEGETATION STRUCTURAL DIAGRAM
LOCATION 14
DATE 6/30/62
VIII
VII
VI
V
IV
III
II
I
SAMPLE AREA DIAMETER 20'



VIII
VII
VI
V
IV
III
II
I

Fig. 16

canopy, large shrubs or small trees. Cover is excellent but passage painfully slow. (Example is shown in fig. 16.)

d. Park-woodland, an arbitrary transition type with numerous taller trees, affording partial overstory closure and little cover in other than ground layer. Passage likely to be fast. (See fig. 17.)

e. Forest with thicket, trees with high canopy but also with a dense understory of woody shrubs, typically Rhododendron, Kalmia, or both. Cover is good, but passage is labored and slow. (See fig. 18.)

f. Forest without thicket, high canopy affords good cover. Stem density permits easy passage. (See figs. 7-11.)

g. Slash-logged areas of great complexity. Low and variable percent of cover at treetop and also lower heights. Brush piles, blackberry patches, stumps, snakes, and poison ivy in varying amounts make passage hazardous. (See fig. 19.)

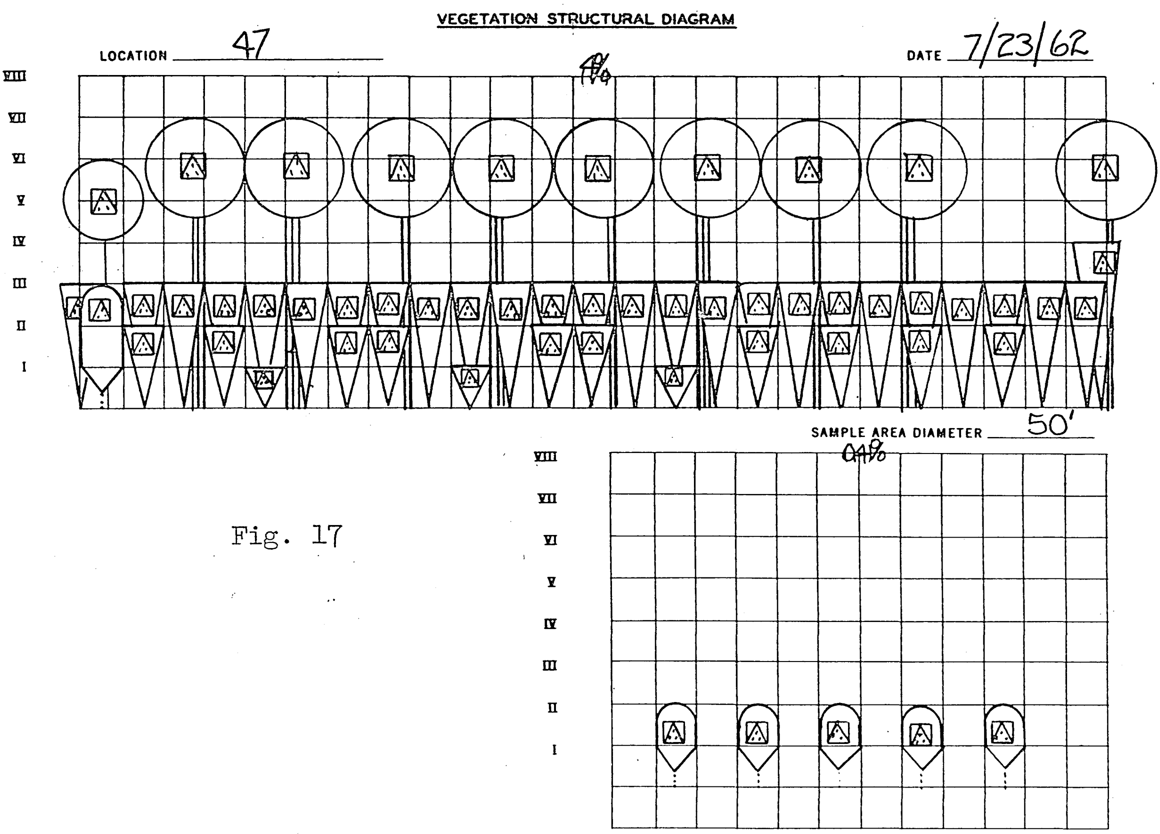


Fig. 17

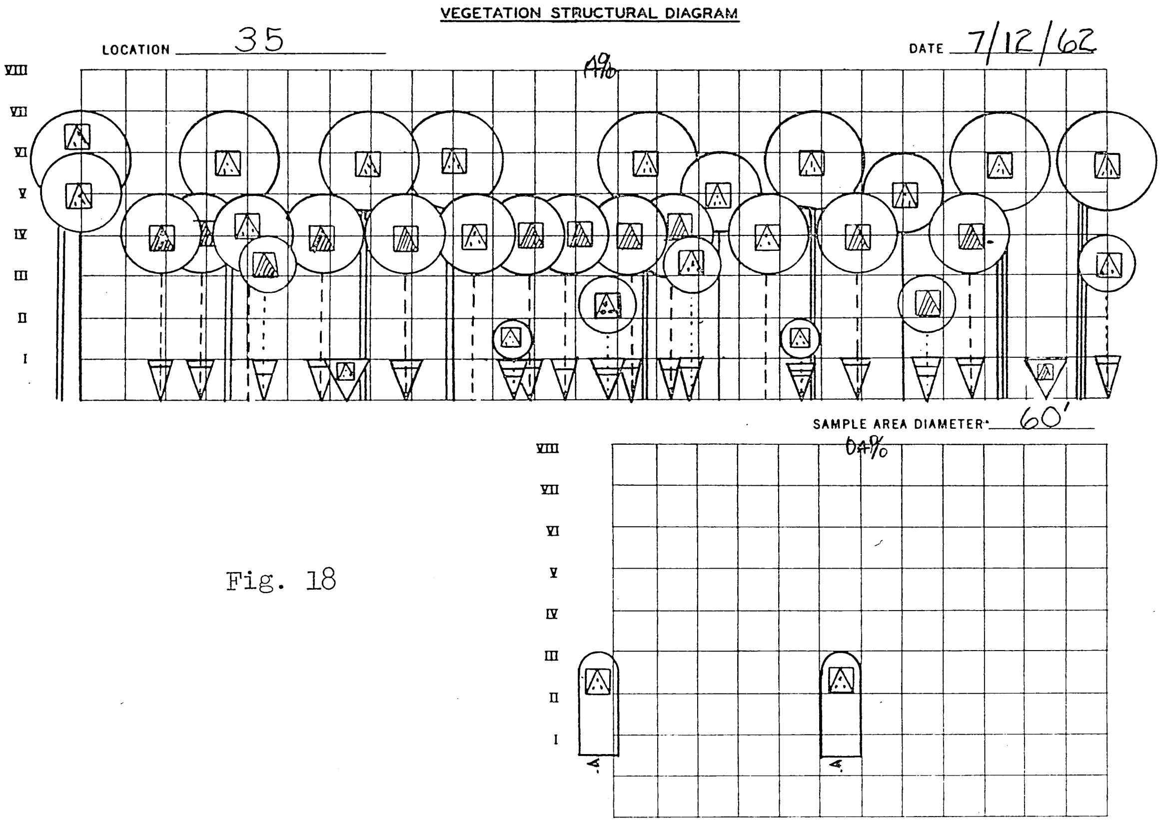

VEGETATION STRUCTURAL DIAGRAM
LOCATION 35
DATE 7/12/62
VIII
VII
VI
V
IV
III
II
I
A%
SAMPLE AREA DIAMETER 60'
0A%

Fig. 18

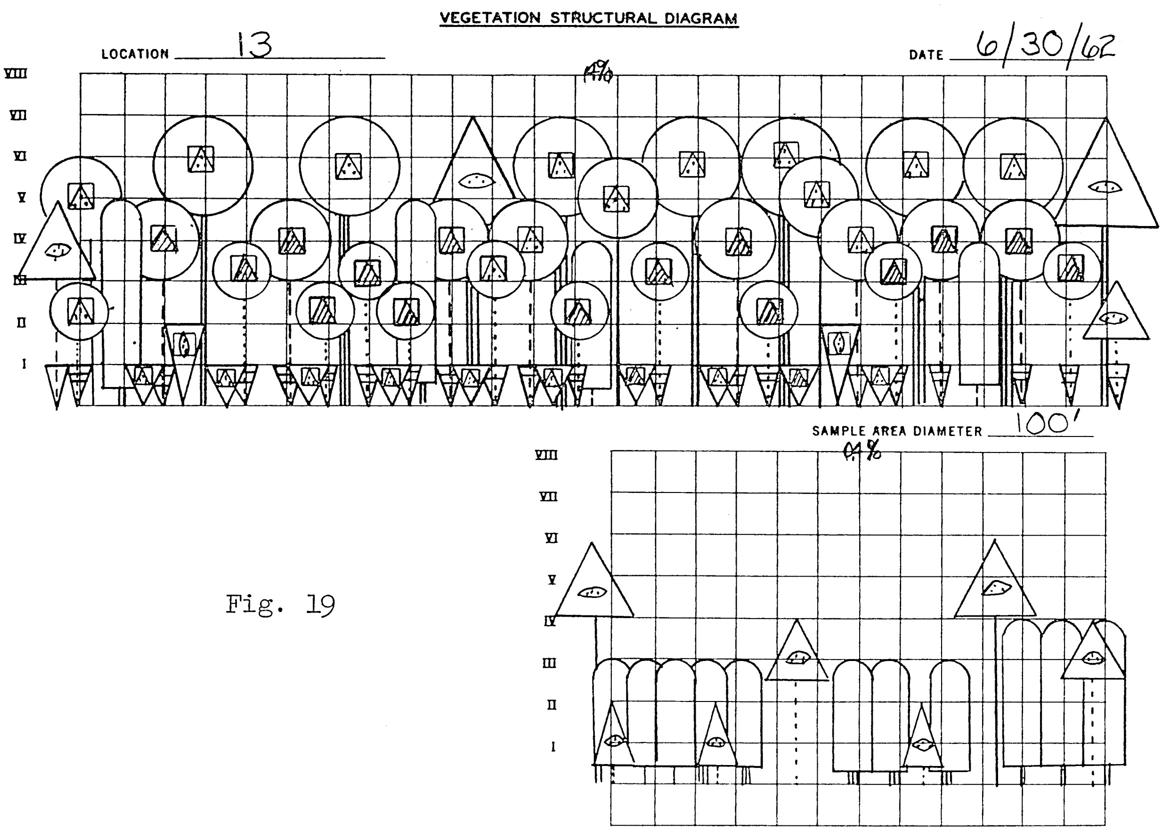

VEGETATION STRUCTURAL DIAGRAM
LOCATION 13
DATE 6/30/62
VIII
VII
VI
V
IV
III
II
I
A%
SAMPLE AREA DIAMETER 100'
0A%

Fig. 19

MOBILITY-ENVIRONMENTAL RESEARCH STUDIES, SOUTHEAST ASIA

by

A. A. Rula[1]

Introduction

In February 1962 the Advanced Research Projects Agency (ARPA) of the Office of the Secretary of Defense (OSD) expressed its intent, as part of Project AGILE, to the Chief of Research and Development (OCRD), Department of the Army, to establish a significant research effort in Southeast Asia to study the physical environment, particularly as it affects the design and employment of materiel and materiel systems. Because of the experience and special capabilities of the Army in various aspects of the work, ARPA proposed that the Army organize and conduct a research project in Southeast Asia under the auspices of ARPA's R&D Field Unit, Combat Development and Test Center (CD&TC), to study the factors of the physical environment that affect surface mobility. In addition, ARPA proposed that a preliminary survey team be assembled and sent to Thailand as soon as possible to act as an advance party for a long-term research effort and to delineate the problems to be investigated in Southeast Asia.

Preliminary Survey Study

Background

OCRD accepted ARPA's proposal and performed a preliminary survey study in accordance with a statement of the mission and activities to be conducted contained in an ARPA memorandum dated 20 April 1962. The study was conducted in Thailand during the period 28 May-31 October 1962 by a team of Army ground mobility-environmental specialists.

Objectives

The specific objectives of the preliminary study were to (a) survey and assemble existing data from all available sources, (b) collect

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1 Chief, Mobility Section, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

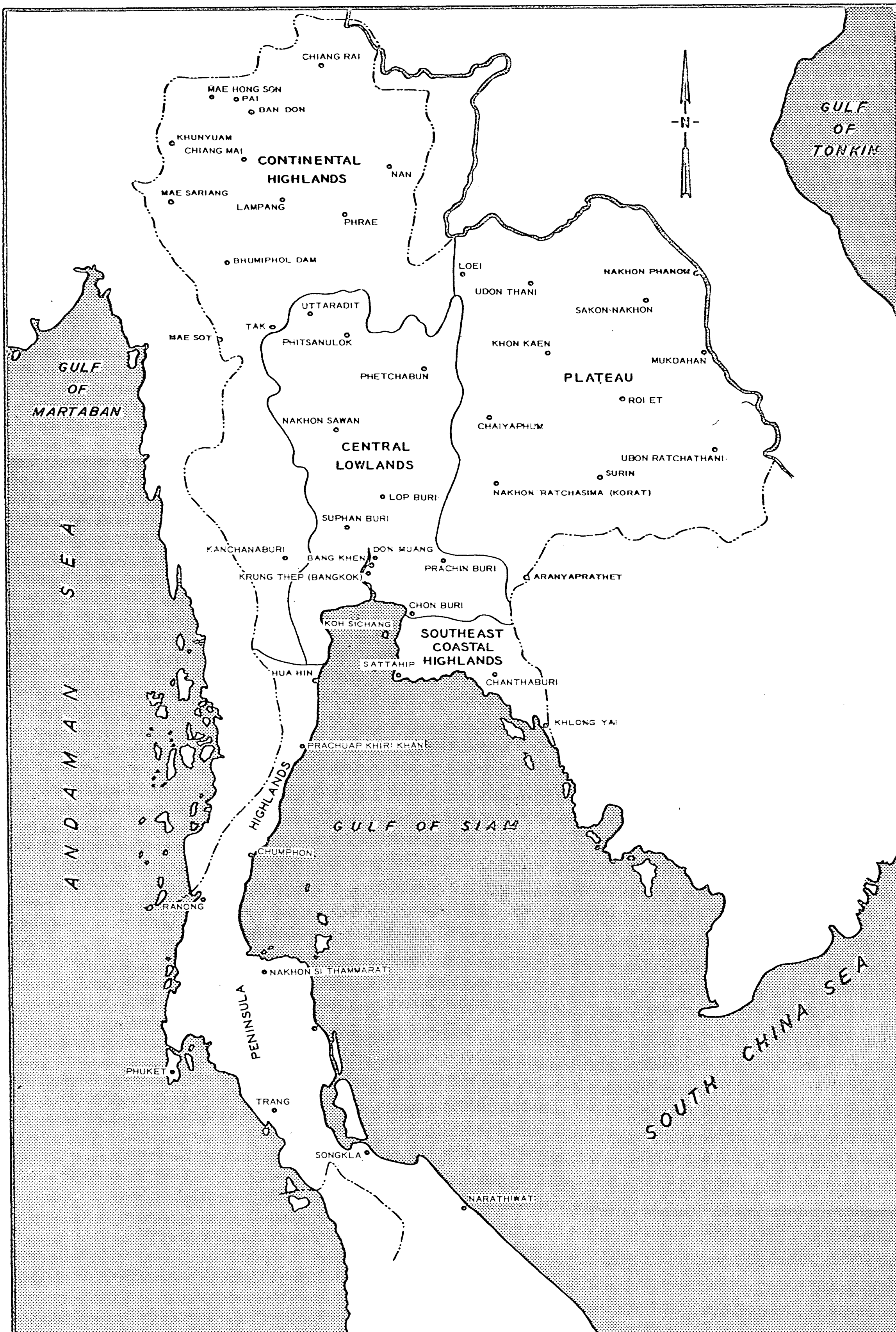


Fig. 1. Physiographic regions

appropriate environmental data to permit an evaluation of the nature and magnitude of the environmental factors that might affect ground mobility operations, (c) assemble all data in a form that would be useful to commercial and military agencies in research on and development of special-purpose vehicles for use by indigenous armed forces in Southeast Asia, and (d) delineate the problems and problem areas to be investigated during the course of the contemplated long-range program.

Thumbnail Sketch of Thailand

Location

Geographically, Thailand is located in Southeast Asia due north of the Gulf of Siam. The northern boundary of Thailand extends to about 20 N latitude, its southern peninsula boundary reaches as far south as about 6 N latitude, its eastern boundary extends to approximately 101 E longitude, and its western boundary extends to about 97 E longitude.

Climate

The climate of Thailand is tropical and is controlled primarily by monsoon winds which produce four distinct seasons: (a) a dry season from December through February caused by the northeast monsoons, (b) a rainy season from June through September caused by the southwest monsoons, and (c) two transitional periods of variable winds and precipitation. Annual rainfall is highly variable; the highest annual maximum, greater than 100 in., occurs along the western edges of the peninsula highlands; and the minimum mean annual rainfall, about 30 in., occurs in the central and eastern sections of Thailand. The rainfall is usually showery in nature throughout most of Thailand. The mean annual maximum temperature is about 84 F and the mean annual minimum is about 75 F.

According to Köppen's classification system, three major climatic groups occur: (a) tropical rainy, (b) tropical rain forest, and (c) tropical savanna.

Physiographic regions

In general, the physiography of Thailand consists of five major regions (fig. 1): (a) the eastern plateau, referred to as the Khorat Plateau; (b) the southeast coastal highlands; (c) the central lowlands; (d) the continental highlands; and (e) the peninsula highlands.

Fig. 2. Rivulet flowing in sandy clay soil in the eastern part of the Khorat Plateau

Fig. 3. Typical wooded rice fields common throughout Thailand

Khorat Plateau. The Khorat Plateau is a very gently undulating surface that is tilted toward the southeast and is underlain by fine-grained sandstone and shale. The soils of the floodplains are usually clays and silty clays (fig. 2), and the soils of the gently undulating surfaces range from fine sands to silts and mixtures thereof. Most of the region is under cultivation, with rice being the principal crop (fig. 3). The central and southern sections of this region are drained by the Chi and Mun Rivers, respectively. During the peak of the wet season most of the bottomland areas are flooded (fig. 4).

Fig. 4. Flooding in the Khorat Plateau area near Surin during the wet season

The escarpment along the edge of the Khorat Plateau is fairly rugged. In areas containing clastic sedimentary rocks, the hills have steep slopes with rounded crests, but the limestone areas contain many almost-vertical cliffs (fig. 5). Many slope surfaces contain erosion channels, boulders, and dense vegetation.

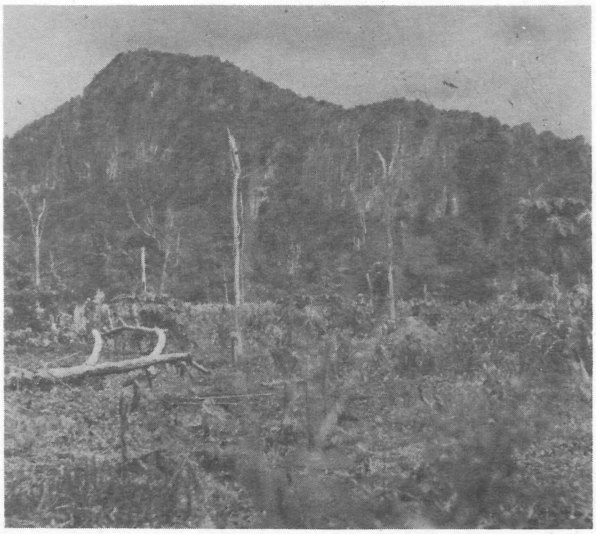


Fig. 5. Limestone hill with near vertical slopes, located in the Khorat escarpment area

Central lowlands. The central lowlands are identified as the Bangkok Plain. The surface is practically featureless except for

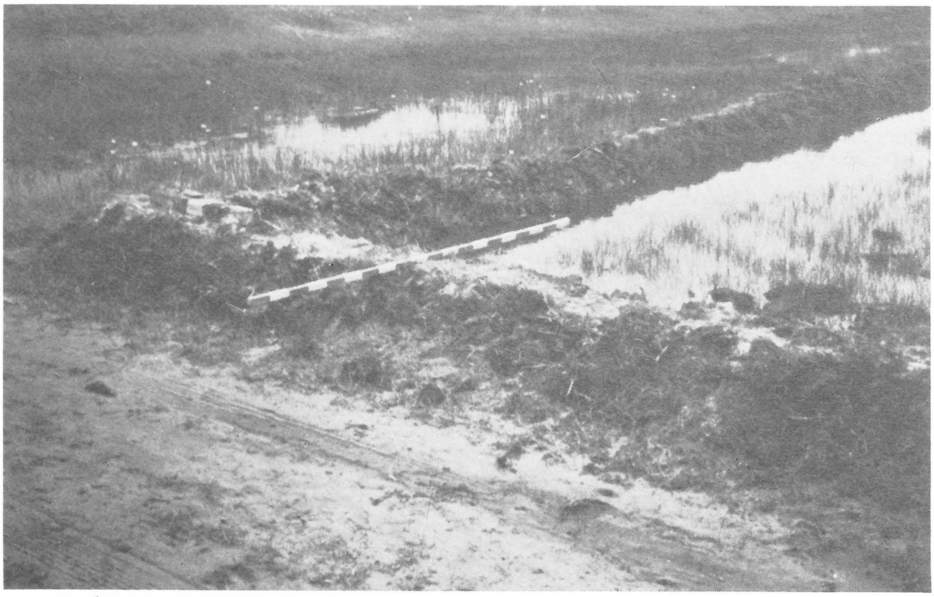


Fig. 6. Rice-field dikes in foreground and road embankment in background; Bangkok Plain area

Fig. 7. Generally featureless area located in the Bangkok Plain

road embankments, canals and associated spoil banks, and widely spaced rice-field dikes (fig. 6). In many sections of the central lowlands, relief may change as little as 1 ft in 2 miles (fig. 7). The parent material is alluvium and the soil types are predominantly clay and silty clay. Rice is grown on the entire area, but in the northern section, where better drained conditions can be found, corn is also grown. The central lowlands are drained by the Chao Phraya River and, during the peak of the wet season, the lowlands are flooded, with areas in the lower reaches of the Chao Phraya River flooding to depths up to 2 m.

Fig. 8. Soil profile in road cut near Chiang Mai in northwestern Thailand. Soil is a residual soil with granitic rock as a parent material

Highlands. The characteristics of the highlands are, in general, similar regardless of their occurrence in Thailand. The relief in the southeast coastal highlands is in the order of several hundred feet, whereas the relief in the continental and peninsula highlands is several thousand feet. The ridges are made up of the usual rock complexes, i.e. sedimentary-metamorphic and igneous of several geologic ages. The residual soils vary in thickness from several centimeters to 4 m (fig. 8). The soil type and other soil characteristics usually reflect the parent material. The ridge slopes are usually steep, with most falling in a slope category between 40 to 80 percent. At the interface of the ridge faces and valley floors, the slopes begin abruptly and a common slope within narrow limits may be maintained throughout a large section of a ridge face. The steep slopes, combined with adverse surface geometry features and vegetation, present great difficulties in negotiating the ridges even by foot (fig. 9). The valleys range in width from a few meters to several kilometers. These areas are intensively cultivated, with rice being the chief crop (fig. 10). The bottomland soils are highly variable, with silt and clay loams being the predominant soil types.

Fig. 9. Typical ridge and valley topography of the continental highlands. The ridges are densely forested and the valleys are cultivated with rice fields

Fig. 10. Terraced rice fields in the continental highlands

Thailand Test Program

Areas visited

A ground reconnaissance was made in each of the physiographic regions previously mentioned, except the peninsula highlands. Fig. 11 shows the location of the sites tested, the routes traveled, and the locations of pertinent cities and towns. The numbers are site numbers, and the letters indicate the type of terrain-factor data collected at each site. For example, "T" signifies that trafficability measurements were made, "V" signifies that vegetation measurements were made, and so on.

Number of sites tested

Data were collected for one or more terrain factors at 379 sites, and data for two or more terrain factors were collected at approximately 200 of the 379 sites.

Data-collection systems

The data-collection systems employed by the preliminary survey team for such terrain factors as soil trafficability, surface geometry, hydrologic geometry, and vegetation were those currently in use at the Waterways Experiment Station (WES); however, because of the reconnaissance nature of the field trips, some of the measuring techniques had to be streamlined to permit visiting more sites at the expense of detailed measurements. Current techniques, evolved as a result of environmental research being conducted at the WES, were used to summarize, evaluate, and portray the data for ground mobility purposes.

In addition to the WES cone penetrometer method for quantifying soil trafficability, the Land Locomotion Laboratory (LLL) bevameter was used to obtain soil values pertinent to the LLL soil-vehicle system for predicting vehicle performance. Because of difficulties encountered in transporting the vehicle (the Polecat) upon which the bevameter equipment was mounted, and because of difficulties in securing access for the vehicle to test sites, the number of sites at which LLL data were collected was limited.

Report

An incomplete preliminary draft report was prepared in Thailand by the survey team and the final report was prepared and will be published (about 15 May 1963) by WES. The report includes a general report and eight appendixes. The general report consists of introductory material and three major technical sections: (a) a discussion on the state of the art of measuring and predicting the effects of environmental factors on ground

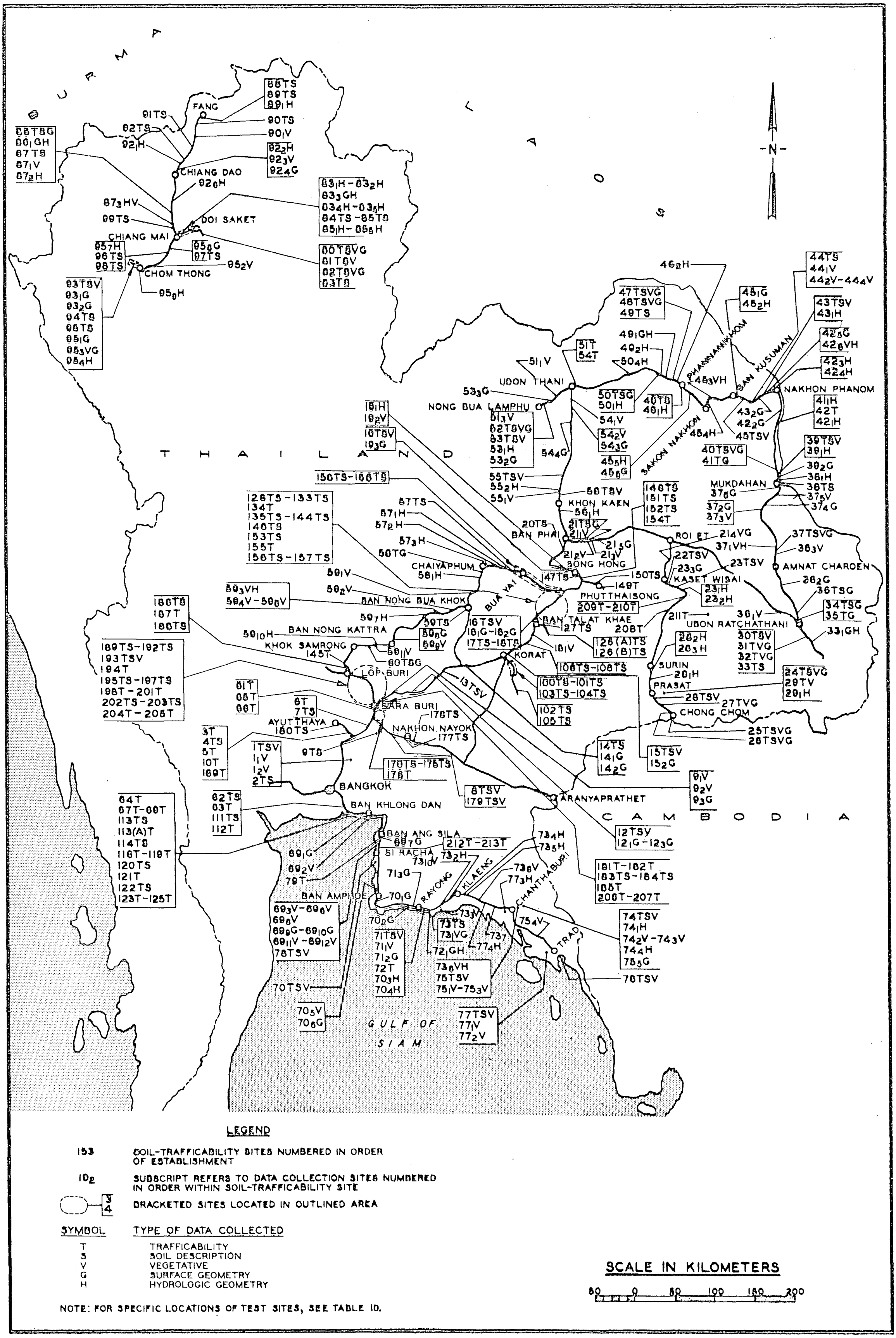


Fig. 11. Thailand data-collection sites

mobility; (b) an examination of the factor-family concept of terrain analysis, with an adaptation suitable to ground mobility purposes; and (c) a catalog (in handbook form) of environmental data by landscape type and subunits that occur in Thailand, with an estimate of the effects that would probably be imposed by the terrain factors on vehicle performance. Appropriate conclusions and recommendations are also presented. The eight appendixes present in detail the measurement methods employed, the data collected, and appropriate discussions.

Data presentation (in handbook form)

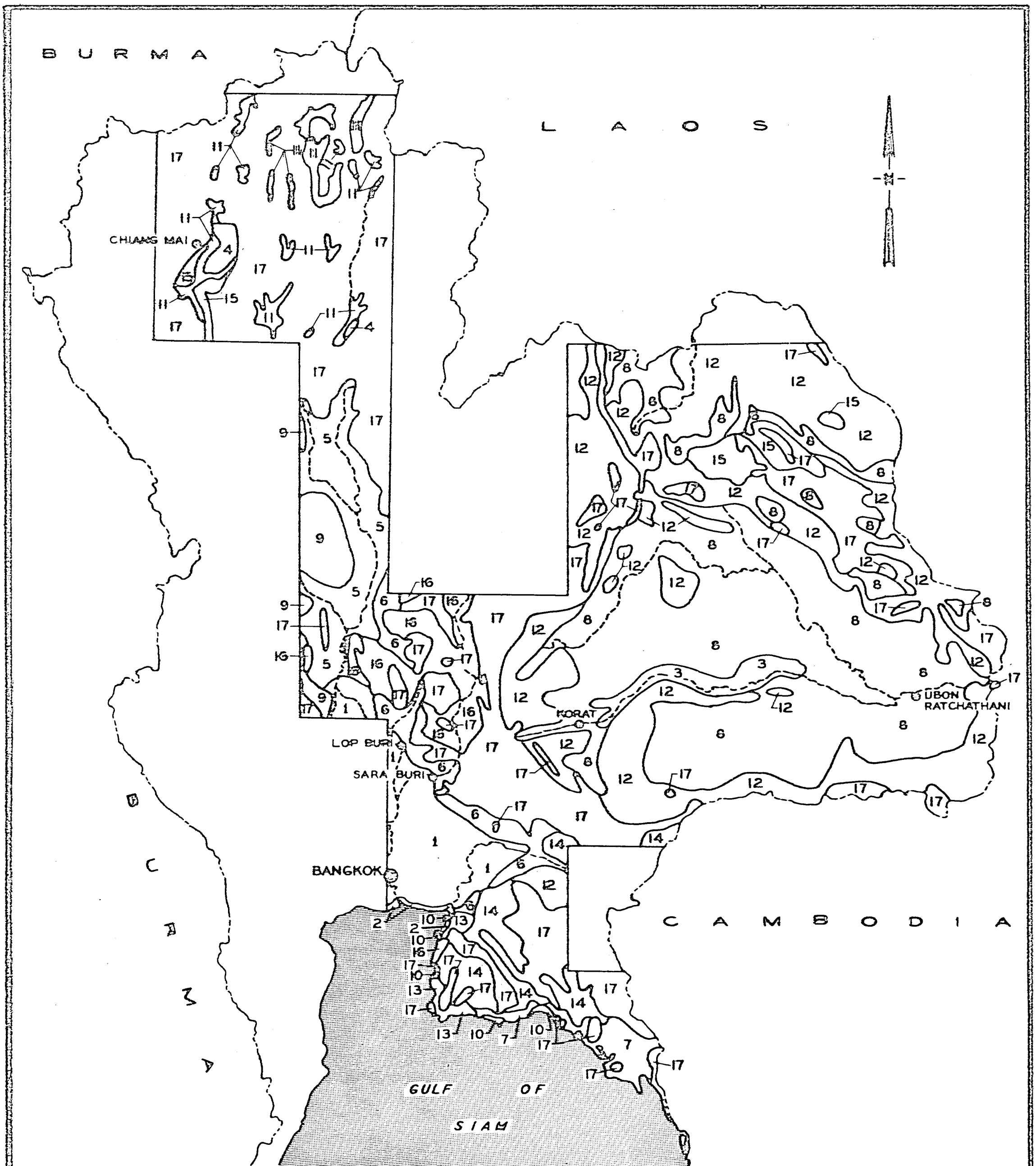
The lack of time and the wide distribution of sampling points precluded the possibility of following rigorous procedures for quantifying terrain factors affecting ground mobility. The identification of terrain units was also limited to the areas visited by the test team and to areas for which the team was reasonably confident that the collected data could be extrapolated. These limitations have undoubtedly resulted in inaccuracies in boundaries established or even in categorizing terrain units.

The technique followed in establishing terrain units for ground mobility purposes involved: (a) the identification of "landform components" on the basis of similarities in the arrays of values exhibited by each pertinent factor within the factor families, (b) the grouping of landform components into "landscape types" on the basis of similar associations of the landform components. Thus, a landscape type consists of a repetitive pattern of landform components, each component of which is similar within prescribed limits to all others in the landscape type.

As a result of this process, a total of 17 landscape types were identified (fig. 12), primarily on the basis of similarity of surface geometry; however, soil consistency and obstacles were also considered. The landscape types and the landform and hydrologic components that make up a landscape were named according to common usage. Each landform component was defined in the following terms:

Name of landform component

(1) Distribution
(2) Surface geometry (or configuration)
(3) Flooding
(4) Vegetation
(5) Soils
(6) Mobility



LEGEND

MAP UNIT	LANDSCAPE TYPE
1	CENTRAL CHAO PHRAYA PLAIN
2	DELTA COAST
3	CENTRAL MAE NAM MUN PLAIN
4	CHIANG MAI PLAINS
5	MAE NAM NAN PLAIN
6	EASTERN MARGINS OF CENTRAL PLAIN
7	SOUTHEASTERN COASTAL TERRACES
8	KHORAT PLATEAU GENERAL SURFACE
9	WESTERN MARGIN OF MAE NAM NAN PLAIN
10	BEACH RIDGES AND FILLED LAGOONS
11	CULTIVATED MOUNTAIN VALLEYS
12	HILL LANDS OF KHORAT PLATEAU
13	COASTAL TERRACES AND LOW MOUNTAINS
14	BROAD MOUNTAIN VALLEYS OF THE SOUTHEAST
15	FOOTHILLS
16	VALLEYS OF THE KHORAT ESCARPMENT
17	MOUNTAINS

——— MAJOR RIVERS

NOTE: TYPES OF LANDFORM AND HYDROLOGIC COMPONENTS OCCURRING IN EACH LANDSCAPE TYPE ARE SHOWN IN TABLE 3.

Fig. 12. Thailand landscape types

Each hydrologic component was defined in the following terms:

Name of hydrologic component

(1) Distribution
(2) Channel geometry
(3) Flow characteristics
(4) Vegetation
(5) Soils
(6) Mobility

An example of the format used in presenting the data for a landform component is illustrated in fig. 13. In this example the landscape type is: Central Chao Phraya Plain. A landform component of this landscape is: nonterraced rice fields. The numbers in parentheses refer to ground photos of the landscape type. A statement is made regarding its distribution. Surface geometry terms define size, shape, and pattern of occurrence of those surface features that directly affect mobility of ground vehicles. Categories of features and quantitative size classes were established; these are identified by the arrays of number and letter symbols such as SI-SSS. A series of statements define seasonal flooding. Two properties of vegetation structures that appear to influence mobility--namely, spacing and visibility--are used to characterize vegetation. These are indicated by values in meters: $S_c = 30$ indicates clumps of plants 30 m apart. For more detailed vegetation data, the reader is referred to the appropriate appendix. If seasonal variations occur, they are also indicated. Predominant soil types that occur in the Unified Soil Classification System and the U. S. Department of Agriculture textural classification are indicated accordingly. Mobility is defined in terms of soil trafficability as measured by the WES system and a series of statements defining impedance to be expected from obstacles. The final estimate of the mobility on a landform component is made in terms of average speed that a highly mobile vehicle, such as the Gama Goat (articulated wheeled vehicle) or the Polecat (articulated tracked vehicle), could maintain on the first pass.

Conclusions and Recommendations

On the basis of the data collected and the observations made by the

SUMMARY OF ENVIRONMENTAL DATA BY LANDSCAPE TYPE

1. Central Chao Phraya Plain

   a. Landform components

      (1) Nonterraced rice fields (1,2)

Distribution: continuous

Surface geometry:
Slope: 1
Dikes: linear reticulate; SI-ŚSS, S7-MMS; occurrence 20 to 200 m
Ditches: linear random; TP-11(1)1, 21(CV1)1, TP21(1)1, TP-22(2)1, TP-22(CV1)1; occurrence 100 to 1000 m

Flooding:
Dec-May: dry
June-Aug: mosaic of dry and wet fields; water depth rarely more than 20 cm
Sept-Nov: continuously flooded; water depth may reach 150 cm for periods up to 10 days; normal water depth 20 to 50 cm

Vegetation: uniform throughout area
June: D-6 (S = oo, V = ∞)
Nov: D-120 (S_c = 30, V = ∞)

Soils:
USCS: mostly CH, some CL and MH
USDA: mostly CL, but a few SCL

Mobility:
Trafficability:
Cone index: min 75; max 430
Rating cone index: min 63; max 430
Obstacles: movement seriously slowed by innumerable small dikes in some areas; however, substantial areas, especially SE and NE of Bangkok, are almost free of dikes. Probable max speed for light vehicles: 3 to 6 km/hr

   b. Hydrologic components

Fig. 13. Example of presentation of data for a landform component

preliminary survey team, some of the conclusions and recommendations made to serve as guidance for a long-range program were:

a. Conclusions

(1) Existing literature in Thailand dealing with terrain factors is in qualitative terms and does not lend itself to suitable quantification for ground mobility purposes.

(2) The areas tested by the preliminary survey team probably represent a substantial number of the environmental variations that exist in Southeast Asia.

(3) Significant seasonal variations of environmental conditions occur in Southeast Asia; therefore, seasonal data are necessary to define mobility characteristics properly.

(4) The application of existing sampling and analysis techniques to Southeast Asia are questionable.

(5) Vehicle-terrain relations for complex associations of terrain factors operating in unison must be developed before dependable qualitative estimates of vehicle performance can be made. It goes without saying that valid test procedures must be developed first.

(6) On an areal and seasonal basis, it is probable that the major factors that would impede the movement of light, highly mobile vehicles in much of Southeast Asia are combinations of surface geometry and obstacles.

b. Recommendations

(1) Areas in Southeast Asia known to produce other environmental variations not tested by the preliminary survey team should be visited and sampled.

(2) Areas characterized by pronounced seasonal changes should be examined each season as well as during transition periods.

(3) Present pedological soil classification programs being conducted in Thailand should be maintained and, if possible, supported if arrangements can be made to include the collection of additional data.

(4) Controlled visibility tests should be conducted, preferably in the U. S. but with some activity in Southeast Asia, in areas that would permit testing against single and combination terrain factors so that reliable vehicle-terrain relations can be developed.

(5) Efforts should be devoted to improving photo interpretation techniques as applied to Southeast Asia so that reasonable estimates of those environmental attributes that are significant to vehicle mobility can be made from airphotos. Other noncontact sensors, such as radar

and infrared, should be incorporated as soon as the capability is developed.

(6) Portrayal systems that will indicate levels of ground mobility performance for the tactical military situations should be developed.

Future Plans

In regard to future plans, a research proposal has been prepared by WES and approved by the Environmental Sciences Branch, R&D Directorate, U. S. Army Materiel Command (AMC), for a long-range mobility-environmental research study. The proposal, along with other pertinent documents prepared by AMC, has been submitted through channels to ARPA for approval.

The proposal envisions a three-year program with concurrent activities being conducted in the U. S., Thailand and other accessible Southeast Asia countries, and several locations in the Caribbean area. It is hoped that enough effort can be directed toward this program, employing capabilities of existing government agencies, private industry, and universities, so that the new knowledge generated will go a long way toward establishing reliable vehicle-terrain relations that will be useful to vehicle designers and military planners.

PROBLEMS AND PLANS

by

Warren E. Grabau[1]

Introduction

All of the major activities of the "Military Evaluation of Geographic Areas" (MEGA) project fall into three general classes, though with a liberal amount of overlap:

a. Theoretical studies, intended to develop systems and refine techniques for describing, classifying, sampling, recording, and otherwise manipulating environmental and military activities data;

b. Data-collection programs, which are intended to provide the necessary detailed and reliable data for use by the theorizers, and ultimately by the still largely hypothetical test teams; and

c. Applications of the systems and techniques to practical problems.

There are specific problems in each of these general areas. Only those problems which are regarded as major will be mentioned, and for the present purpose a major problem is one for which there is scarcely a glimmer of an idea toward a solution.

Problems

First, consider the field of theoretical studies, in which the chief concern is with the adequacy of descriptive and classification systems:

a. The surface macrogeometry system, while apparently sufficiently precise and meaningful, is very laborious to manipulate. The derivations of the various index numbers are so time-consuming that it is impractical to apply them on a really broad scale. As a result, it is necessary when large areas must be analyzed, to confine actual measurement to very small sample areas, and to interpolate between them by purely subjective means. Normally the measured sites are spaced so

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widely that the interpolations are subject to challenge. Thus, a much more rapid method of deriving the pertinent factor values is needed. It may also be, of course, that a basically simpler descriptive system could be evolved, thus reducing labor and saving time at various phases of the analysis.

b. There are two obvious problems in the field of hydrologic geometry. The first of these is concerned with the form that the system should take. At the moment, it is the conviction of the Area Evaluation Section (AES) that it should be a series of numbers derived by a method analogous to that discussed in the report on the status of the hydrologic geometry factor family (Grabau; "Hydrologic Geometry for Military Purposes," pp 33-39); that is, that the various attributes be defined in terms of equations for irregular curves, and that numerical factor values be derived and stored as coefficients of those equations. The question is, therefore: What form should a description of hydrologic geometry take?

The second question emerges from a consideration of the peculiar effects that water bodies impose on military activities. The experimental results presently available suggest that the most important consideration is not water per se, but rather the water-land interface. Thus the question becomes: Is hydrologic geometry properly a factor family, or would it be more appropriate to specifically investigate the interface as a factor family?

c. Two major problems persist in the field of vegetation analysis. Actually, it may be that there is only one, because the two are related in a special way. The first of these is concerned with the concept of spacing. Only rarely are natural distributions truly random; much more commonly they are ordered to some extent. That is, trees tend to aggregate in complex and subtle ways, and these aggregations are often neither easy to detect nor to measure. Yet the only really convenient measure of distribution, the so-called "nearest neighbor value," is valid only for true random distributions and for completely ordered distributions such as trees in an orchard. Fig. 1 illustrates the nine basic ways in which points in space can be ordered. It should be noted that standard statistical measures, such as those for central tendencies and skewness, shed some light on this, but it turns out to be astonishingly difficult to correlate such measures with effects on military activities. One of the reasons for this is that a relatively small change in the sample size, which in the diagram is one of the small squares, will profoundly affect the values for central tendency and skewness. The first question thus becomes: Is there an adequate measure of aggregation in slightly ordered populations, and if so, what is it?

The second problem is closely related to the first; namely, how are nonrandom distributions recognized and

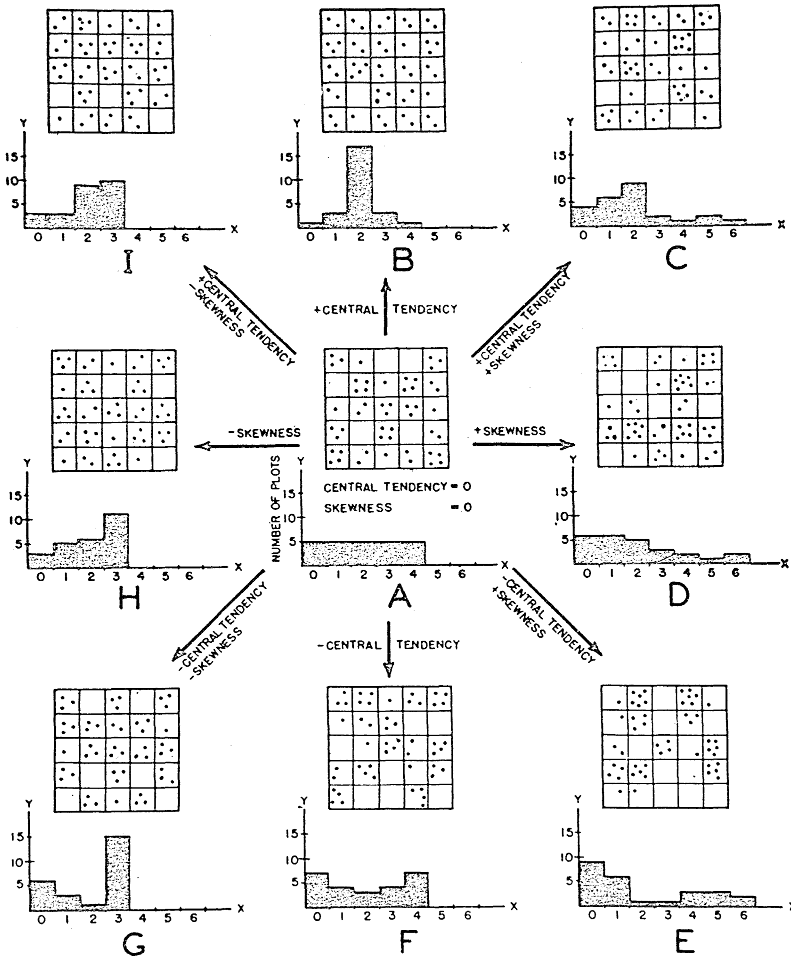

Fig. 1. Nine basic ways in which points in space can be ordered

measured in the field, without mapping or otherwise examining the entire population? This problem can be stated in a different way: How can discontinuities be defined and described? A solution to that problem will assist in many areas other than vegetation analysis; there are others in laboratories both at home and abroad who would appreciate a solution.

The WES data-collection programs have encountered problems which look trivial on the surface, but which become increasingly important as the field efforts, including testing programs, enlarge. One of these problem areas lies in the field of instrumentation. One would assume that after all the years of surveying, sampling, and the like, instruments to meet all possible requirements would be available, but this turns out to be a delusion. Most existing instruments are too heavy, or too delicate, or both, for the purposes for which they are needed by WES personnel. It is amazing how heavy a set of standard instruments can become after being toted a couple of kilometers through flooded rice fields. Three rather special requirements are:

- *a*. An optical range finder, accurate to within 1 percent, with a range from 2 to 100 m. It should be light, small, and sturdy.
- *b*. A very small, very light, but also very sturdy instrument to take the place of a telescopic alidade or a surveying transit. The old artillery aiming circle is a close approximation, but what is needed is an instrument with a telescope of about 3 to 4 power, and a somewhat more precise level. A measure of optical precision would be willingly sacrificed for a sharp reduction in size and weight, because the device would rarely be used at ranges of more than about 100 m. It would also be nice if this gadget were adaptable as an alidade, so that it could be used on a plane table as well as from a tripod.
- *c*. A water-current measuring device, accurate to within about 5 percent with the entire mechanism weighing less than 10 lb. This need not include a weight to keep the sensing device submerged; presumably a disposable weight, such as a rock, could be used.
- *d*. These devices are all intended to reduce the time now required to obtain a valid sample of a set of terrain factors. Probably the greatest single obstacle to the project as a whole is the time, and therefore the expense, of making the required measurements of natural attributes. Any refinement of technique or instrumentation would be of benefit.

The testing programs in which AES has already engaged have revealed a number of problems, and some of these are truly major. And at least one of these is singularly baffling, because it is so difficult to define--so difficult, in fact, that it leads to the suspicion that it is several interrelated problems, rather than a single one. It is concerned with the design of environmental experiments. Up to the present time, tests designed for the study of environmental effects have always omitted consideration of several factors, and this circumstance deserves some elaboration.

- *a*. Nature operates with a large number of factors acting in concert. The relative importance of each of those factors changes from place to place, but it also varies from activity to activity. Soil strength profoundly affects cross-country mobility, but not visibility. On top of this inherent complexity, the tests have revealed that there are problems which can only be called psychological. The trouble is that the very conditions which are being examined are also those conditions in which people must make decisions. Those decisions are often based on a logic peculiar to an individual and these are hardly susceptible of analysis. It may be argued that the answer is to test with a large sample population, thus achieving statistical distributions of human variance. But the amount of testing which would be required to accomplish this is so great as to be utterly impractical.

b. It should be noted that this problem cannot be eliminated by, for example, using the same person throughout the test, as a part of the test instrument. Drivers learn as they go along; they also experiment. And every time they either learn or experiment, it blurs the relation between their machine and the terrain.

c. There is still another attribute of this general problem that deserves attention. The problem is to determine the cause-effect relation as it would be exhibited in a "real" operation, since the purpose of learning about nature is after all to enable one to predict occurrences, and thus avoid or ameliorate them. Therefore, the tests must be so designed that the results will reflect an approximation of the response to a "real" situation. The trouble is that the "real" situation permits practically unlimited freedom of choice, while the test situation must be kept within relatively strict limits; if it is not, control is lost and the test reveals little or nothing. The design of a test that achieves a reasonable balance between the "real" and the artificial has proven to be very difficult. It is apparent that a good deal more needs to be known about the design of experiments involving man and nature. Perhaps some special adaptations of games theory might contribute to understanding in this area.

Plans

With this brief exposition of some of the problems of the MEGA project, let us now consider plans for the future.

First, an intensive study of the hydrologic geometry problem is proposed with special emphasis on the water-land interface. To this end, two research contracts have been proposed. One of these will be restricted to streams and lakes; it will include an intensive data-gathering phase in the United States and in selected areas overseas, followed by an attempt to devise an analytical descriptive method of some kind. The first attempt will be based on a scheme previously proposed (Grabau; "Hydrologic

Geometry for Military Purposes," pp 33-39). If this fails, alternatives will be sought.

The second contract will deal with shorelines of the sea, estuaries, and large lakes, and will be concerned with the nature of the zone bounded by water more than about 2 m deep on one hand, and a line just above the limit of maximum storm waves on the other. This will be, at least initially, almost entirely a data-collection effort, but it will be followed up by an attempt to devise analytical descriptive and classification systems. After about one year of basic research effort, some tests will be designed to define the nature and magnitude of the effects of water bodies, and of the water-land interface, on some selected military activities. Assistance is earnestly solicited.

The operations of the field team in Puerto Rico will be continued for another year at least. Puerto Rico is a convenient tropical location, with an enormous diversity of environmental conditions in a relatively small area. It is also free from political entanglements, a matter of some concern. All of these factors make it an extremely useful laboratory for testing field sampling and analysis procedures. The information derived from the island also materially contributes to our general data collection in tropical environments.

Efforts in Central America will probably be concentrated in Costa Rica, chiefly because of environmental complexity and political stability. The Costa Ricans have indicated a willingness to assist with these studies; therefore, it is proposed to study the environmental gradients across the isthmus with a short-term but intensive field effort, somewhat analogous to the Thailand adventure (Rula; "Mobility-Environmental Research Studies, Southeast Asia," pp 213-228). Apropos of this, cooperation, in a somewhat similar way, is also anticipated in an "Advanced Research Projects Agency" (ARPA) project in southeast Asia.

Oddly enough, knowledge of the temperate zones is inadequate to the purposes of the MEGA project, chiefly because of the lack of quantitative data. It is therefore proposed that a data-collection program in northern Florida, Georgia, Kentucky, Indiana, and Wisconsin shall be undertaken, to provide some quantitative terrain data on temperate environments. This zone is, after all, the locale of most past wars, and it seems reasonable to suppose that its popularity will not diminish in the future. These collection programs will be coupled with efforts to refine field sampling methods and classification systems.

It is proposed that a series of tests be conducted, within a year if possible, in the Ranger training areas in Georgia and Florida. Environmental data have been collected on those areas for a year, and have been previously reported (McLaughlin and Norris; "Environmental Descriptions of Ranger Training Areas," pp 196-212). The Ranger Department has expressed willingness to cooperate in such tests; the only deterrent is the lack of knowledge concerning how to go about measuring the effects of environment on a small group of men moving across country in the dead of night--which is the specialty of the Rangers. What, pray, constitutes a measure of performance?

A series of tests to determine visibility characteristics within vegetation structures also is planned for the coming year. Tests are tentatively planned in Florida, Georgia, Kentucky, Mississippi, Wisconsin, Puerto Rico, and possibly Southeast Asia. In the course of this program it is hoped that an adequate test procedure will be developed for measuring visibility in various assemblages. However, problems are anticipated. Visibility is partly psychological in nature, and there is therefore a morass of conflicts concerning the shape, size, and color of the object to be observed, the sequence of events leading up to recognition of an object, and so on. As a result, it is proposed that some cautious exploration in the design of the experiments be indulged in before a full-scale testing program is launched.

Summary

In summary, then, the following major problems remain for the MEGA project.

a. Can the macrogeometry analysis be made simpler and faster? If so, how? If not, should possible alternate systems be examined?

b. What form should the hydrologic geometry description take? Is the very tentative approach which has been suggested practical? If not, what alternative seems most appropriate?

c. Is the water-land interface a separate factor family? If so, what definable and measurable factors comprise the factor assemblage?

d. How can nonrandom distributions be analytically described?

e. How can population discontinuities be defined and described? How, in fact, can they be recognized in the field without mapping the entire population?

f. What constitutes a valid environmental test, and how does one go about designing one? This question may be not really answerable, because a different solution may be needed for each activity. Nevertheless, it would be helpful if the requirements of a valid test could be clearly formulated. Considering MEGA's commitments elsewhere, it is wondered if it would not be wise to give this problem to a university or other research organization for study, prior to undertaking a major testing program. The only deterrent is the intuition that this problem can only be solved by trial and error; that it is a "learn by doing" proposition.

Instrumentation problems are really only problems of specification and design. They can be solved by committing the appropriate amount of money to a competent agency. The question then becomes: Is the design and construction of those special instruments which are needed to speed up the data-collection program a proper disposition of effort for the MEGA project? Or should the project be satisfied with existing equipment, and the funds used for additional research studies?

The plans for the future can be summarized as follows:

a. Intensive study of the problem of describing and classifying hydrologic geometry.

b. Intensive study of the water-land interface, to develop quantitative descriptive and classification techniques, and to provide a data base on the nature of the water-land interface.

c. Continuation of the field team in Puerto Rico, to provide an on-site laboratory in the tropics for testing procedures and techniques, as well as to provide data for studies of tropical environments.

d. Intensive short-term study of environmental gradients in Costa Rica, chiefly to expand the data base on tropical environments.

e. Expansion of a basic data-gathering effort in temperate environments by studies in Florida, Georgia, Kentucky, Indiana, and Wisconsin.

f. Performance of a limited series of tests, chiefly in temperate climates, to determine the quantitative relations between environmental factors and the type and magnitude of effects they impose on selected military activities. The activities will include small unit operations, visibility, and cross-country mobility. Others may be included if the opportunity presents itself. For example, some experimentation with the effective range of small arms in vegetation assemblages would appear to be appropriate. This is a matter of very real concern, especially in the tropics. The MEGA project would welcome the opportunity to cooperate with Ordnance on this matter.

g. Concurrent effort to refine descriptive and classification systems, field sampling methods, and test control techniques.

Conclusion

In conclusion, there remain some very general questions concerning what might be called the philosophy of conduct of the entire project.

a. First, is the "factor family concept" a valid approach to the problem of determining and predicting the effects of the environment on military activities, men, and materiel? If it is not, can a more suitable approach be presently formulated?

b. Second, do the proposals to conduct special tests to establish cause-and-effect relations constitute a proper approach to the project objectives? The alternative appears to be to accept the limitations inherent in such data sources as after-action reports, maneuver reports, materiel acceptance tests, and the like.

c. Should special or concerted effort be devoted at this stage to the devising of portrayal systems for quantitative environmental data *per se*, and for cause-and-effect data? Or, as an alternative, should such an effort be deferred until the types and magnitudes of such cause-and-effect relations are better known?