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TERRAIN ANALYSIS FOR THE ARMORED
RECONNAISSANCE SCOUT VEHICLE TEST
PROGRAM

D. D. Randolph, et al

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

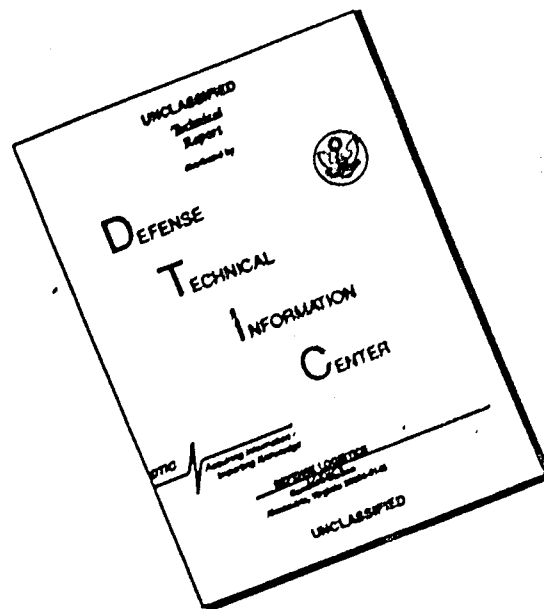
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SCOUT VEHICLE TEST PROGRAM

by

D. D. Randolph, C. A. Blackmon



March 1974

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and

U. S. Army Tank-Automotive Command
Warren, Michigan

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FOREWORD

The study reported herein was conducted during the period December 1972-October 1973 by the U. S. Army Engineer Waterways Experiment Station (WES) and the U. S. Army Tank-Automotive Command (TACOM) for the Armored Reconnaissance Scout Vehicle (ARSV), XM800 Project Manager.

This study was conducted under the general supervision of Messrs. W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory (MESL), A. A. Rula, Chief, Mobility Systems Division (MSD), MESL, and C. J. Nuttall, Jr., Chief, Mobility Research and Methodology Branch (MRMB), MSD. The field data at Fort Knox were collected under the supervision of Mr. D. D. Randolph by Messrs. J. H. Robinson, R. P. Smith, and R. H. Johnson, MSD, who also prepared the areal and linear terrain factor complex maps of Fort Knox. The late Mr. C. A. Blackmon, MSD, prepared the revised areal terrain factor complex maps of the West Germany transect and assisted Mr. Randolph with the comparison of the selected Fort Knox and West German areal terrains. Mr. L. A. Martin, Mobility Systems Division, TACOM, and Mr. D. A. Sloss, Stevens Institute of Technology, Hoboken, N. J., assisted with the comparison of selected linear terrains at Fort Knox and West Germany. Acknowledgment is also made to Mr. A. W. Criswell, U. S. Army Materiel Systems Analysis Agency (AMSAA), for his review of this report and spirited criticism. This report was prepared by Messrs. Randolph and Blackmon.

BG Ernest D. Peixotto, CE, and COL G. H. Hilt, CE, were Directors of WES during the conduct of this study and the preparation of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	25.4	millimeters
feet	30.48	centimeters
square inches	6.4516	square centimeter
pounds	0.45359237	kilograms
tons (2000 lb)	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic inch	276.80	kilograms per cubic centimeter
foot-pounds	0.138255	meter-kilograms
feet per second	30.48	centimeters per second
miles per hour	1.609344	kilometers per hour

SUMMARY

Two study areas (FK1 and FK2), totaling approximately 11 sq miles, were selected at Fort Knox, Kentucky, for comparison with a previously mapped 60-sq-mi sample of terrain in West Germany (WGT) and as potential areas for field tests with the prototype Armored Reconnaissance Scout Vehicles (ARSV's) and comparison vehicles. Areal and linear terrain data from 119 sites, aerial photographs, and other pertinent information were used to prepare the Fort Knox terrain factor complex maps. These areal maps describe the terrain characteristics that affect vehicle performance, i.e. soil type, soil strength, topographic slope, obstacles, vegetation, surface roughness, and visibility. The linear terrain factor complex maps describe the terrain characteristics that determine "go or no-go" vehicle performance, i.e. linear feature geometry, water depth, and water velocity.

The Fort Knox study areas and the West German transect were compared on the basis of general descriptions (land physical characteristics, land use, etc.), areal and linear occupancy and occurrence of terrain units and terrain mobility factors, and parameters (i.e. vehicle speed and performance diagnostics) reflecting the combined effects of the terrain upon the mobility performance of the M114A1E1 armored command and reconnaissance carrier and the M151A2, 1/4-ton truck, as predicted by the AMC-71 mobility model.

The major differences in the areas arise from the land use. Over 70 percent of WGT is used for agricultural purposes, largely croplands, but including orchards, vineyards, and some cultivated forests. A large part of FK1 is used as a buffer zone around an impact area and is therefore idle; most of FK2 is used as a military training area. These differences in land use are reflected in a difference in obstacles, vegetation, surface irregularities, and linear feature characteristics. Terrain units and terrain factor classes can be found in FK1 or FK2 that are similar to many of those in WGT although the areal extent may be different.

The mobility performances of the two selected vehicles predicted by the AMC-71 mobility model show that the Fort Knox study areas are somewhat similar to the West German transect in regard to the overall effect on mobility, with the performance of the M114A1E1 being more similar than that of the M151A2.

The performance diagnostics showed that although the predicted speeds were similar, the controlling factors were often different.

It was concluded that sufficient terrain variations existed in FK1 and FK2 to provide the range of conditions needed for mobility evaluation tests of the ARSV's and that the terrain conditions in Fort Knox and WGT are such that tests in FK1 and FK2 can be used to establish the level of confidence in the AMC-71 mobility model predictions in WGT and subsequent mobility evaluations of the ARSV's.

It is recommended that mobility tests be conducted with the ARSV's and comparable vehicles along selected traverses in FK1 and FK2, that results of these tests be used to validate predictions for these areas made by the AMC-71 mobility model, that mobility evaluations of the ARSV's and comparable vehicles be made in the West German transect with the AMC-71 mobility model, and that final judgments of the relative mobility potential be based upon the results of simulations in light of the validation.

Appendix A presents the procedures used in preparing areal and linear terrain factor complex maps for selected Fort Knox terrains (FK1 and FK2). It includes definitions of terrain terms applicable to mobility and procedures for field data collection. It also includes a discussion of the revised method used to assign surface roughness to the areal terrain units of the West German transect.

Comparisons of the terrains in the three study areas (FK1, FK2, and WGT) made on the basis of the general descriptions, the areal occupancy and occurrence of terrain units and terrain factors, and the basis of the performance of two vehicles (one each wheeled and tracked) as predicted by the AMC-71 mobility model are presented in detail in Appendix B.

TERRAIN ANALYSIS FOR THE ARMORED RECONNAISSANCE
SCOUT VEHICLE TEST PROGRAM

PART I: INTRODUCTION

Background

1. The Armored Reconnaissance Scout Vehicle (ARSV) Project Manager assigned the U. S. Army Tank-Automotive Command (TACOM) Systems Analysis Division the responsibility for the conduct of a cost and performance study of the ARSV. TACOM then tasked the U. S. Army Materiel Systems Analysis Agency (AMSAA) with the responsibility for the performance areas (except reliability and maintenance) of the total cost and performance study.

2. In August 1973, the U. S. Army Engineer Waterways Experiment Station (WES) Mobility Systems Division (MSD) and the Mobility Systems Division, TACOM, were asked to prepare a joint cost, time, and manpower estimate for terrain mapping and analysis, validation testing, and mobility evaluation in support of AMSAA's efforts in the cost and performance study of the ARSV. The task and associated subtasks suggested by AMSAA are given in table 1. Subsequent to the initial request, Task D, "Mobility Effectiveness Evaluation," was added to the ARSV program.

3. A proposal outlining a WES-TACOM work plan was submitted to AMSAA in September 1972. During October 1972, AMSAA representatives visited WES to discuss the proposal with WES-TACOM personnel before preparing a work statement. In November 1972 AMSAA prepared a work statement that included a general work plan covering tasks associated with performance aspects of the study.

4. WES was assigned the primary responsibility for Task A, "Terrain Analysis for the Armored Reconnaissance Scout Vehicle Test Program," in cooperation with TACOM, the U. S. Army Test and Evaluation Command (TECOM), and the U. S. Army Armor and Engineer Board, Fort Knox. The original plan stated that all terrain mapping would be accomplished at selected areas at

Fort Knox, Kentucky, and in West Germany. During a meeting at Fort Knox on 16 and 17 January 1973, Aberdeen Proving Ground (APG) was included as a potential military reservation for terrain mapping. Fort Knox and APG were selected because the ARSV's were scheduled for testing at these installations. West Germany was selected because of its military relevance and because terrain maps containing much of the data to be used in this study were already available for a sample strip (or transect) in West German terrain. The original plan also called for sending a team to West Germany to collect additional ground truth data to complete the available maps of the West German transect. Independent requests by WES and TACOM to visit West Germany were denied; therefore, the original plan was modified to use existing data only. This report describes the work accomplished under Task A only.

Purpose and Approach

Purpose

5. The main purpose of this study was to prepare terrain data, in the form of terrain factor complex unit maps, for selected areas of Fort Knox and/or Aberdeen Proving Ground to be used in the mobility evaluation and testing of the prototype armored reconnaissance scout vehicles (ARSV's) and comparison vehicles in support of the ARSV Cost and Performance (C/P) Study. The terrain maps developed will be used with the AMC-71 mobility model* to predict vehicle mobility performance in terms of speeds and factors controlling speed in both this phase and later phases of the C/P Study. The validity of these predictions will also be examined in these later phases of the C/P Study by actually testing the ARSV prototypes in these mapped terrain areas during developmental testing.

6. The secondary purpose of this study was to make a quantitative comparison of the Fort Knox terrain with the West German terrain. The

* U. S. Army Tank-Automotive Command and U. S. Army Engineer Waterways Experiment Station, "The AMC '71 Mobility Model," Technical Report No. 11789 (LL 143), July 1973, U. S. Army Tank-Automotive Command, Warren, Mich.

results of this comparison will be used to judge the applicability of vehicle test results obtained at Fort Knox to the West German transect. It will also indicate the degree to which validation of the AMC mobility model in the Fort Knox terrains will encompass the ranges of terrain characteristics in the West German transect and thus serve as validation of the model's predictions in that environment as well.

Approach

7. The terrain factor maps* for both areal and linear terrain features were developed by field sampling of the selected Fort Knox areas, review of existing terrain data in the form of maps, geologic survey data, and air photos, and application of the techniques currently developed for the generation of factor maps for use with the AMC-71 mobility model. The areal and linear terrain factor maps for the West German transect were prepared in a similar manner except that field sampling data were not available.

8. The terrain comparison methodology included examination of the following parameters or combinations of parameters as a basis for comparing terrains.

General description	{ Land physical characteristics Land use
Terrain units terrain factors Vehicle speed Terrain factors controlling vehicle speed	{ As defined in the AMC-71 mobility model

9. Where possible, examination of these parameters considered the areal occupancy and frequency of occurrence as a basis for comparison. In the case of terrain factors, the predominant range of terrain characteristics for each area was examined for its effect on vehicle speed.

* See Appendix A for a detailed explanation of the mapping techniques used to develop factor maps.

PART II: STUDY AREAS

U. S. Terrains

Selection

10. WES personnel reconnoitered both Fort Knox, Kentucky, and APG, Maryland, to select areas for terrain mapping and subsequent vehicle testing. The selection was limited to areas that could be mapped by use of the WES terrain descriptive system (Appendix A) within the time frame and funding constraints of the study. Another important constraint was the selection of a minimal number of areas that would provide a sufficient number of terrain units to produce differences in vehicle speeds ranging from about 2 to 20 mph. Additional considerations were availability, accessibility, and representation of natural terrain features. Finally, some consideration was given to the presence of suitable terrain conditions for validation of the AMC-71 mobility model.

11. On the basis of the foregoing criteria, two areas were selected at Fort Knox and approved by AMSAA. These areas, designated as Fort Knox area 1 (FK1) and Fort Knox area 2 (FK2), were mapped in March 1973, and assurance was given that they would be made available for vehicle testing in the spring of 1974. Because available areas at APG did not meet the selection criteria, no areas were selected at APG for mapping.

Location

12. FK1 is located in the northeastern part of the Fort Knox Military Reservation (fig. 1). It is irregular in shape--about 4 miles long and 1.3 to 2.0 miles wide, with a total area of 6.1 sq miles. An areal mosaic showing most of FK1 is given in fig. 2.

13. FK2 is located in the south central portion of the Fort Knox Military Reservation. It is nearly rectangular in shape, having a maximum length of 3.5 miles, a maximum width of 1.9 miles, and a total area of 4.7 sq miles. A mosaic showing all of FK2 is given in fig. 3.

Description

14. A general description of the Fort Knox study areas is given in the following paragraphs.

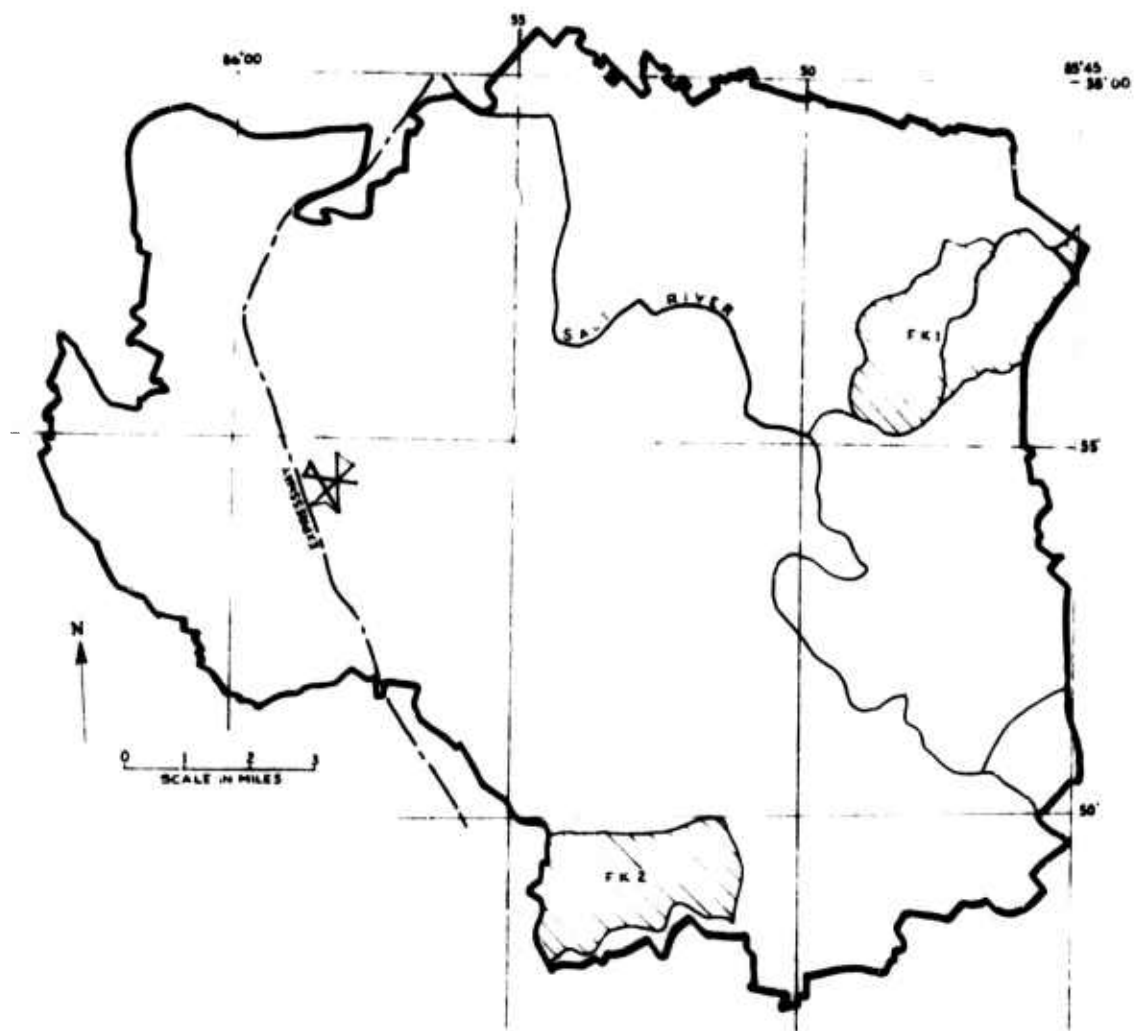


Fig. 1. Location of Fort Knox, Kentucky, study area



Fig. 2. Mosaic of Fort Knox terrain - FK1

Scale 1:25,000

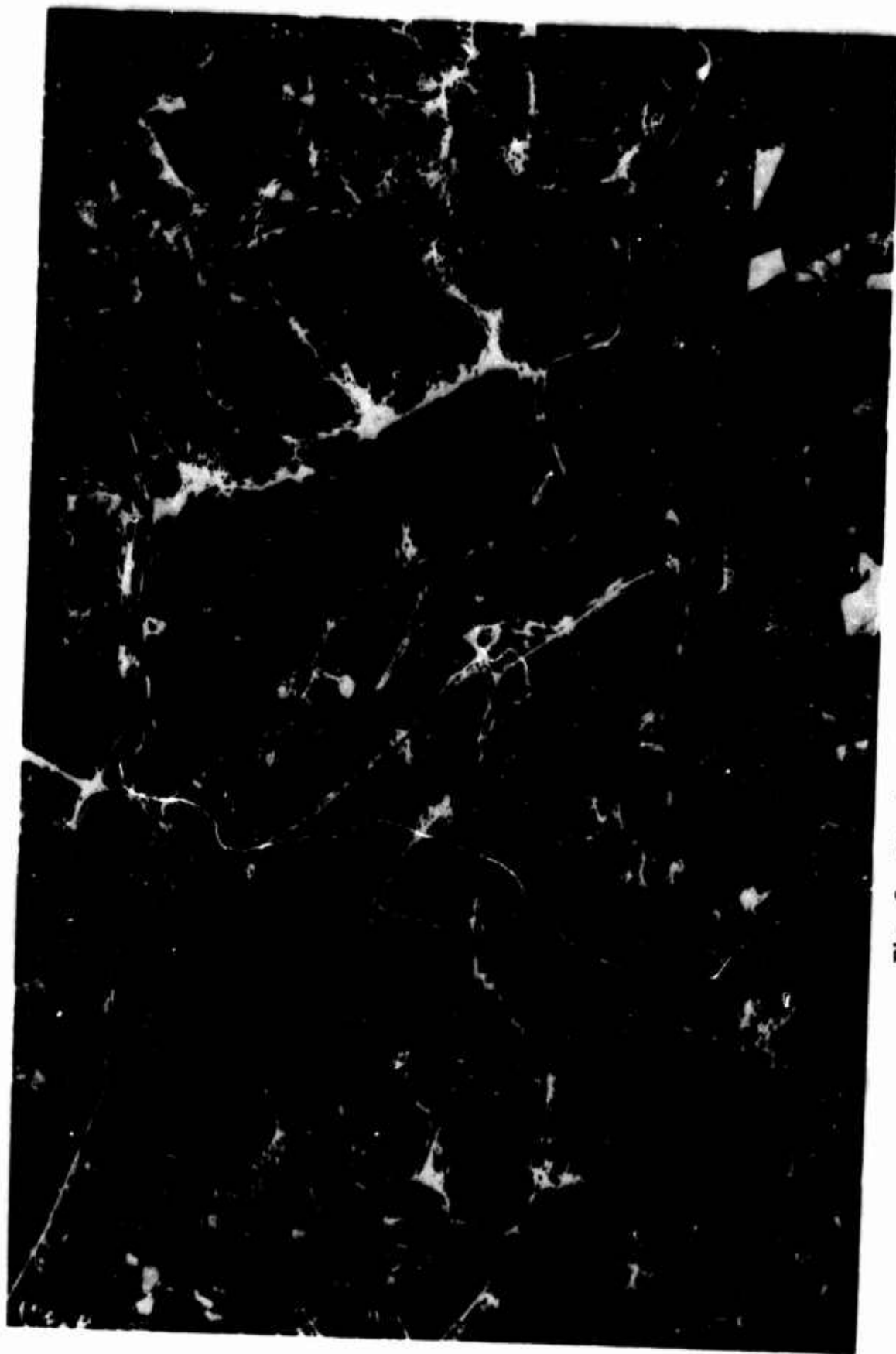


Fig. 3. Mosaic of Fort Knox terrain - FK2

Scale 1:25,000

15. Physiography. FK1 is located in the Salt River floodplain, which varies in width from 1 to 3 miles. Most of FK1 is very flat (typical of floodplains) except where boundaries extend slightly into the knobs, thereby incorporating some steeply sloping terrain. The elevations in FK1 (including knobs) vary from about 400 ft MSL along the Salt River to about 600 ft along the southeastern boundary.

16. FK2 is located in the Pennyroyal Plateau, which is a rolling upland developed on thick limestone bedrock. The plateau ranges from 6 to 20 miles in width across much of northern Kentucky and southern Indiana. The elevations in FK2 vary from about 600 ft MSL along Mill Creek to about 800 ft at the highest point.

17. Drainage. The Salt River is the major drainage system in FK1. Its location within the study area, together with other drainage features, is shown in fig. 1. Numerous small streams and ditches empty into the Salt River, providing adequate drainage except when the river is in flood stage. The Salt River varies from approximately 50 ft in width and 20 to 30 ft in depth during low-water stage to more than 300 ft in width and 40 ft in depth during the flood stage. The groundwater table for a large portion of FK1 is at or near the surface during periods of high river stages.

18. Mill Creek, Douglas Branch, and Dorrets Run provide excellent drainage in FK2 all year. The gradients of these streams are such that high water velocity may occur during high-intensity rains.

19. Soils. Most of the soils in FK1 are water deposited and vary from poorly drained silty clays located on flats of the Salt River bottom to variably drained silty clays on gently to steeply sloping knobs adjacent to the bottomland.

20. The soils in FK2 are residual and vary from clayey to silty clay soils that are moderately cherty. Most of these soils are well drained, occurring on uplands with narrow undulating ridge crests on moderately to steeply sloping hillsides. When wet these soils are very slippery.

21. Land use. The section of FK1 west of the Salt River is used primarily as a live firing range and impact zone. That part of FK1 east

of the Salt River is seldom used by the military except as a buffer zone between the impact area and private property. Most of the land in FK1 is covered with deciduous or evergreen trees; however, some open land exists on both sides of the Salt River. Some of the land on the east side of the river has been cultivated within the last several years.

22. FK2 is used extensively by the military for training purposes. Parts of the area are subjected to frequent use by tracked vehicles. Numerous ditches occur in the area as a result of the tank ruts and subsequent erosion. A large part of FK2 is covered by deciduous or evergreen trees.

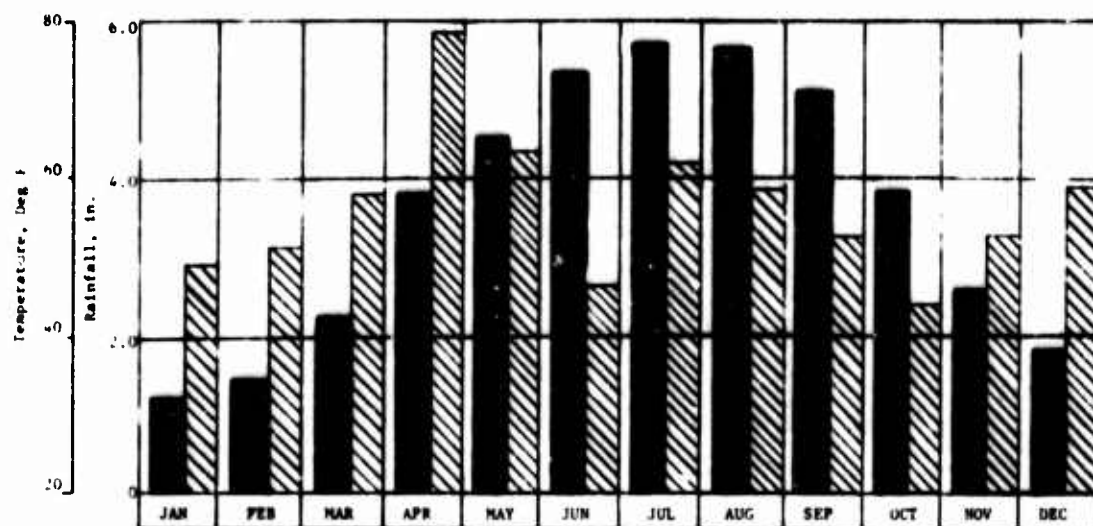
23. Weather and climate. The long-term (5-yr average) monthly rainfall and mean temperature data for Fort Knox (both FK1 and FK2) are given in fig. 4a. More than 2 in. of rain falls in each month of the year; the lowest rainfall occurs in October and the highest in April. The yearly mean average is 44 in. The mean monthly temperature is typical of a temperate climate, with an increase from January to July and then a decrease to December. The long-term mean monthly snowfall is as follows:

November	- 1.2 in.
December	- 2.1 in.
January	- 4.2 in.
February	- 3.1 in.
March	- 3.9 in.

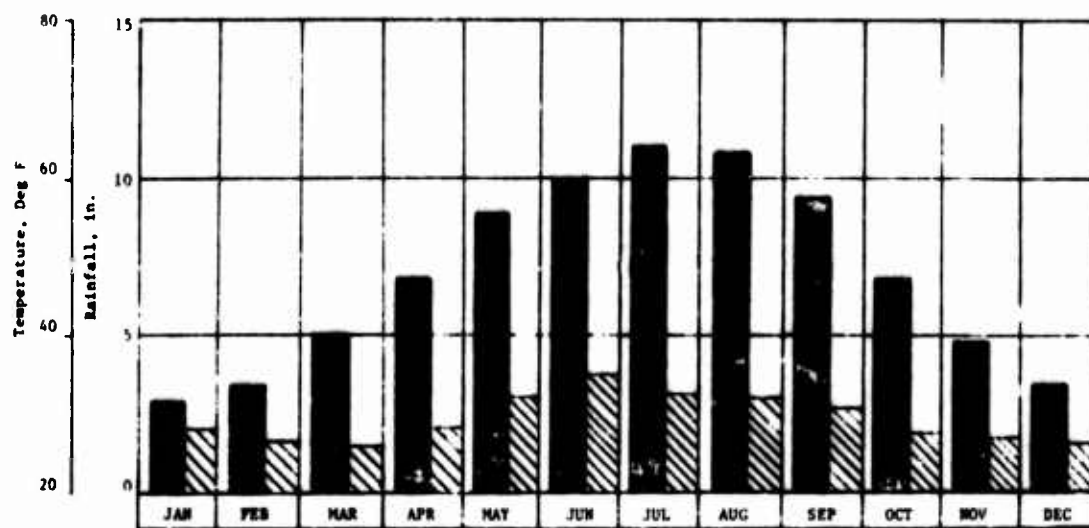
The snow cover rarely remains on the ground more than a few days.

24. Road network. The principal road in FK1 is a secondary-type road that runs northeast and southwest on the west side of the Salt River. A similar road is found just outside the area along its eastern boundary. Trails lead from the secondary road to the river or to old farmlands. A four-wheel-drive vehicle is required to negotiate the trails in the wet season. The perimeter of FK2 is a paved road. The area within FK2 is crossed in a northwest-southeast direction by several trails that have been made during Army field training exercises. Many of the old trails are now ditches that cannot be negotiated.

25. Towns and villages. There are no towns or villages in either FK1 or FK2. However, FK2 is located much closer to the cantonment area of Fort Knox than is FK1.



a. Fort Knox, Kentucky.



b. Stuttgart, West Germany

Legend:
 ■ Long-Term Average Monthly Temperature
 ▨ Long-Term Average Monthly Rainfall

Fig. 4. Monthly rainfall and temperature data

West German Terrain

Selection

26. For mobility and comparative terrain study purposes the West German transect (WGT) data were the best available. However, the procedures to assign surface roughness required revision to make the WGT terrain descriptions comparable to the Fort Knox study areas.

Location

27. WGT is located in the southwestern part of West Germany (fig. 5). It is bounded by the following map coordinates: latitude 49°02' to 49°04' north, and longitude 8°39' to 9°22' east. The transect is 3 km wide and 52 km long, with an area of 156 km² (approximately 60 sq miles). Several aerial photographs of the area within the transect, located as shown in fig. 6, are given in figs. 7, 8, and 9.

Description

28. A general description of WGT is given in the following paragraphs.

29. Physiography. WGT is located in the Bavarian Plateau, which is a roughly triangular region covering most of southern Germany. The average elevation at the east end of the transect is about 1250 ft MSL, and at the west end about 600 ft, giving a relief of about 650 ft. The transect is crossed from south to north by the Neckar River, a tributary of the Rhine River. East of the river, the area consists mostly of hills capped with sandstone underlain by shale. Some sections of the hilly area are rugged, but for the most part the terrain is rolling. West of the river, the area is tableland which consists mostly of undulating to gently undulating terrain underlain primarily by limestone.

30. Drainageways. The Neckar is the main river in the area. Several smaller rivers and streams originate in or cross the transect at various angles. Flat, narrow terraces are frequently found along the banks of the rivers and streams. Some stream channels have been modified, and the banks may have man-made structures to protect against erosion. Many slopes along drainageways are steep and consist of rock outcrops.

31. Soils. The soils are mainly residual with clays and silts developed from the shales and limestones. Isolated patches of alluvial

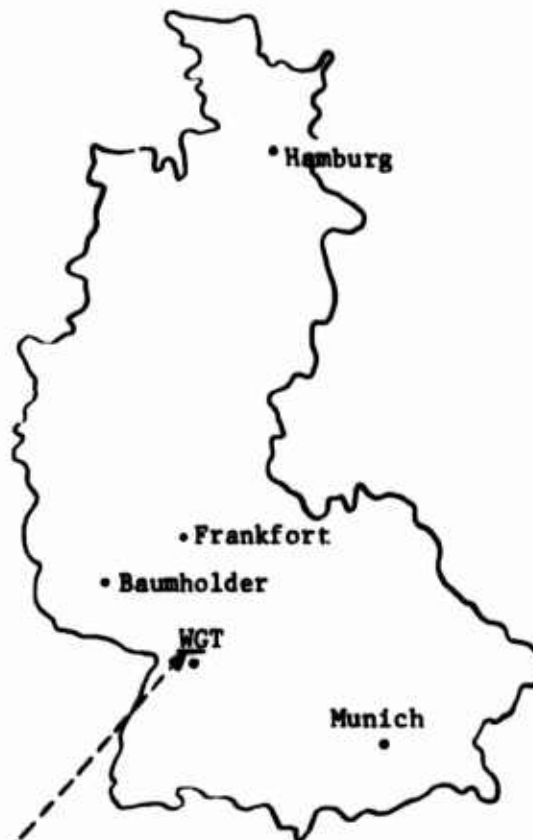


Fig. 5. Geographic location of West German transect (WGT)



Fig. 6. Location of air photos along WGT



Scale 1:24,000

Fig. 7. Air photo of West Germany transect - west section



Fig. 8. Air photo of West Germany transect - middle section

Scale 1:24,000



Fig. 9. Air photo of West Germany transect - east section

Scale 1:24,000

sands and gravels are found along former stream courses. Deposits of loess are commonly found adjacent to the Neckar River.

32. Land use. About 70 percent of the area in the transect is used for agriculture, with grain the principal crop. The higher, hilly lands and some of the bottomlands are forested; but in some hilly areas, vineyards are fairly common on the hillsides and are associated with man-made terraces.

33. Weather and climate. Long-term monthly rainfall and mean temperature data for Stuttgart, which is in the vicinity of the study area, are shown in fig. 4b. It can be seen that the rainfall is fairly evenly distributed throughout the year, ranging from 2 to 4 in. per month, with the heavier amounts occurring during the summer season. The rainfall amounts and distribution would indicate that excessive soil wetting would not occur except in the low-lying areas; thus, fairly high soil strength would exist most of the time in areas with reasonable surface drainage. The mean monthly temperature pattern is typical of temperate climates, with an increase in mean temperature from January to July or August and then a decrease to December.

34. The long-range maximum snow depth by month in the area of the transect is as follows:

October - 0.8 in.	February - 8.7 in.
November - 1.6 in.	March - 5.5 in.
December - 4.7 in.	April - 1.6 in.
January - 5.1 in.	

The snow cover rarely remains on the ground more than two or three days except during December, January, and February, when it may remain for periods of one to three weeks. During this time the average snow depth is generally less than 4 in.

35. Road network. A fairly well-developed network of primary, secondary, and trail-type roads exists in the area. Many trail-type roads occur throughout the countryside.

36. Towns and villages. Several towns and villages are located inside the transect, the principal ones being Kirchheim am Neckar, Gemmrigheim, Bonningheim, and Bretten.

PART III: RESULTS

Terrain Maps

37. Field inspection of FK1 and FK2 revealed a wide range of terrain conditions. Terrain data were collected at 119 sites and, together with other available data such as topographic maps, aerial photographs, etc., were used to prepare areal and linear terrain factor complex maps. A detailed explanation of the procedures used in collecting field data and preparing terrain unit maps is given in Appendix A. With the aid of the terrain factor complex maps, traverses can be selected in the Fort Knox study areas which will contain sufficient terrain variations for conducting valid mobility evaluation tests with the ARSV's. These vehicle tests can be used to establish confidence (difference between predicted and measured vehicle performance) in the AMC-71 mobility model predictions.

Comparison of Fort Knox and West German Terrains

38. The Fort Knox and West German terrains considered in this study were compared on the bases of general description, areal occupancy, and occurrence of terrain units, terrain factors, vehicle performance, and factors controlling speed. These comparisons are presented in detail in Appendix B.

General descriptions

39. The area mapped as WGT is nearly six times as large as the combined areas of FK1 and FK2. WGT and FK2 are located on plateaus; FK1 is located in a floodplain. Both FK1 and WGT are crossed by a large river and contain some small streams; FK2 has no large river but has numerous small streams. Drainage is excellent in WGT and FK2 throughout the year, while during most of the year drainage is poor in FK1.

40. Soils in FK1 are largely alluvial silty clays, in FK2 are usually residual silty clays, and in WGT are mostly residual silts and clays although some alluvial soils are found along the rivers and streams.

41. Climate is generally similar in the three areas, although the

temperature and rainfall are slightly higher in FK1 and FK2 than in WGT.

42. The most important difference in the areas is in land use. Approximately 70 percent of the land in WGT is used for agricultural purposes, with grain as the principal crop. FK1 and FK2 are portions of a military reservation primarily used for training purposes; more than 80 percent of FK1 and 50 percent of FK2 is covered by deciduous or evergreen woodlands. WGT contains many towns and villages and a dense road network, whereas FK1 and FK2 contain no towns or villages and only a few improved roads.

43. From this general comparison the terrain in WGT as a whole would appear significantly different from that in FK1 and FK2. However, a consideration of specific areas in terms of landform, soils, climate, and land use can reveal highly analogous areas.

Areal occupancy

44. The areal and linear terrain units and the factors used to describe them indicated little similarity between the Fort Knox and West German terrains when considered on the basis of areal occupancy.

Terrain units

45. No single terrain unit in WGT is exactly duplicated in FK1 or FK2. However, terrain units very similar to those in the forested areas of WGT can be located in FK1 or FK2, although their relative size and frequency of occurrence will differ.

46. The terrain units in the croplands, which comprise more than half of WGT, do not occur in FK1 or FK2. However, there is some land in FK1 and FK2 that is very similar to the croplands of WGT except for the presence of crop rows, and these could be added by the simple process of plowing a few furrows.

47. The chief difference in the linear terrain units in WGT and those in FK1 and FK2 is the extensive road network in WGT. While this road network is not duplicated in FK1 or FK2 as presently mapped, the extension of the linear terrain factor complex map to include the perimeter road around FK2 would provide many terrain units similar to those in WGT. Many similarities can be found in the terrain units comprising the drainage features in Fort Knox and WGT.

Terrain factors

48. Areal terrain factors. Although the areal occupancy and frequency of occurrence of individual terrain factor values do differ, generally the factor values which occur in WGT can be found in FK1 or FK2.

For example:

- a. Soil strength. All of the soil strength classes occurring in WGT can be found in FK1 or FK2.
- b. Slopes. Slopes which occur in WGT and not in FK1 or FK2 represent only 0.2 percent of WGT.
- c. Surface roughness. All of the surface roughness classes which occur in WGT can be found in FK1 or FK2.
- d. Visibility. All of the visibility classes occurring in WGT can be found in FK1 or FK2.
- e. Obstacles. The major obstacles in WGT which are not found in FK1 or FK2 are the crop rows, which can be easily duplicated.
- f. Vegetation. All of the stem diameter classes found in WGT occur in some terrain units of FK1 or FK2. The spacing classes that are not duplicated represent areas of widely spaced trees that have little or no effect on vehicle performance. In any event, these spacing classes could conceivably be duplicated at Fort Knox by removing a few trees.

49. Linear terrain factors. All of the linear terrain factor values occurring in WGT can be found in FK1 or FK2 except low bank heights and approach angles. However, the overall range of low bank heights in WGT is duplicated in FK1 or FK2, and the missing classes represent only 2.0 percent of the WGT linear features. Most of the approach angles that do not occur in FK1 or FK2 as presently mapped would be found if the road around FK2 were included. The few steeper approach angles in WGT do not exist in FK1 or FK2.

Vehicle performance

50. The range of speeds for both vehicles that was predicted for WGT was also predicted for FK1 or FK2, although the relative areas for which these speeds were predicted did in some cases differ significantly.

Factors controlling speed

51. The predicted speeds for the M114A1E1 in FK1 and WGT were very similar. However, distribution of the controlling factors was different.

Primarily the obstacles (croplands) in the croplands limited speed of the M114A1E1 in WGT and vegetation-soil-slope combination limited speed in FK1. There was less similarity between predicted speeds for the M151A2 in WGT and in the Fort Knox study areas because of the even greater influence of the croplands in WGT on the speed of the M151A2.

52. The only immobilizing factor which occurred in WGT and not in FK1 or FK2 was the surface soil strength factor, which represents only 0.2 percent of WGT for the M151A2 and 0.1 percent of WGT for the M114A1E1.

53. All of the factors limiting speed that occurred in WGT also occurred in both FK1 and FK2.

Assessment

54. Terrain units can be selected in FK1 and FK2 that will yield vehicle performance similar to that in terrain units in WGT and for the same reasons. With some slight modifications of a few terrain units in FK1 and the extension of FK2 to include the perimeter road, most of the variations in WGT can be located in FK1 or FK2. However, it is cautioned that the differences in areal distributions would prevent a direct comparison of traverse speeds in FK1 or FK2 with traverse speeds in WGT. Nevertheless, the range of terrain conditions in FK1 and FK2 is sufficiently wide that the results of tests with the ARSV's and comparable vehicles over carefully selected traverses in FK1 and FK2 may be used to establish confidence in the AMC-71 mobility model predictions. The AMC-71 mobility model may then be used to extend the evaluation of the performance of the ARSV's over traverses in WGT.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

55. Based on the analysis presented herein, and principally upon the mobility predictions and diagnostics from AMC-71, and considering terrain impact on the evaluation of the ARSV's, it is concluded that:

- a. Traverses can be selected in the Fort Knox study areas that will contain sufficient terrain variations for conducting valid mobility evaluation tests with the ARSV's.
- b. The terrain conditions that can be found at Fort Knox are sufficiently comparable to those in WGT that confidence in the AMC-71 mobility model (difference between predicted and measured vehicle performance) established with the ARSV's and comparable vehicles in the Fort Knox terrain would be expected to also apply to a mobility evaluation of these vehicles in WGT using the AMC-71 mobility model.

Recommendations

56. It is recommended that:

- a. Mobility tests be conducted with the ARSV's and comparable vehicles along selected traverses in FK1 and FK2.
- b. Results of these tests be used to validate predictions for these areas made by the AMC-71 mobility model.
- c. Mobility evaluations of the ARSV's and comparable vehicles in WGT be made with the AMC-71 mobility model.
- d. Final judgments of the relative mobility potential of the ARSV prototypes and comparison vehicles be based upon the results of simulations c in light of the validation in b.

Table 1

Outline of Required Tasks

Task A: Terrain Analysis for the ARSV Test Program

1. Collect field data.
2. Prepare terrain factor maps of selected areas at Fort Knox.
3. Compare U. S. with West German terrains.

Task B: Validation Testing

1. Select traverses for field validation testing at Fort Knox.
2. Predict performance of selected vehicles in all Fort Knox terrain units and over selected traverses using AMC-71 mobility model.
3. Provide TECOM support (personnel and instrumentation).
4. Compare field and predicted vehicle performance data and adjust or extend AMC-71 mobility model as required.

Task C: Mobility Evaluation

1. Predict performance for six vehicles using AMC-71 mobility model and WGT.
2. Select mission traverses and collect vehicle performance data as required.
3. Evaluate performance of BTR-40P-2 over same traverses.
4. Conduct parametric analyses of specific design features.

Task D: Mobility Effectiveness Evaluation

1. Describe procedures for performing mobility-visibility effectiveness analysis.
2. Evaluate the mobility-visibility effectiveness of standard vehicles to be compared with ARSV.

APPENDIX A: PROCEDURES USED IN PREPARING TERRAIN MAPS
OF FORT KNOX AND WEST GERMAN TERRAINS

Introduction

1. This appendix presents the procedures used in preparing areal and linear terrain factor complex maps for selected Fort Knox terrains (FK1 and FK2). It includes definitions of terrain terms applicable to mobility and procedures for field data collection. It also includes a discussion of the methodology used to revise the existing areal terrain factor complex maps of the West Germany transect (WGT).

Definitions

2. The general terrain terms used in this report are as follows:

a. Terrain factor. Any attribute of the terrain that can adequately be described at any point (or instant of time) by a single measurable value, for example, slope or obstacle height.

b. Terrain factor value. A specific occurrence of a terrain factor. For example, 2 percent is a factor value of the terrain factor, slope.

c. Terrain factor class (class range). A specified range of factor values established for a specific purpose; for example, a range of slope from 0 to 2 percent.

d. Terrain factor class number. A number assigned to a terrain factor class range. For mobility purposes, terrain factor class numbers are assigned in order of increasing severity of effect on vehicle performance.

e. Terrain factor complex number. A combination of two or more terrain factor class numbers chosen for a specific purpose.

f. Terrain unit. A patch (areal) or length (linear) of homogeneous terrain as defined by a specific array of terrain factors.

g. Terrain factor family. Two or more terrain factors grouped together.

h. Terrain factor map. A map showing the terrain factor class number associated with specific map coordinates.

i. Terrain factor group map. A map showing a series of terrain factor class numbers associated with specific map coordinates.

j. Terrain factor complex map. A map which shows all pertinent terrain factor class numbers associated with all areal terrain or all linear terrain shown on the map.

3. The surface composition terms used in this report are as follows:

a. Fine-grained soil. A soil of which more than 50 percent of the grains, by weight, will pass through a No. 200 U. S. standard sieve (smaller than 0.074 mm in diameter).

b. Coarse-grained soil. A soil of which more than 50 percent of the grains, by weight, will be retained on a No. 200 sieve (larger than 0.074 mm in diameter).

c. Organic soils (muskeg). A terrain surface composed of a living organic mat of mosses, sedges, and/or grasses with or without tree or shrub growth. Underneath the surface there is a mixture of partially decomposed and disintegrated organic material, commonly known as "peat" or "muck."

d. Cone index (CI). An index of shearing resistance of soil obtained with the cone penetrometer. The value represents the resistance of the soil to penetration of a 30-deg cone of 0.5 sq in. base or projected area at a penetration of 6 ft/min.

e. Rating cone index (RCI). Product of CI and remolding index (RI). RI is the ratio of remolded soil strength to original strength. RCI expresses the soil strength rating of a soil subjected to vehicular traffic.

4. Surface geometry terms used in this report are as follows:

a. Slope. The angular deviation of a surface from the horizontal, expressed as a percentage.

b. Obstacle approach angles (A). The angle formed by the inclines at the base of a positive or top of a negative vertical obstacle that a vehicle must sense in surmounting the obstacle (see sketch).

c. Obstacle base width (WB). The distance across the bottom of the obstacle (see sketch).

d. Obstacle spacing (OBS). The horizontal distance between contact edges of vertical obstacles (see sketch).

e. Obstacle spacing type (OBST). The pattern of obstacle location (linear or random--see f and g).

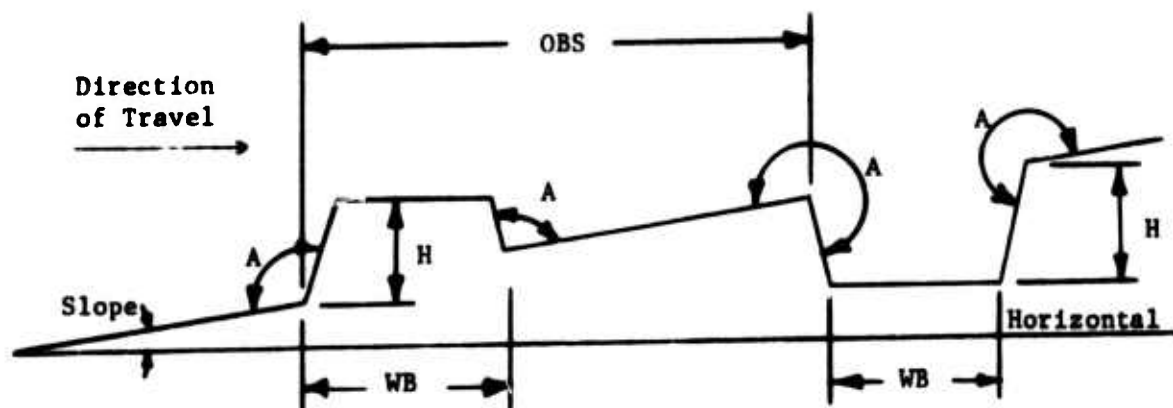
f. Linear obstacle spacing (LST). Distance between obstacles which cross the entire terrain unit and have a somewhat regular pattern, such as row crops or rice field dikes.

g. Random obstacle spacing (RST). Obstacles which do not cross the entire terrain unit and have a somewhat random location, such as stumps or logs.

h. Obstacle vertical magnitude (H). The vertical distance from the base of a vertical obstacle to the crest of the obstacle (see sketch).

i. Obstacle length (OBL). The length of the long axis of the obstacle.

j. Surface roughness. Microvariations of the terrain surface that adversely affects vehicle ride dynamics.



5. Vegetation terms used in this report are as follows:

a. Stem diameter. The diameter of the tree stems at breast height (4.5 ft) above the ground.

b. Stem spacing. The average distance between tree stems. This value is computed from the number of stems per unit area.

c. Recognition distance. The distance at which a vehicle driver can see and recognize objects that may be hazardous to his vehicle or to himself.

6. Linear geometry terms used in this report are:

a. Left approach angle (LAA) and right approach angle (RAA). The angle the stream bank or obstacle slope makes with a horizontal plane. (Left and right are determined looking upstream.) (See sketch.)

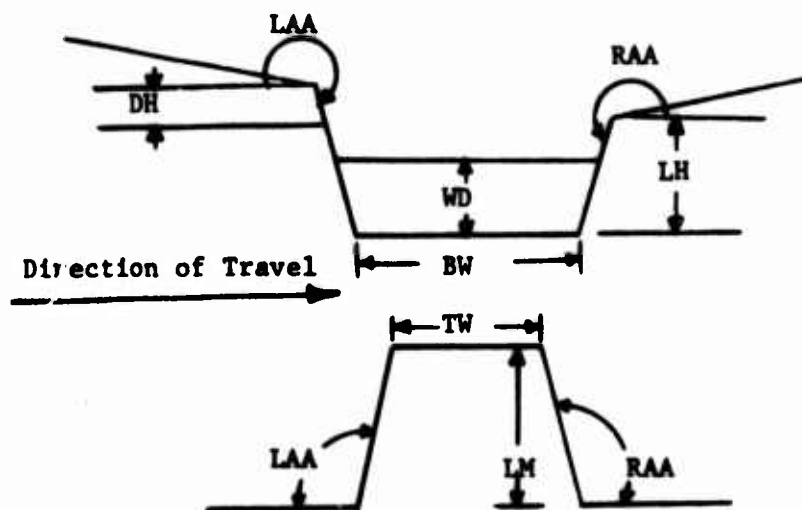
b. Differential bank height (DH) or differential vertical magnitude (DM). The difference in elevation between the two banks or obstacle approaches (see sketch).

c. Low bank height (LH) or least vertical magnitude (LM). Least difference in elevation between top and bottom of linear feature (see sketch).

d. Base width (BW) or top width (TW). Horizontal distance between two banks for concave feature and horizontal distance across top of convex feature (see sketch).

e. Water depth (WD). Vertical height of water above bottom of stream (see sketch).

f. Water velocity (WV). Maximum velocity of water in stream.



Fort Knox Terrains

Literature survey

7. A literature survey was conducted to review all pertinent terrain data, maps, and aerial photographs concerning the study areas. Agencies contacted were the U. S. Army Armor and Engineer Board, U. S. Geological Survey Library, Defense Mapping Agency, and the Department of Agriculture. As expected, little or no quantitative data were available in terms of terrain factors needed for this study.

8. Topographic maps of Fort Knox at scales of 1:25,000 and 1:50,000 were obtained for this study. Geological, landform, and soils maps at a scale of 1:50,000 prepared by the United States Geological Survey, Department of Interior, were also available. The search for the most recent aerial photographic coverage at a scale of 1:20,000 revealed that FK1 was last photographed in 1965 and FK2 in 1972. These aerial photos were obtained from the Defense Mapping Agency.

Data collection

9. The field data-collection program was conducted during 6-24 March 1973. During this period, the following number of sites were sampled:

<u>Area</u>	<u>Areal Terrain Sites</u>	<u>Linear Terrain Sites</u>	<u>Total</u>
FK1	47	12	59
FK2	<u>38</u>	<u>22</u>	<u>60</u>
Total	85	34	119

The location of each sample site is shown in plates A1 and A2.

10. Data sites were selected by studying air photos, photo mosaics, and topographic maps and by making ground reconnaissance. The mosaics were examined to identify variations in tone and texture indicative of different terrain conditions. In most cases, the sites selected were based primarily on vegetation differences and topographic slope since often the other terrain factors are closely related to these terrain factors. After the sites had been selected, their locations were spotted on topographic maps of each area. A limited ground reconnaissance was made of

each area to inspect the selected sites and to select additional sites where there were terrain variations that had not been detected from the air photos. Some additional sites were also selected during the sampling program when other variations were observed.

11. Waterways Experiment Station (WES) methods were employed in collecting data for each terrain factor. Terrain factor values required for mapping were obtained at each site. Since some sites were selected to describe particular terrain factors that were different from others in the surrounding area, those terrain factors that were not different were not remeasured. The primary reason for not measuring all terrain factors at each site was to conserve time and thereby permit more sites to be visited.

12. Surface composition. Surface composition data collected included cone index (CI), remolding index (RI), bulk samples, moisture content and density, and surface sheargraph¹ measurements. Cone index was measured by making 10 penetrations in an area 10 ft by 20 ft in size. For each penetration, the CI was measured at the surface and at 3-in. vertical increments to a depth of 12 in. RI was measured for the 0- to 6-in. layer near the center of the sample area. RI was measured for the 6- to 12-in. layer for only a few sites in each study area.

13. Representative bulk samples were taken for laboratory determination of Atterberg limits and other soil properties necessary for soil classification. Samples were also obtained for laboratory analysis of moisture and density; these samples were usually taken from sites adjacent to where RI was measured. Sheargraph measurements of c and ϕ were obtained at a few sites.

14. Surface geometry. The surface geometry data collected included slope, obstacle geometry, and surface roughness descriptions.

a. Slope. The slope representative of the sample site was measured with an Abney level. The azimuth looking upslope was determined using a Brunton compass.

b. Obstacle geometry. The obstacle (log, boulder, ditches), if any, most typical of the sample area was selected for description purposes. The obstacle was described in terms of approach angle, vertical

magnitude, length, width, spacing, and spacing type. The orientation of linear obstacles was measured. In some cases no obstacles were found in the sample area and this was noted.

c. Surface roughness. A profile of the ground surface representative of the sample site was measured with an engineer level, a steel tape, and a Philadelphia rod. The length of the profile varied but was normally about 200 ft. Vertical elevations were taken at 1-ft horizontal increments except where the ground surface was judged exceptionally smooth. The azimuth of the profile was measured with a Brunton compass. The profile data were processed to obtain the root mean square (rms), a measure of the deviation of the amplitudes from the mean. Prior to the calculation of rms, special techniques were used in processing the data to remove slope and long wave lengths from the profile.

15. Vegetation. The vegetation factors measured were stem size, stem spacing, stem diameter, visibility, and tree height.

16. Stem diameter and stem spacing measurements were made in accordance with the structural cell sampling technique. In brief, a structural cell may be defined as a minimum area which includes a statistically significant sample of all the important variations in terms of selected parameters present in a given vegetation assemblage. In this study, the major interest was the distribution of tree stems of specific diameters.

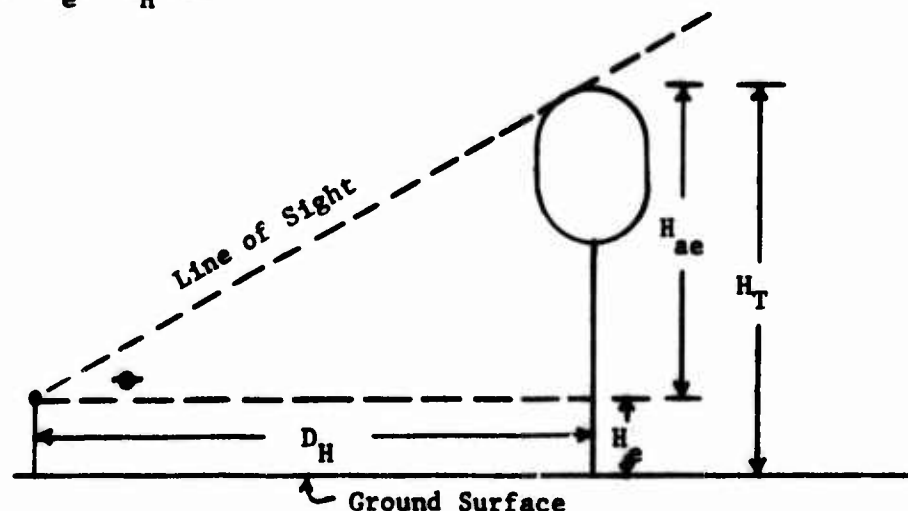
17. The sampling procedure used for describing vegetation stem is as follows: A cell center that appears to be representative of the area is selected in the vegetation assemblage. A cell size is then selected that contains 20 or more stems of the classes of stem sizes of interest. The diameter of the sample cell and the diameter of each stem in the cell are measured. Procedures for computing stem spacing from number of stems and area of cell are described in reference 2.

18. Visibility was sampled at each site; a five-point star was used as a target to determine recognition distance at 1 ft above ground. The sampling procedure at each site was as follows. A five-point star target was held 1 ft above the ground along an azimuth of the vegetation structural cell center. An observer directed the individual to move away

from the structural cell until he could recognize only two points of the star target. The distance from the observer to the target was recorded as the recognition distance. This procedure was repeated along two additional azimuths. These data were averaged for the site.

19. Tree-height measurements were made at each data site for use in the mobility effectiveness efforts (task D) of the ARSV cost and performance study. Tree height was determined from measurements with a Haga altimeter and a steel tape. The method of determining tree height is illustrated below:

$$H_T = H_e + D_H \tan \phi$$



where:

H_T = Height of tree

H_{ae} = Height of tree above observer's eye

H_e = Height of observer's eye

$\tan \phi$ = Read directly from Haga altimeter

20. Linear geometry. Field data collected for each linear feature included a profile taken perpendicular to the feature. The section selected for measurement was a typical cross section of the features, such as streams, ditches, road embankments, road cuts, etc. A starting point was selected some 20-30 ft from the edge of the feature, and a base line

perpendicular to the feature was established. The azimuth of the base line was determined with a Brunton compass. A steel tape was placed at the original point and extended along the base line to a terminal point 20 to 30 ft from the edge of feature on the opposite bank. Horizontal distances were measured directly from the tape. Vertical offsets were taken with the transit and a Philadelphia rod. When the water in the linear feature was too deep for wading, the vertical offsets were obtained with a sounding line. CI was measured on both banks of the feature and in the streambed or on top of embankment features. Normally, three measurements were made at each of the above locations of the linear feature.

21. When applicable, current velocities and water depth were measured. The velocity was measured by placing a wood chip in the water and measuring the time required for it to travel a specified distance.

22. Supplementary data. Other terrain data collected at each site were land use, depth to water table, ground cover, and topographic position. Ground photos were also obtained at each data site.

23. Photographs taken at some of the data sites and at other selected locations in FK1 and FK2 are shown (photographs 1-5). The photographs are located by their military grid coordinates.

Data summaries

24. Summaries of the field data collected at each areal and linear terrain site are given in tables A1-A7.

Terrain factor classification

25. In order to show factor values as areal or linear phenomena rather than as a number of isolated points, it is necessary to group terrain factor values into terrain factor classes. The terrain factor classes used in this study to describe areal terrain factors and linear terrain factors are given in tables A8 and A9, respectively. Each terrain factor value measured or estimated was placed into a terrain factor class on the field data form.

Preparation of terrain factor and factor group maps

26. The data site locations were plotted on a photo mosaic. The mosaic was then used to prepare overlays showing both the location of

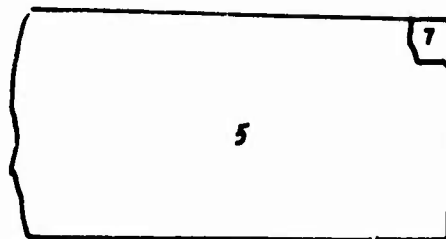
each site and the appropriate terrain factor class numbers or terrain factor group numbers assigned to the site. These overlays served as a base for preparing surface composition, slope, obstacle geometry, surface roughness, vegetation, and visibility maps.

27. Drafting, reproduction, and symbol recognition considerations dictated that the minimum width of any delineated area would be approximately 1/10 in.; thus, the smallest mappable area was a circle 1/10 in. in diameter, which represents 208 ft on the base map (scale 1:25,000). Terrain factor maps or terrain factor group maps were prepared as follows.

28. Surface composition map. The surface composition factors mapped in this study were surface material type and surface strength. Since field samples revealed that all the soils in both FK1 and FK2 were fine-grained, both surface material type and surface strength were portrayed on the same map. Surface strength was mapped at only the moisture condition that was encountered during the time of measurement (wet season); although the largest amounts of rainfall generally occur in April and May, the soil moisture was at field maximum at the time of testing. Topographic position, depth to bedrock, topographic slope, drainage characteristics, and land use were used in establishing the boundary between soil strength classes. Separate surface composition maps were prepared for linear and areal terrains. An example of a surface composition map for a portion of FK2 used in formulating areal terrain units is given in fig. A1.

29. Slope map. Slope factor maps were prepared from topographic maps having a scale of 1:50,000 and 20-ft contour intervals. Topographic maps having a scale of 1:25,000 with some 10-ft contours were used to supplement the 1:50,000 maps where required. Field data were used to verify the slopes established from topographic maps. A slope factor map for a portion of FK2 is given in fig. A2.

30. Obstacle maps. Recognition and description of obstacles from aerial photos are difficult to impossible in most cases. For example, an area on a photo that appears to contain large trees spaced closely together may or may not contain logs or stumps. Thus, the field data collected for



Scale: 1:25,000

LEGEND (partial)

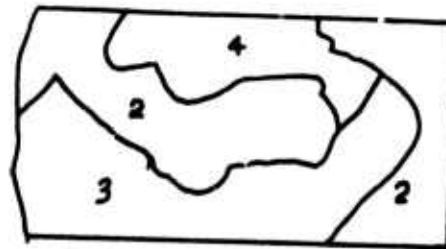
MAP UNIT*	SOIL TYPE*	SOIL STRENGTH*
5	1	5
7	1	7

* Each map unit represents an array of two symbols indicating soil type and soil strength.

Mapping class ranges for soil type and soil strength are:

SOIL TYPE		SOIL STRENGTH	
FACTOR CLASS NO.	TYPE	FACTOR CLASS	RCI
1	Fine grained soil	1	>280
2	Coarse grained soil	2	221 - 280
3	Muskeg	3	161 - 220
		4	101 - 160
		5	61 - 100
		6	41 - 60
		7	33 - 40
		8	26 - 32
		9	17 - 25
		10	11 - 16
		11	0 - 10

Fig. A1. Surface composition map (multiple factor)



Scale: 1:25,000

LEGEND

FACTOR	
CLASS NO.	SLOPE, %
1*	0 - 2
2	2.1 - 5
3	5.1 - 10
4	10.1 - 20
5	20.1 - 40
6*	40.1 - 60
7*	60.1 - 70
8*	>70

* Units not on map.

Fig. A2. Slope map (single factor).

describing the obstacle factors (approach angle, vertical magnitude, length, width, spacing, and spacing type) were used to identify and describe obstacles. Tone and texture patterns, topographic maps, and land use were used to establish boundaries between obstacle classes.

31. Since the data measured at each site describe a specific obstacle, it was more convenient to prepare a single map for obstacles than to prepare individual factor maps for each obstacle factor. The obstacle map for a portion of FK2 is given in fig. A3.

32. Surface roughness maps. Surface roughness (rms) was determined from measured microprofile data. Boundaries for the surface roughness factor were established with the aid of air photos and field observations. Fig. A4 is a surface roughness factor map of a portion of FK2.

33. Vegetation. Boundaries of different vegetation assemblages were drawn on air photos on the basis of pattern identification. For this study, field measurements of stem diameter and stem spacing were associated with particular air-photo patterns. Since all eight factors that describe a single vegetation assemblage were related to particular air-photo patterns, it was more convenient to prepare a single map containing all eight factors than to prepare individual factor maps for each stem diameter size.

34. The vegetation map for a portion of FK2 is shown in fig. A5.

35. Visibility. As a general rule, boundaries for the visibility factor maps followed closely those of the vegetation map, except where boundaries were noted to be different during field sampling. A portion of a visibility factor map for FK2 is given in fig. A6.

36. Linear geometry. Stereoscopic examination of the air photos, topographic maps, field measurements, ground photos, personal observations of areas, and background knowledge of hydrologic principles were the basic tools for mapping linear features. The first step was to prepare a base map identifying the linear features. A linear geometry map was then established by use of a specific combination of terrain factor classes measured at each site. Tick marks were used to separate linear features into segments.



Scale: 1:25,000

LEGEND (partial)

MAP UNIT*	OBSTACLE APPROACH ANGLE**	OBSTACLE VERTICAL MAGNITUDE**	OBSTACLE WIDTH**	OBSTACLE LENGTH**	OBSTACLE SPACING**	OBSTACLE SPACING TYPE**
1	1	1	1	1	1	1
18	13	2	5	6	3	1
22	14	6	3	6	5	1

* Each map unit represents an array of six symbols indicating mapping classes of obstacle approach angle, obstacle vertical magnitude, obstacle length, obstacle width, obstacle spacing, and obstacle spacing type.

** Mapping class ranges for each factor used in describing obstacles are:

OBSTACLE APPROACH ANGLE		OBSTACLE VERTICAL MAGNITUDE		OBSTACLE WIDTH		OBSTACLE LENGTH		OBSTACLE SPACING		OBSTACLE SPACING TYPE	
FACTOR CLASS NO.	DEG.	FACTOR CLASS NO.	IN.	FACTOR CLASS NO.	IN.	FACTOR CLASS NO.	FT.	FACTOR CLASS NO.	IN.	FACTOR CLASS NO.	TYPE
1	178.6 - 180.0	1	0 - 6	1	47	1	.0 - 1	1	Bare	1	Random
2	180.0 - 181.5	2	6.1 - 10.0	2	36 - 46.9	2	1.1 - 3.3	2	65.7 - 197.0	2	Linear
3	175.6 - 178.5	3	10.1 - 14.0	3	24 - 35.9	3	3.4 - 6.6	3	36.4 - 65.6		
4	181.5 - 184.5	4	14.1 - 18.0	4	12 - 23.9	4	6.7 - 10.0	4	26.5 - 36.3		
5	170.1 - 175.5	5	18.1 - 23.6	5	0 - 11.9	5	10.1 - 19.9	5	18.3 - 26.4		
6	184.5 - 190.0	6	23.7 - 33.5			6	20.0 - 492.0	6	13.4 - 18.2		
7	158.1 - 170.0	7	33.5			7	492	7	8.3 - 13.3		
8	190.1 - 202.0							8	.0 - 8.2		
9	149.1 - 158.0										
10	203.1 - 211.0										
11	135.1 - 149.0										
12	211.1 - 225.0										
13	90.0 - 135.0										
14	226.0 - 270.0										

Fig. A3. Obstacle map (multiple factors)



LEGEND

FACTOR CLASS NO.	SURFACE ROUGHNESS, rms
1*	.0 - .4
2	.5 - 1.5
3	1.6 - 2.5
4*	2.6 - 3.5
5	3.6 - 4.5
6*	4.6 - 5.5
7*	5.6 - 6.5
8*	6.6 - 7.5
9*	>7.6

* Units not on this map.

Fig. A4. Surface roughness map (single factor)



LEGEND (partial)

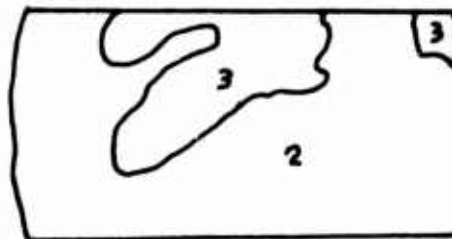
MAP UNIT*	STEM SPACING (CLASS)** OF STEM DIAMETER (CLASS)** EQUAL OR > THAN							
	1	2	3	4	5	6	7	8
1	1	1	1	1	1	1	1	1
15	8	8	8	8	8	7	7	6
21	8	8	7	6	5	1	1	1

* Each map unit represents an array of eight symbols indicating mapping classes of stem spacing of stem diameters equal to or greater than the stem diameter class shown.

** Mapping class ranges for stem diameter and stem spacing are:

STEM DIAMETER		STEM SPACING	
FACTOR CLASS NO.	IN.	FACTOR CLASS NO.	FT
1	> .0	1	328
2	>1.0	2	65.6 - 327.9
3	>2.4	3	36.4 - 65.5
4	>3.9	4	26.5 - 36.3
5	>5.5	5	18.3 - 26.4
6	>7.0	6	13.4 - 18.2
7	>8.7	7	8.3 - 13.3
8	>9.8	8	.0 - 8.2

Fig. A5. Vegetation map (multiple factors)



LEGEND

FACTOR CLASS NO.	RECOGNITION DISTANCE, ft
1*	>164
2	79.0 - 163.9
3	39.6 - 78.9
4	29.8 - 39.5
5*	20.0 - 29.7
6*	15.1 - 19.9
7*	10.1 - 15.0
8*	5.1 - 10.0
9*	.0 - 5.0

* Units not on map.

Fig. A6. Visibility map (single factor)

Preparation of terrain
factor complex maps

37. Areal terrain factor complex maps. The areal terrain factor complex maps prepared for the Ft. Knox study areas are composite terrain factor maps. In this study surface composition, slope, obstacle geometry, surface roughness, vegetation structure, and visibility maps were combined in that order to formulate the terrain factor complex maps. This process is illustrated in fig. A7 in which the sample terrain factor and factor group maps in figs. A1-A6 are successively overlaid.

38. A transparent copy of a surface composition factor-family map was used as a base for an areal factor complex map. Each map unit was identified by a single number that represented the class values of soil type and soil mass strength (figs. A1 and A7a). The slope map was then superimposed on the surface composition map and all lines that did not coincide with the lines on the surface geometry map were transcribed. Every outlined area was then identified by two numbers, the first of which represents a map unit of surface composition and the second, a map unit of slope (fig. A7b). For example, the shaded area designation (5, 2) indicates a map unit of 5 for surface composition and a map unit of 2 for slope. The obstacle geometry map was then superimposed on the surface composition-slope map and all lines not coincident were transcribed. The resulting areas were identified by three numbers or number designations representing map units of soil composition, slope, and obstacle geometry, in that order (fig. A7c). For example, in the designation (5, 2, 18), 5 identifies the surface composition map unit, 2 identifies the slope map unit, and 18 identifies the obstacle geometry map unit.

39. The surface roughness map, the vegetation structure map, and the visibility map were superimposed on the surface composition-slope-obstacle map one at a time, and each time lines that were not coincident were added and a map number designation added (figs. A7d, A7e, and A7f). This resulted in a six-number designation. For example, in the designation (5, 2, 18, 2, 01, 2), the 5 identifies the surface composition, 2 identifies the slope,

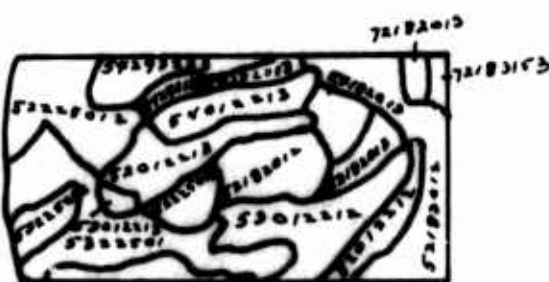
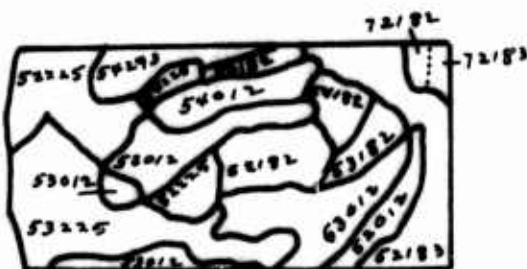
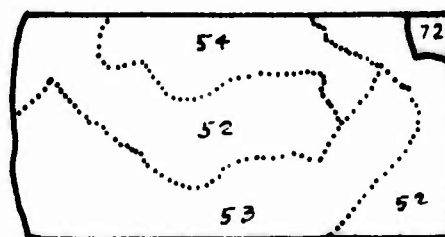
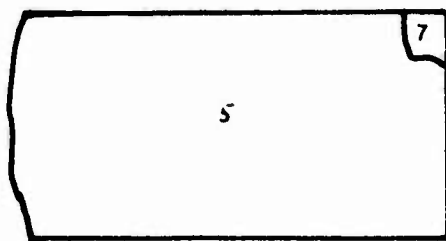


Fig. A7. Results of overlaying processes in formulating terrain factor complex map

18 identifies the obstacle geometry, 2 identifies the surface roughness, 01 identifies the vegetation, and the 2 identifies the visibility. The designation was then replaced by a single number (82) keyed to the map units for surface composition, slope, obstacle geometry, surface roughness, vegetation structure, and visibility (fig. A8). This number is called the terrain unit number.

40. One hundred ninety-two areal terrain units were required to describe FK1 and 193 areal terrain units were required to describe FK2. Separate areal terrain factor complex maps of FK1 and FK2 are given in plates A3 and A4, respectively. Legends for the factor maps of FK1 and FK2 are given in tables A10 and A11, respectively.

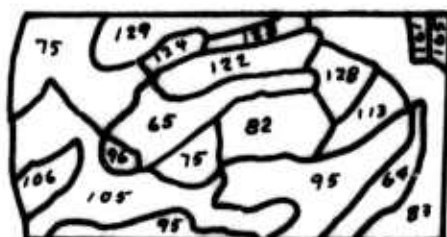
41. Linear terrain factor complex maps. The linear factor complex map is a composite of linear geometry and surface composition maps. The linear terrain map includes the geometry of drainage features, escarpments, and road embankments. The linear factor complex map was compiled from the linear surface composition map and the linear surface geometry in the same manner as the areal terrain factor complex map.

42. Seventeen linear terrain units were required to describe FK1 and 13 linear terrain units were required to describe FK2. Linear terrain factor maps and map legends for FK1 and FK2 are given in plates A5 and A6 and tables A12 and A13, respectively.

West German Terrain

Revision of surface roughness factor

43. The units shown on the available areal terrain factor complex map of the West German transect were formed by the process of superimposing all the terrain factors shown in table A14 except surface roughness. In the original mapping, a statistical sampling procedure was used to assign a surface roughness factor class to each terrain unit. Although this scheme was adequate for some earlier studies, it was believed that for the current study a more realistic approach was required for the determination of the surface roughness.



Scale: 1:25,000

LEGEND (partial)

T E R R A I N	S U R F A C E	S U R F A C E	S U R F A C E	-----OBSTACLE-----										S U R F A C E	S U R F A C E	R E C O G .			
				A P P R O A C H	V P R O A C H	M A C H	L P G	S P G	H S P G	W E A T N C I Y E S	E A T N C I Y E S	L P G	W E A T N C I Y E S						
Spacing of Stems Equal to or Greater than Given Stem Diameter Class																			
T	E	H	E	R	E	H	H	G	E	S	1	2	3	4	5	6	7	8	T
65	1	5	2	1	1	1	1	1	1	2	8	8	7	6	5	1	1	1	3
82	1	5	2	13	2	5	6	3	1	2	1	1	1	1	1	1	1	1	2
95	1	5	3	1	1	1	1	1	1	2	8	8	7	6	5	1	1	1	2
105	1	5	3	12	6	3	6	5	1	5	1	1	1	1	1	1	1	1	2
106	1	5	3	12	6	3	6	5	1	5	8	8	7	6	5	1	1	1	2

Fig. A8. Terrain factor complex map

44. Ideally the solution would be to prepare a surface roughness map based on measured surface profiles in the area. The original plan called for exactly that--to send a team to West Germany to collect additional ground truth data to complete the existing maps of the West German terrain. A request by WES and TACOM to visit West Germany was denied; therefore, the plan was modified to use available data to develop a more realistic estimate of rms for terrain unit on the existing map. No new terrain units would be created as a result of surface roughness revisions.

45. The available data consisted of air photographs and topographic maps of the transect area. Measured profiles and ground-level photos in somewhat similar areas in Germany and in the United States, descriptions and ground-level photographs of other areas in West Germany, and the aforementioned terrain factor complex map were also available.

46. Obviously, surface roughness in terms of rms cannot be read directly from an air-photo or topographic map. It was suspected, however, that rms could be inferred from other things that could themselves be recognized on air photos and topographic maps. After examination of the available data (including comparison of ground-level photographs taken in West Germany and the United States) and a visual inspection of the terrain in the local (Warren County, Mississippi) area, it was concluded that a reasonable approximation of surface roughness could be inferred from land use when cognizance is taken of topographic slope.

47. Land-use map. Accordingly, a land-use map of the transect was prepared from the air photos. The classes of land use that could be recognized on the air photos and that were assumed to be significant in this exercise were:

- a. Towns: including industrial and residential areas.
- b. Natural woodland: woodlands along streams and rivers, and occasionally on steep slopes, which do not appear to be cultivated woodlands.
- c. Dense woodland: woodlands of sufficient density that individual trees cannot be recognized, with crowns of approximately uniform height, suggesting cultivation.

d. Sparse woodland: woodlands of such density that individual trees can be recognized.

e. Cleared: grass- or brush-covered areas within or along the edge of woodlands.

f. Orchard: trees obviously in a regular geometric pattern.

g. Cropland: including both row and broadcast cultivated areas.

h. Vineyard: a distinct and easily recognizable feature on steep slopes.

i. Pasture: grass-covered areas, usually along streams, which do not have the rectangular pattern associated with croplands.

j. Quarry: an easily recognizable feature, devoid of vegetation, usually with near-vertical depressions.

k. Bare: areas devoid of vegetation, which lack the rectangular pattern associated with croplands and the near-vertical depressions associated with quarries; possibly construction sites or borrow areas.

48. Surface roughness factor map. The land-use map and the existing slope factor map were then combined into a surface roughness factor map using the surface roughness classes given in the following tabulation. The range of each surface roughness class in terms of rms is given in table A8.

Land Use	Surface Roughness Class						
	Slope Class 1	Slope Class 2	Slope Class 3	Slope Class 4	Slope Class 5	Slope Class 6	Slope Class 7
Cropland	2	2	2	2	2	2	2
Orchard	2	2	2	2	2	2	2
Dense woodland	2	2	2	2	2	2	2
Natural woodland	2	2	2	4	4	4	4
Sparse woodland	2	2	3	4	4	4	4
Cleared	2	2	3	4	4	4	4
Pasture	2	2	3	4	4	4	4
Quarry	-	-	-	4	4	4	4
Vineyard	-	-	-	-	4	4	4
Towns	Special Rules Apply						
Bare	Special Rules Apply						

49. The classes of surface roughness assigned in the foregoing tabulation were developed from the available data where possible. Although

previous terrain and mobility studies^{3,4} in West Germany have not included surface profiles taken to establish surface roughness values, they have included some surface profiles that can be used for this purpose and have included descriptions from which rms can be reasonably inferred. Surface roughness data for some areas in the United States were available from studies conducted for the validation of the AMC-71 mobility model. For land use-slope combinations for which no data were available, the surface roughness class was assigned on the basis of existing data, engineering judgment, and knowledge of the general area, tempered by an awareness of how surface roughness affects vehicle performance and of how these data are used in the AMC-71 mobility model.

50. Note that only three classes of surface roughness occur in the tabulation--surface roughness classes 2, 3, and 4 from table A8. Surface roughness class 1, which represents an rms value range of 0.0 to 0.4 in. is, by existing ground rules, reserved for roads. (An rms value in this range could occur on playas, salt flats, or beach flats, but the likelihood of such occurrence in this area of West Germany is virtually nonexistent.) No surface roughness class greater than 4 is shown in the table for two reasons--first, class 4 extends to an rms value of 4.5 and greater values are rarely found; second, the difference in the effect of surface roughness class 4 and higher classes on speed predictions is insignificant.

51. The limited data available indicated that surface roughness generally increased with an increase in slope for the same land use. Normally, erosion may be expected to be more severe on steeper slopes, with an accompanying increase in surface roughness. The broadness of the class ranges of surface roughness tends to obscure this in the tabulation, although the indication exists with some exceptions.

52. The measured values of surface roughness for cropland were available only for croplands on the lower slopes. These data yielded a surface roughness class 2. This same class of surface roughness was assigned to croplands on higher slopes because it was believed that the surface roughness in croplands would be almost entirely dependent upon

agricultural practices. Moreover, it seemed likely that the slope itself may have been modified; the land-use identification from the air photos is more reliable than the slope values from the topographic map.

53. The establishment of the surface roughness for orchards generally followed the reasoning given above for croplands, except that orchards on slope classes 6 and 7 were assigned a surface roughness class of three.

54. Sufficient data were available to fix the surface roughness class of dense woodlands and natural woodlands throughout the slope range with confidence.

55. The establishment of surface roughness for sparse woodland, cleared, and pasture areas was aided by inspection of similar terrain in Warren County, Mississippi, to supplement the available data.

56. A class 4 surface roughness was assigned to vineyards and quarries on the basis of discussions with personnel familiar with the area.

57. The special rules which apply to towns and to bare areas are discussed in paragraphs 58 and 59.

58. It should be pointed out that not all of the land use-slope combinations shown in the tabulation occur in the West German transect--for instance, pastures were not found on the steeper slopes, orchards were not found on the lower slopes, etc.

59. Assignment of surface roughness to terrain units. To determine surface roughness class for each terrain unit, the areal terrain factor complex map and the surface roughness factor maps were overlaid. Some terrain units which occurred many times were found in areas of different surface roughness as indicated by the surface roughness factor map. This was expected since several patches of terrain could be described in exactly the same way on the terrain factor complex map and still have different land uses and, hence, different surface roughnesses. For instance, a particular terrain unit might occur in cropland and also occur in a cleared or pasture area. Both would be properly described by the same areal terrain factor complex number (except for surface roughness, which was not evaluated in the original preparation of the areal terrain factor complex maps). The same condition obtains for orchards and certain

woodlands. Since one of the constraints of this exercise prohibited the establishment of additional terrain units, it was impossible to assign different surface roughness values to separate occurrences of the same terrain unit. Therefore, when a terrain unit fell into different surface roughness classes as indicated by the surface roughness values to separate occurrences of the same terrain unit. Therefore, when a terrain unit fell into different surface roughness classes as indicated by the surface roughness factor map, the surface roughness class which represented the largest area was assigned to that terrain unit.

60. The treatment of towns was admittedly arbitrary and, hopefully, a one-time-only procedure solely for this exercise. It is believed that vehicles traveling through town will use streets and roads which will generally fall into surface roughness classes 1 or 2. However, towns, per se, were not delineated on the areal terrain factor complex map. As a result, a given terrain unit may occur within and outside of a town. In this event, the surface roughness class applicable to the occurrence outside of the town was assigned to the terrain unit. When all occurrences of a terrain unit fell within a town, a surface roughness class 2 was assigned to the terrain unit.

61. For terrain units occurring in bare areas, the surface roughness class was established by consideration of the obstacles present. If no obstacles were present, surface roughness class 2 was assigned; if small obstacles were present, the area was considered to be the same as cleared areas (for the purpose of surface roughness) and the values of surface roughness established for cleared areas in the foregoing tabulation were used; if large obstacles were present, a surface roughness class 4 was assigned to the terrain unit.

62. It should be noted that the procedures given herein were generally followed to the maximum practical extent. However, some terrain units were examined individually (in stereo) and assigned a surface roughness class of best fit based on experience and judgment. This procedure was occasionally necessitated when land-use boundaries and terrain-unit

boundaries did not coincide, when land-use identification was questionable or did not clearly fit one of the established categories, and when an apparent anomaly existed.

Areal terrain factor complex map

63. The areal terrain factor complex maps for WGT are given in plate A7; the new legend prepared for this study is given in table A14.

Linear terrain factor complex maps

64. The linear terrain factor complex maps for WGR are given in plates A8 and A9; the legend is given in table A15.

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3. Woods, H. K. and Shamburger, J. H., "Quantitative Description of Selected West German Terrain for Ground Mobility," Technical Report M-70-6, Apr 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
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Table A1

Summary of Soil Strength for Areal Terrain Sites, Ft. Knox, Kentucky

Site No.	1973 Date	Grid Co-ordinates	Average Cone Index					RI			Bearing			Remarks
			1	2	3	4	5	6	7	8	9	10	11	
1	12 Mar	040407	38	42	51	50	63	41	55	41	12.0	0.2	17.0	RI from site 1
2	12 Mar	040409	52	117	135	226	253	121	218	73	40	0.2	17.0	RI from site 1
3	12 Mar	040409	22	74	91	156	172	62	184	73	40	0.2	17.0	RI from site 1
4	12 Mar	040408	24	100	159	174	192	94	175	73	40	0.2	17.0	RI from site 1
5	12 Mar	040402	42	118	160	176	180	107	172	73	40	0.2	17.0	RI from site 1
6	12 Mar	050406	50	82	90	114	116	74	106	47	35	0.2	17.0	RI from site 1
7	12 Mar	050408	20	34	51	82	132	35	78	55	39	0.2	17.0	RI from site 1
8	12 Mar	051002	44	171	192	246	249	136	236	73	40	0.2	17.0	RI from site 1
9	14 Mar	052004	55	154	158	165	185	123	173	56	40	0.2	17.0	RI from site 1
10	14 Mar	052004	16	48	102	126	138	81	105	56	40	0.2	17.0	RI from site 1
11	14 Mar	052004	22	62	102	126	138	81	105	56	40	0.2	17.0	RI from site 1
12	14 Mar	052004	22	108	150	202	250	93	191	50	40	0.2	17.0	RI from site 1
13	14 Mar	052004	26	52	141	162	164	73	154	50	40	0.2	17.0	RI from site 1
14	14 Mar	052004	39	77	82	85	82	66	81	46	40	0.2	17.0	RI from site 1
15	15 Mar	052007	10	39	131	204	229	60	189	46	40	0.2	17.0	RI from site 1
16	15 Mar	052007	29	46	125	132	161	81	139	40	40	0.2	17.0	RI from site 1
17	15 Mar	052007	18	85	135	158	176	79	156	55	43	0.2	17.0	RI from site 1
18	15 Mar	052007	34	14	174	182	190	121	182	47	57	0.2	17.0	RI from site 1
19	15 Mar	052007	34	14	174	182	190	121	182	47	57	0.2	17.0	RI from site 1
20	15 Mar	052007	25	104	144	178	188	92	171	49	52	0.2	17.0	RI from site 1
21	15 Mar	052007	32	96	118	138	160	82	139	49	40	0.2	17.0	RI from site 1
22	15 Mar	060012	14	56	96	114	126	57	112	60	34	0.2	17.0	RI from site 1
23	15 Mar	060011	30	41	70	80	98	44	81	39	17	0.2	17.0	RI from site 1
24	15 Mar	060011	32	102	139	153	163	87	135	51	40	0.2	17.0	RI from site 1
25	15 Mar	060013	32	102	139	153	163	87	135	51	40	0.2	17.0	RI from site 1
26	16 Mar	060014	25	36	81	181	201	47	154	35	40	0.2	17.0	RI from site 1
27	18 Mar	054007	30	73	106	112	122	66	113	76	50	0.2	17.0	RI from site 1
28	18 Mar	072011	37	1	83	148	166	60	167	57	46	0.2	17.0	RI from site 1
29	18 Mar	072011	44	71	178	218	221	65	181	51	45	0.2	17.0	RI from site 1
30	18 Mar	072012	32	74	126	138	148	60	161	71	38	0.2	17.0	RI from site 1
31	18 Mar	044005	44	58	79	116	130	61	104	40	28	0.2	17.0	RI from site 1
32	18 Mar	044005	36	67	96	135	161	66	131	43	28	0.2	17.0	RI from site 1
33	18 Mar	044006	51	162	160	176	182	118	176	47	55	0.2	17.0	RI from site 1
34	19 Mar	093015	28	52	130	155	164	73	150	73	53	0.2	17.0	RI from site 1
35	19 Mar	093015	51	98	108	108	108	83	107	58	48	0.2	17.0	RI from site 1
36	19 Mar	093015	34	58	108	108	108	83	107	58	48	0.2	17.0	RI from site 1
37	19 Mar	093015	30	43	114	136	147	66	133	56	37	0.2	17.0	RI from site 1
38	19 Mar	093015	30	43	114	136	147	66	133	56	37	0.2	17.0	RI from site 1
39	19 Mar	093015	17	56	164	184	189	72	174	50	38	0.2	17.0	RI from site 1
40	19 Mar	093015	61	135	182	212	237	133	210	47	63	0.2	17.0	RI from site 1
41	19 Mar	093015	22	44	79	131	190	48	140	38	18	0.2	17.0	RI from site 1
42	19 Mar	093015	24	46	75	90	94	48	86	39	19	0.2	17.0	RI from site 1
43	23 Mar	075004	27	73	143	175	204	81	174	59	48	0.2	17.0	RI from site 1
44	23 Mar	075004	55	61	96	128	137	71	120	59	47	0.2	17.0	RI from site 1
45	23 Mar	075004	18	60	104	158	176	61	146	59	36	0.2	17.0	RI from site 1
46	23 Mar	093017	20	70	108	116	115	66	120	59	36	0.2	17.0	RI from site 1

(Continued)

90/5 - coneograph measurements made with rubber head.

100 - coneograph measurements made with metal head.

A - angle of internal friction, deg.

C - cohesion, psi.

depth below surface, in.

Soil layer, in.

Table A1 (Continued)

Site No.	1973 Date	Grid Co-ordinates	Average Core Index			RI 0-6 6-12	RI 0-6 6-12	RI 0-6 6-12	at Cor Class 0-6	Shrinkage			Remarks
			0	1	2	0-6	6-12	6-12		R/S	Net R/S	Net R/S	
1	6 Mar	012851	46	258	300	300	300	221	4				RI from Site 6
2	6 Mar	012851	26	143	300	300	300	156	5				RI from Site 6
3	6 Mar	012851	46	278	300	300	300	215	4				RI from Site 6
4	6 Mar	009854	92	890	900	900	900	231	4				RI from Site 6
5	6 Mar	011870	44	197	900	900	900	179	4				RI from Site 6
6	6 Mar	009855	45	106	136	88	104	96	6				RI from Site 6
7	6 Mar	009866	70	248	248	248	271	187	4				RI from Site 6
8	6 Mar	011853	24	160	900	900	900	168	5	1.2	20.5	1.0 15.0	2.3 23.0
9	6 Mar	007861	48	800	900	900	900	216	4				RI from Site 6
10	6 Mar	004852	44	135	206	144	204	229	4				RI from Site 6
11	6 Mar	004857	39	71	48	103	114	70	6	0.4	19.0	0.2 7.0	1.1 21.1
12	6 Mar	002858	10	182	300	300	300	171	5				RI from Site 17
13	6 Mar	001858	70	900	900	900	900	223	4				RI from Site 17
14	6 Mar	001864	54	90	70	82	114	71	6				RI from Site 17
15	6 Mar	009865	28	62	52	77	61	47	7				RI from Site 17
16	6 Mar	006868	47	800	800	900	900	216	4				RI from Site 6
17	6 Mar	006859	52	112	145	180	222	103	4				RI from Site 6
18	6 Mar	009870	32	58	178	340	900	90	5				RI from Site 6
19	6 Mar	022867	124	250	261	300	300	212	4	1.3	30.0	1.2 27.0	3.4 30.0
20	6 Mar	064861	38	71	136	164	204	61	7				RI from Site 20
21	6 Mar	066853	40	69	128	171	188	86	7				RI from Site 20
22	6 Mar	075866	58	116	160	232	300	111	8				RI from Site 20
23	6 Mar	066862	44	174	90	60	108	74	6				RI from Site 20
24	6 Mar	071851	58	264	300	900	900	20	4				RI from Site 20
25	6 Mar	075866	58	300	300	300	300	221	4				RI from Site 20
26	6 Mar	075867	24	230	258	260	264	174	2				RI from Site 20
27	6 Mar	072850	81	300	300	900	900	227	4				RI from Site 20
28	6 Mar	064862	20	144	206	138	259	121	5	0.4	21.5	0.5 20.2	1.0 26.2
29	6 Mar	006853	76	300	300	900	900	225	4				RI from Site 20
30	6 Mar	003874	33	300	360	300	300	211	5				RI from Site 20
31	6 Mar	003874	63	177	205	201	224	153	4				RI from Site 20
32	6 Mar	072861	81	160	184	136	150	137	4				RI from Site 20
33	6 Mar	091865	88	122	208	240	262	136	5				RI from Site 20
34	6 Mar	065864	79	222	208	240	262	136	5				RI from Site 20
35	6 Mar	005870	48	255	263	300	900	188	4				RI from Site 20
36	6 Mar	092867	88	160	144	134	150	137	4				RI from Site 20
37	6 Mar	070864	20	144	200	238	259	121	5				RI from Site 20
38	6 Mar	097865	20	144	200	238	259	121	5				RI from Site 20

(Continued)

Supplementary Soils Data Summary for Areal Terrain Sites
Ft. Knox, Kentucky

(Continued)

1 of 2 Sheets

Table A2 (Concluded)

Site No.	1973 Date	Grid Coordinates	Dry Density, lb/ft ³		Moisture Content, %			Soil Classification			
			0-6 in.		0-1/4 in.	0-6 in.	6-12 in.	USCS, 0-6 in.			Soil Type
								Atterberg Limits			
								LL	PI	PI	
1	6 Mar	012051									
2	6 Mar	012052									
3	6 Mar	012054	83.9				23.2	32.1	20.2	11.9	CL
4	6 Mar	004059					31.4				ML
5	6 Mar	011870					30.0				
6	6 Mar	009875					20.1				
7	6 Mar	009866	84.4	95.9			31.8				
8	7 Mar	011853	25.3				28.8	27.3			
9	8 Mar	007861	100.3				93.0				
10	7 Mar	004852					22.6				
11	7 Mar	004857					24.9				
12	7 Mar	002858	85.8	97.9			26.4				
13	7 Mar	001858					11.5	25.5			
14	7 Mar	001864	85.8	97.9			18.7				
15	7 Mar	999865	94.4				11.5	25.5			ML
16	8 Mar	008868	82.0	91.4			26.6				
17	7 Mar	998859					32.6	27.7			
18	8 Mar	989870	89.2				21.2				
19	10 Mar	982867	92.7				28.1				
20	9 Mar	984861	92.7		28.0		26.2	30.8	23.1	7.3	ML
21	8 Mar	986853	92.2	96.3			26.0				ML
22	7 Mar	975846	95.8				27.0	24.5			ML
23	7 Mar	968842	78.5				22.1	32.8	21.2	11.6	CL
24	8 Mar	971851	81.3	89.8			45.8	31.1	24.0	7.1	ML
25	6 Mar	967869	109.6				33.8	28.3			CL
26	11 Mar	004867					20.8				
27	8 Mar	972850	107.5		37.2		24.6				
28	8 Mar	964862					22.9				
29	7 Mar	006853					34.8				
30	8 Mar	997871	87.6				22.7	70.9	26.3	44.6	CL
31	8 Mar	003874	92.2				28.7				CH
32	10 Mar	972861					19.6	26.1			CL
33	10 Mar	993865	94.2		51.0		26.2	34.1	25.2	8.9	ML
34	11 Mar	985864					29.0	39.2	19.7	14.5	CL
35	11 Mar	005870	91.8		30.0		27.8				
36	21 Mar	992867			23.8		21.2				MH
37	22 Mar	970864					29.0				
38	22 Mar	967865					34.8				

(Concluded)

Table A3

Summary of Surface Geometry Data (Except Surface Roughness)
For Aerial Terrain Sites
Ft. Knox, Kentucky

Site No.	1973 Date	Grid Coordinates	Azimuth deg	Topographic Slope %	Approach Angle deg	Vertical Magnitude in.	Obstacle				Spacing ft	Spacing Type ^a
							Base Width in.	Length ft				
PK1												
1	12 Mar	079987	29	1	90	4	4	15	100		R	
2	12 Mar	040989	270	58	90	4.5	4.5	19	15		R	
3	12 Mar	047992	44	1	210	16	33	3	200		R	
4	12 Mar	046998	ND	1	No obstacles recognized						R	
5	12 Mar	046002	278	2	60	12	48	4	100		R	
6	12 Mar	055984	174	1	No obstacles recognized						R	
7	12 Mar	056988	279	1	No obstacles recognized						R	
8	12 Mar	055992	153	11	120	7	40	4	100		R	
9	14 Mar	052994	174	2	No obstacles recognized						R	
10	14 Mar	050996	ND	6	210	6	30	3	100		R	
11	14 Mar	999052	25	8	No obstacles recognized						R	
12	14 Mar	000059	90	1	90	7	7	20	150		R	
13	14 Mar	58006	40	3	205	8	24	2	25		R	
14	14 Mar	055007	120	40	250	14	24	100	200		R	
15	15 Mar	067022	341	1	No obstacles recognized						R	
16	15 Mar	070023	71	1	90	8	6	50	150		R	
17	15 Mar	068021	ND	7	197	5	10	60	150		R	
18	15 Mar	069014	206	12	200	3	18	150	100		R	
19	15 Mar	066016	223	0	220	6	6	50	10		R	
20	15 Mar	061008	275	10	No obstacles recognized						R	
21	15 Mar	057009	130	1	No obstacles recognized						R	
22	15 Mar	068012	80	1	No obstacles recognized						R	
23	15 Mar	069011	52	7	No obstacles recognized						R	
24	15 Mar	069008	207	25	200	3	6	150	50		R	
25	15 Mar	064013	310	15	90	6	6	19	80		R	
26	16 Mar	094014	21	2	No obstacles recognized						R	
27	18 Mar	058978	40	1	90	5	5	30	20		R	
28	18 Mar	072011	275	1	90	10	10	10	150		R	
29	18 Mar	074010	278	6	200	10	40	10	150		R	
30	18 Mar	079022	90	1	250	15	22	2	200		R	
31	18 Mar	044985	270	1	90	4	4	15	35		R	
32	18 Mar	041982	90	2	210	7	36	3	150		R	
33	18 Mar	040984	ND	3	235	10	48	4	150		R	
34	19 Mar	095015	ND	2	90	24	24	2	100		R	
35	19 Mar	081951	66	47	90	8	8	15	60		R	
36	19 Mar	082996	12	6	No obstacles recognized						R	
37	19 Mar	084998	90	1	90	14	14	35	250		R	
38	19 Mar	086001	ND	3	No obstacles recognized						R	
39	19 Mar	083003	90	1	No obstacles recognized						R	
40	19 Mar	089005	90	1	No obstacles recognized						R	
41	19 Mar	087020	41	1	90	26	13	1.1	150		R	
42	19 Mar	088017	ND	1	No obstacles recognized						R	
43	21 Mar	081997	0	1	No obstacles recognized						R	
44	23 Mar	079999	270	1	No obstacles recognized						R	
45	23 Mar	077004	140	1	90	5	5	20	100		R	
46	23 Mar	084012	215	1	90	4	4	100	100		R	
47	23 Mar	091007	45	1	90	8	8	30	150		R	

(Continued)

^aR - random.
 L - linear.

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Table A3 (Concluded)

Sta No.	1973 Date	Grid Coordinates	Azimuth deg	Topographic Slope %	Approach Angle deg	Obstacle		Length ft	Spacing ft	Spacing Type*
						Vertical Magnitude in.	Base Width in.			
PK2										
1	6 Mar	012051	200	4	20	10	36	500	30	L
2	6 Mar	012052	0	1.8	No	obstacles	recognized			R
3	6 Mar	012054	4	11	No	obstacles	recognized			R
4	6 Mar	009059	80		142	66	60	300	50	R
5	6 Mar	011070	270	5.8	90	9	9	40	150	R
6	6 Mar	009075	ND	0.1	No	obstacles	recognized			R
7	6 Mar	009066	265	3.1	45	18	120	19	100	L
8	7 Mar	011053	187	8	90	12	12	25	85	R
9	8 Mar	007061	255	5	225	17	20	250	100	R
10	7 Mar	004052	345	13	90	9	9	50	100	P
11	7 Mar	004057	115	7	225	52	96	100	250	R
12	7 Mar	002050	210	4	260	18	50	150	40	R
13	7 Mar	001050	115	16	30	17	60	5	30	R
14	7 Mar	001064	340	5	225	18	275	30	200	R
15	7 Mar	999065	270	16	90	20	23	2	100	R
16	8 Mar	006060	360	3	210	8	54	100	100	R
17	7 Mar	996059	225	9	40	16	30	25	70	R
18	8 Mar	999070	100	13	90	8	8	2	100	R
19	10 "	982067	97	2	210	5	14	100	150	R
20	9 "	984061	53	24	220	18	24	30	150	R
21	8 Mar	986053	220	9	90	8	8	25	50	R
22	7 Mar	975046	45	11	90	10	7	50	150	R
23	7 Mar	966042	50	8.3	20	6	24	100	200	R
24	8 Mar	971051	308	3	178	4	40	10	50	R
25	8 Mar	967069	150	24	90	7	7	40	100	R
26	11 Mar	004067	0	4	225	16	48	150	200	L
27	8 Mar	972050	0	3	No	obstacles	recognized			R
28	8 Mar	964062	200	11	225	24	24	25	20	R
29	7 Mar	006053	217	15	105	10	10	19	200	R
30	5 Mar	997071	128	8	250	7	20	100	100	L
31	8 Mar	003074	130	8	225	24	36	250	50	R
32	10 Mar	972061	285	7	No	obstacles	recognized			R
33	10 Mar	993065	207	8	90	9	8	40	50	R
34	11 Mar	985064	100	10	220	12	18	30	100	R
35	11 Mar	005070	314	7	210	14	24	150	100	R
36	21 Mar	992067	ND	5	90	10	24	100	250	R
37	22 Mar	970064	175	8	90	12	12	15	50	R
38	22 Mar	967065	200	11	225	24	24	25	20	R

(Concluded)

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Table A4

Summary of Surface Roughness Data for Areal Terrain Sites
Fort Knox, Kentucky

<u>Site No.</u>	<u>Surface Roughness</u> <u>rms, in.</u>	<u>Site No.</u>	<u>Surface Roughness</u> <u>rms, in.</u>
	<u>FK1</u>		<u>FK2</u>
1	0.602	1	0.957
3	1.619	2	1.242
6	1.810	3	3.107
8	1.399	4	1.613
9	1.162	5	2.630
10	1.210	6	1.347
11	1.021	7	3.441
12	1.035	9	3.033
13	2.033	10	2.344
15	0.749	12	4.403
18	1.485	16	2.340
19	1.182	19	1.188
23	0.699	20	3.367
24	0.821	22	1.597
26	1.223	23	1.114
27	0.626	24	1.135
34	0.381	26	1.233
42	1.545	27	1.139
		30	3.078
		31	2.929
		34	2.264
		35	3.050

Table A3
Summary of Vegetation Data for Aerial Terrain Sites
Ft. Knox, Kentucky

Site No.	1973 Date	Grid Coordinates	Avg. Stem Spacing, ft., for Indicated Stem Dis., in. of								Tree Height		Recognition Distances of Target at These Locations, 1 ft. Above Ground				
			3	4.0	4.5	5.0	5.5	6.0	6.5	7.0	Max	Min	1	2	3	4	5
PMA																	
1	12 Mar	039007	10.0	11.2	21.1	23.3	40.3	320.0	320.0	320.0	20	15	60	60	75	50	
2	12 Mar	040909	6.1	7.2	9.4	12.1	23.1	20.3	320.0	320.0	70	40	40	45	40	42	
3	12 Mar	047992	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	1	1	200	200	200	200	
4	12 Mar	046998	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	12	6	35	35	35	35	
5	12 Mar	044002	4.4	9.1	15.0	18.0	23.7	320.0	320.0	320.0	27	20	25	20	30	25	
6	12 Mar	035904	10.6	11.3	14.8	20.9	32.6	72.5	72.5	320.0	25	20	75	65	60	67	
7	17 Mar	056908	18.6	20.1	22.9	29.4	110.0	14.0	320.0	320.0	27	18	90	100	75	88	
8	12 Mar	051992	8.1	8.1	8.9	10.2	13.3	19.4	38.9	38.9	55	40	100	95	105	100	
9	14 Mar	052994	8.3	9.1	13.3	20.7	31.6	54.8	77.5	320.0	30	30	26	65	70	75	
10	14 Mar	050996	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	2	0	160	165	150	158	
11	14 Mar	999032	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	0	0	120	110	100	110	
12	14 Mar	000059	10.3	10.3	11.6	15.3	25.0	30.6	33.5	37.5	90	75	90	100	100	96	
13	14 Mar	058006	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	2	0.5	160	160	80	133	
14	14 Mar	055007	21.6	21.6	22.0	24.0	29.4	31.8	31.8	33.2	90	70	50	20	20	30	
15	15 Mar	067022	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	2	1	60	60	96	72	
16	15 Mar	070023	6.2	7.1	9.7	12.0	16.6	24.5	24.5	26.8	70	50	160	160	160	160	
17	15 Mar	068021	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	8	1	60	10	150	80	
18	15 Mar	069014	5.1	5.9	9.3	10.6	15.8	19.4	19.4	33.6	60	40	110	45	100	102	
19	15 Mar	066016	6.7	6.7	9.3	17.3	21.2	26.8	42.4	60.0	30	26	95	100	90	95	
20	15 Mar	061008	12.5	12.5	15.1	18.4	24.2	25.6	26.5	30.9	95	75	30	40	35	35	
21	15 Mar	057009	7.8	8.6	13.2	23.9	33.7	39.0	47.7	47.7	60	30	35	80	90	68	
22	15 Mar	068012	5.5	7.7	16.5	70.0	320.0	320.0	320.0	320.0	30	20	40	40	40	40	
23	15 Mar	069011	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	30	10	60	80	100	80	
24	15 Mar	069009	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	6	1	100	100	100	100	
25	15 Mar	064013	12.3	12.3	12.3	12.9	14.4	15.6	20.8	28.3	70	60	160	150	150	153	
26	16 Mar	094014	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	2	1	54	160	150	121	
27	18 Mar	058978	7.9	7.9	7.9	10.0	13.5	18.7	32.4	72.5	75	55	60	120	100	93	
28	18 Mar	072011	8.5	8.5	10.5	12.8	15.5	18.1	30.0	30.0	50	45	70	60	80	70	
29	18 Mar	074010	5.9	7.3	11.2	14.5	22.1	28.6	40.4	40.4	50	40	30	60	64	52	
30	18 Mar	079022	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	10	7	10	20	10	13	
31	18 Mar	044985	7.5	8.8	12.3	16.8	16.8	16.8	16.8	16.8	100	90	70	80	70	80	
32	18 Mar	041982	12.5	13.7	16.7	19.6	27.1	45.0	90.0	320.0	30	18	50	60	50	53	
33	18 Mar	040984	11.0	11.5	14.9	23.0	46.0	65.0	320.0	320.0	20	10	40	35	45	40	
34	19 Mar	095015	8.6	9.5	11.8	15.0	17.4	19.5	22.7	24.5	90	70	75	60	140	92	
35	19 Mar	081994	12.1	12.1	14.3	16.1	17.7	19.4	21.8	22.5	100	85	30	35	75	47	
36	19 Mar	082996	4.5	4.5	8.2	15.0	45.0	320.0	320.0	320.0	40	21	25	30	20	25	
37	19 Mar	086998	8.4	8.4	9.8	13.2	17.0	21.1	28.6	31.1	90	70	50	75	100	75	
38	19 Mar	086001	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	25	6	10	15	30	18	
39	19 Mar	083003	5.0	5.7	11.4	21.2	320.0	320.0	320.0	320.0	30	18	50	60	40	50	
40	19 Mar	089005	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	1	1	60	45	160	88	
41	19 Mar	087020	8.7	12.7	14.4	15.8	18.1	19.5	20.6	21.9	90	70	150	160	140	150	
42	19 Mar	088017	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	1	1	80	160	160	133	
43	23 Mar	081997	5.2	6.2	9.1	14.3	320.0	320.0	320.0	320.0	45	30	40	45	35	40	
44	23 Mar	079999	8.0	9.5	13.9	18.0	20.6	28.5	31.8	31.8	90	60	75	85	70	77	
45	23 Mar	077004	9.0	10.5	15.9	18.8	22.5	25.0	25.0	25.0	80	65	150	160	145	152	
46	23 Mar	084012	10.3	11.9	14.4	19.6	23.2	30.0	34.0	34.7	90	75	125	90	120	116	
47	23 Mar	091007	11.8	11.8	13.9	16.4	20.6	31.8	40.2	45.0	70	60	150	160	155	155	

(Cont. (nued))

1 of 2 Sheets

Table A5 (Continued)

Site No.	1973 Date	Grid Coordinates	Avg. Stem Spacing, ft. for Indicated Stem Dia., in. of							Tree Heights		Recognition Distances of Target at Three Locations, 1 ft. Above Ground				Avg.
			0	>1.0	>2.4	>3.0	>3.5	>7.0	>8.7	>9.8	Max	Mean	1	2	3	
PK2																
1	6 Mar	012051	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	65	60	100	56	75	77
2	6 Mar	012052	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	96	8	44	75	65	61
3	6 Mar	012054	8.1	8.5	14.6	17.3	42.4	320.0	320.0	320.0	75	42	90	90	95	92
4	6 Mar	009059	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	0	0	200	200	200	200
5	6 Mar	011870	22.5	22.5	27.5	27.5	27.5	29.4	29.4	30.5	90	72	80	100	175	118
6	6 Mar	009075	5.6	5.6	8.0	10.9	15.9	31.8	320.0	320.0	70	60	57	64	60	61
7	6 Mar	009066	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	0	0	39	110	150	100
8	7 Mar	011053	9.4	12.0	17.6	24.6	28.4	38.9	41.6	41.6	81	72	60	135		98
9	8 Mar	007061	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	40	10	21	25	23	23
10	7 Mar	004052	11.8	12.7	17.4	22.7	25.6	30.1	32.1	34.7	95	85	120	90	150	130
11	7 Mar	004057	5.0	6.6	9.0	13.9	18.9	22.4	25.0	25.0	60	60	75	100	85	87
12	7 Mar	002050	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	0	0	160	38	38	79
13	7 Mar	001050	14.9	14.9	15.3	16.8	17.4	18.0	19.6	21.7	78	78	160	100	120	127
14	7 Mar	001064	15.0	15.4	16.2	20.1	25.0	30.0	30.0	31.8	75	60	100	145	150	132
15	7 Mar	009065	11.8	12.1	15.9	17.7	19.6	21.2	22.5	25.0	90	81	115	110	120	115
16	8 Mar	006060	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	0	0	30	24	30	28
17	7 Mar	006059	8.0	8.4	10.6	14.5	18.7	29.6	36.2	36.2	60	52	100	100	114	105
18	8 Mar	009070	9.7	10.7	15.4	18.8	20.6	22.5	25.0	27.1	65	51	180	160	50	130
19	10 Mar	002067	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	8	3	100	63	40	68
20	9 Mar	004061	7.4	8.7	11.6	12.5	5.0	15.0	15.0	15.9	45	45	65	23	25	30
21	8 Mar	006053	5.0	5.6	6.9	7.2	7.5	9.9	11.9	16.8	50	42	125	125	100	117
22	7 Mar	007066	11.8	12.5	14.1	14.6	15.0	15.0	16.0	17.3	84	75	75	135	180	130
23	7 Mar	006062	12.5	13.2	16.2	17.7	19.8	24.7	26.2	29.1	75	40	60	130	100	97
24	8 Mar	007051	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	50	5	115	110	100	100
25	8 Mar	007009	10.1	13.0	20.5	23.7	25.4	26.3	26.3	26.3	40	25	44	80	40	55
26	11 Mar	004067	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	15	3	30	35	30	32
27	8 Mar	007050	7.6	9.6	13.3	15.9	27.5	320.0	320.0	320.0	45	25	50	42	30	41
28	8 Mar	004062	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	1	1	75	90	90	85
29	7 Mar	006055	10.3	10.7	12.5	14.2	18.2	21.7	21.7	26.5	60	54	160	155	160	150
30	8 Mar	007071	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	30	8	51	40	30	40
31	8 Mar	003074	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	10	5	150	120	30	100
32	10 Mar	007061	4.5	5.2	8.4	13.4	22.5	320.0	320.0	320.0	45	30	45	50	30	42
33	10 Mar	003065	9.4	10.5	15.0	16.4	19.0	20.6	21.9	24.5	65	52	100	75	75	83
34	11 Mar	005064	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	30	2	60	50	110	75
35	11 Mar	005070	320.0	320.0	320.0	320.0	320.0	320.0	320.0	320.0	18	2	40	30	45	38
36	21 Mar	002067	4.8	4.8	6.6	14.1	320.0	320.0	320.0	320.0	20	15	8	10	8	9
37	22 Mar	007064	7.6	8.9	16.2	20.4	21.7	24.6	24.6	24.6	80	60	50	70	80	67
38	22 Mar	007065	3.9	4.2	6.3	6.9	8.3	10.0	12.2	15.0	65	50	75	75	60	70

(Continued)

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Table A6
Summary of Terrain Data for Linear Terrain Sites
Ft. Knox, Kentucky

Site No.	1973 Date	Grid Co-ordinates	Average Cone Index						RI		RCI		Shearograph*						Profile Azimuth deg	Left AA deg	
			0-2	3 6 9 12				0-6	6-12	0-6	6-12	R/S		Wet R/S		Vane					
				C	φ	C	φ					C	φ	C	φ						
FK1																					
1	12 Mar	052991	42	128	154	205	190	109	183	.73	-	79	-	0.5	11.0	0.7	9.0	1.7	6.0	43	200.0
2	14 Mar	056008	39	77	82	85	82	46	83	.66	-	44	-	2.0	17.5	1.3	17.5	3.4	25.0	0	190.0
3	15 Mar	061008	25	104	146	178	188	92	171	.49	-	45	-	0.8	27.3	0.4	22.8	2.6	31.4	183	203.0
4	15 Mar	059008	32	71	88	102	131	64	107	.77	-	49	-	1.6	13.0	0.3	12.5	4.7	14.0	324	225.0
5	15 Mar	079009	55	61	96	128	137	71	120	.59	-	42	-							180	215.0
6	18 Mar	058977	20	73	106	112	122	66	113	.76	-	50	-							150	195.0
7	18 Mar	071011	37	61	83	98	106	60	96	.76	-	46	-							265	196.0
8	19 Mar	094019	51	142	160	176	192	118	176	.47	-	55	-							270	235.0
9	19 Mar	087022	61	155	182	212	237	133	210	.47	-	63	-							50	204.0
10	18 Mar	057977	20	73	106	112	122	66	113	.76	-	50	-							230	212.0
11	19 Mar	085022	32	78	89	115	137	66	114	.47	-	31	-							210	206.0
12	19 Mar	080019	36	110	131	171	202	92	168	.47	-	43	-							260	218.0
FK2																					
1	6 Mar	012855	42	147	300	300	300	163	300	.58	-	95	-							255	249.0
2	6 Mar	011856	123	300	300	300	300	241	300	.58	-	140	-							125	190.0
3	6 Mar	012866	23	90	212	300	300	108	271	.58	-	63	-							273	230.0
4	6 Mar	012847	30	109	174	233	190	104	236	.58	-	60	-							187	190.0
5	10 Mar	974868	54	72	72	108	153	66	114	.44	.56	29	64	1.5	15.0	1.2	10.0	1.8	8.0	61	195.0
6	8 Mar	006865	17	29	41	45	57	29	48	.45	.73	13	35							225	190.0
7	11 Mar	984862	31	61	72	112	151	55	112	.57	-	31	-							59	235.0
8	12 Mar	979866	42	159	300	300	300	167	300	.43	-	72	-							220	216.0
9	10 Mar	986866	17	38	104	179	300	53	194	.43	-	23	-	0.4	5.0	-	-	1.2	16.0	181	198.0
10	9 Mar	982858	24	73	106	126	128	68	120	.58	-	39	-							210	230.0
11	11 Mar	979846	20	57	104	98	140	60	114	.42	-	25	-							108	193.0
12	9 Mar	978859	55	80	110	170	218	82	166	.58	-	48	-	0.6	25.0	1.4	2.5	1.0	28.0	310	230.0
13	10 Mar	976858	34	142	300	300	300	159	300	.58	-	92	-	1.5	10.0	1.5	13.0	1.1	15.5	310	195.0
14	10 Mar	976841	55	80	110	170	218	82	166	.58	-	48	-							45	237.0
15	10 Mar	979853	18	44	58	58	40	58		.45	-	17	-							41	196.0
16	8 Mar	973848	34	62	112	192	226	69	177	.42	-	29	-							130	201.0
17	8 Mar	003873	20	114	192	300	300	109	264	.58	-	63	-							310	197.0
18	7 Mar	998865	43	76	99	126	122	73	116	.42	-	31	-							140	235.0
19	21 Mar	008869	44	192	300	300	300	179	300	.58	.66	104	198							245	214.5
20	21 Mar	007869	24	238	258	250	264	173	257	.58	.66	100	170							180	221.0
21	21 Mar	006848	24	238	258	250	264	173	257	.58	.66	100	170							190	210.5
22	21 Mar		70	248	268	266	271	187	268	.58	.66	113	177							170	234.5

*R/S - rubber to soil.
c - cohesion, psi.
φ - angle of internal friction, deg.
vane - metal to soil.
**Depth below surface, in.
+Soil layer, in.

A

Table A6

Summary of Terrain Data for Linear Terrain Sites
Fl. Knox, Kentucky.

Stn	Shearograph								Profile Azimuth deg	Left AA deg	Delta BH ft	Right AA deg	Low BH ft	BK or TK ft	Water Depth ft	Water Velocity ft/sec	Remarks	
	RCL		R/S		Wet R/S		Vane											
	0-6	6-12	C	I	C	I	C	I										
PK1																		
79	-	-	0.5	11.7	0.7	9.0	1.7	6.0	43	208.0	0.1	204.8	4.10	6.00	0.10	0.1	RI from Areal Site 3.	
46	-	-	2.0	17	1.3	17.5	1.4	25.0	0	198.5	0.6	200.5	1.40	0.25	2.00	2.0		
45	-	-	0.8	2	0.4	22.8	2.6	11.4	183	203.0	1.0	211.0	6.00	2.00	0.00	0.0	Soils data from Areal Site 20.	
49	-	-	1.6	11.0	0.3	12.5	5.7	14.0	324	225.0	3.0	209.8	0.50	1.00	0.17	0.2		
42	-	-	-	-	-	-	-	-	180	215.0	1.0	220.0	3.00	4.00	0.00	0.0	Soils data from Areal Site 45.	
50	-	-	-	-	-	-	-	-	150	195.0	22.0	193.0	48.00	30.00	0.00	6.0	Soils data from Areal Site 27.	
46	-	-	-	-	-	-	-	-	265	196.0	0.5	195.0	19.50	22.00	15.00	6.0	Soils data from Areal Site 27.	
55	-	-	-	-	-	-	-	-	270	235.0	0.1	231.0	4.20	2.00	0.50	0.1	CI from Areal Site 34. RI from Areal Site 18.	
61	-	-	-	-	-	-	-	-	50	206.0	0.5	200.7	9.00	4.00	0.20	0.1	RI from Areal Site 41.	
50	-	-	-	-	-	-	-	-	230	212.0	0.5	217.0	8.00	2.00	2.50	0.1	Soils data from Areal Site 27.	
31	-	-	-	-	-	-	-	-	210	204.0	0.0	202.0	1.20	1.70	0.10	0.1	RI from Areal Site 41.	
43	-	-	-	-	-	-	-	-	260	218.0	1.0	210.0	2.00	2.50	0.30	0.1	RI from Areal Site 41.	
PK2																		
95	-	-	-	-	-	-	-	-	255	249.0	0.2	245.0	1.25	1.90	0.00	0.0	RI from Areal Site 6.	
140	-	-	-	-	-	-	-	-	215	198.0	0.1	205.0	1.05	12.00	0.00	0.0		
63	-	-	-	-	-	-	-	-	273	238.0	1.9	209.0	1.90	6.00	0.00	0.0	RI from Areal Site 6.	
60	-	-	-	-	-	-	-	-	187	190.0	5.5	186.0	0.60	5.00	0.30	0.2	RI from Areal Site 6.	
29	64	1.5	1.0	1.2	10.0	1.8	8.0	81	195.0	0.2	250.0	6.70	62.00	0.50	0.5			
13	35	-	-	-	-	-	-	225	198.0	1.3	210.0	1.40	12.00	0.50	1.5			
31	-	-	-	-	-	-	-	5	235.0	1.0	189.0	2.00	14.00	1.00	1.0			
72	-	-	-	-	-	-	-	220	216.0	0.1	195.0	2.70	20.00	1.00	6.0	RI from Linear Site 9.		
23	-	0.4	5.0	-	-	1.2	16.0	181	198.0	0.4	188.0	1.20	9.00	0.80	1.7			
39	-	-	-	-	-	-	-	210	190.0	0.6	225.0	1.90	4.00	0.30	0.6			
25	-	-	-	-	-	-	-	108	192.0	1.0	226.0	4.40	45.00	1.50	5.0			
48	-	0.6	25.0	1.4	2.5	1.0	28.0	310	238.0	0.0	238.0	5.30	30.00	0.90	3.7	RI from Linear Site 10.		
92	-	1.5	10.0	1.5	11.0	1.1	15.5	310	195.0	0.5	197.0	2.90	12.00	1.50	3.0	RI from Linear Site 10.		
48	-	-	-	-	-	-	-	45	237.5	10.0	206.0	6.50	17.00	1.50	4.5	CI from Linear Site 12. RI from Linear Site 10.		
17	-	-	-	-	-	-	-	41	196.0	1.0	215.0	1.00	5.00	0.50	0.6			
29	-	-	-	-	-	-	-	130	201.0	4.4	207.0	3.30	19.00	0.50	4.9	RI from Areal Site 22.		
61	-	-	-	-	-	-	-	310	197.0	0.2	225.0	2.00	10.00	0.10	4.3	RI from areal Site 6.		
31	-	-	-	-	-	-	-	140	233.0	0.0	211.0	1.70	6.00	2.00	1.5	RI from Areal Site 22.		
104	198	-	-	-	-	-	-	245	214.5	1.1	211.5	4.20	9.00	0.00	0.0	Soils data from Areal Site 5.		
100	170	-	-	-	-	-	-	180	221.0	0.0	208.0	2.30	14.00	0.00	0.0	Soils data from Areal Site 26.		
100	170	-	-	-	-	-	-	190	210.5	0.1	201.0	2.70	2.00	0.00	0.0	Soils data from Areal Site 26.		
113	177	-	-	-	-	-	-	170	234.5	1.0	224.0	2.00	2.00	0.00	0.0			

B

Table A7

Supplementary Soils Data Summary, Linear Terrain Sites
Ft. Knox, Kentucky

Site No.	1973 Date	Grid Coordinates	Dry Density, lb/ft ³		FK1	Moisture Content, %			Soil Classification			
			0-6			0-1/4	0-6	6-12	USCS, 0-6 in.			Soil Type
			in.	in.					Atterberg Limits			
									LL %	PL %	PI %	
1	12 Mar	052991				41.2			42.0	26.2	15.8	CL
2	14 Mar	056008	83.1			46.2	34.6		-	-	-	-
3	15 Mar	061008	75.9			62.9	40.7		-	-	-	CL*
4	15 Mar	059008	90.4			77.1	30.4		-	-	-	-
5	15 Mar	079009	87.0				32.9		-	-	-	-
6	18 Mar	058977	87.6				34.0		-	-	-	CL*
7	18 Mar	071011	86.0				34.4		-	-	-	CL*
8	19 Mar	094019	88.8			70.6	29.6		-	-	-	-
9	19 Mar	087022	91.1				28.1		-	-	-	-
10	18 Mar	057977	86.0				34.4		-	-	-	-
11	19 Mar	085022	91.1				28.1		-	-	-	-
12	19 Mar	080019	91.1				28.1		-	-	-	ML*
FK2												
1	6 Mar	012855					26.3		-	-	-	-
2	6 Mar	011856	84.4	95.9			28.8		-	-	-	-
3	6 Mar	012866	97.3				21.9		-	-	-	-
4	6 Mar	012867	92.9				25.7	-	-	-	-	-
5	10 Mar	974868				21.2	27.0		-	-	-	ML*
6	8 Mar	006865	89.4	94.8		20.1	28.5	24.9	33.3	19.0	14.3	CL
7	11 Mar	984862	91.4			30.2	28.4		-	-	-	-
8	12 Mar	979866					26.3		-	-	-	-
9	10 Mar	986866	91.1			41.5	24.5		-	-	-	-
10	9 Mar	982858	87.8				27.7		-	-	-	-
11	11 Mar	979846	91.9			27.0	25.6		-	-	-	-
12	9 Mar	978859	93.2			44.6	24.8		-	-	-	-
13	10 Mar	976858	93.2			38.3	24.8		-	-	-	-
14	10 Mar	976861					18.7		-	-	-	-
15	10 Mar	979853	91.7				28.6		-	-	-	-
16	8 Mar	973848					27.4		-	-	-	-
17	8 Mar	003873					22.3		-	-	-	-
18	7 Mar	998865	78.5				45.8		31.1	24.0	7.1	ML
19	21 Mar	008869					31.8		-	-	-	-
20	21 Mar	007869	107.5			32.2	24.6		-	-	-	-
21	21 Mar	006868	107.5			32.2	24.6		-	-	-	-
22	21 Mar	004872	-			-	-		-	-	-	-

*Field classification.

Table A8

Terrain Factor Class Ranges Used to Describe Areal Terrains

Terrain Factors	Class Numbers													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Surface Type	Fine-Grained Soil	Coarse-Grained Soil	Muskeg											
Surface Strength (CI or RCI)	>280	221-280	161-220	101-160	61-100	41-60	33-40	26-32	17-25	11-16	0-10	13-25	7-12	0-6
Slope (Z)	0-2	2.1-5	5.1-10	10.1-20	20.1-60	40.1-60	60.1-70	>70						
Obstacle Approach Angle (deg)	178.6-180	180-181.5	175.6-178.5	181.5-184.5	170.1-175.5	184.5-190	158.1-170	190.1-202	149.1-158	202.1-211	135.1-149	211.1-225	90.0-135	226-270
Obstacle Vertical Magnitude (in.)	0-6	6.1-10	10.1-14	14.1-18.0	18.1-23.6	23.7-33.5	>33.5							
Obstacle Base Width (in.)	>47	36.1-47	24.1-24	12.1-24	0-12									
Obstacle Length (ft)	0-1	1.1-3.3	3.4-6.6	6.7-10.0	10.1-19.9	20.0-492	>492							
Obstacle Spacing (ft)	>197.0	65.7-197.0	36.4-65.6	26.5-36.3	18.3-26.4	13.4-18.2	8.3-13.3	0-8.2						
Obstacle Spacing Type	Random	Linear												
Surface Roughness	0-0.4	0.5-1.5	2.6-3.5	3.6-4.5	4.6-5.5	5.6-6.5	6.6-7.5	>7.6						
Stem Diameter (in.)	>0.1	>1.0	>2.4	>3.9	5.5	7.0	8.7	9.8						
Stem Spacing (ft)	>328	65.6-328	36.4-65.5	26.5-36.3	18.3-26.4	13.4-18.2	8.3-13.3	0-8.2						
Visibility (ft)	>164	79.0-164	39.6-78.9	29.8-39.5	20.0-29.7	15.1-19.9	10.1-15.0	5.1-10.0	0-5.0					

Table A9
Terrorain Factor Class Ranges Used to Describe Linear Terraines

Class Numbers																						
Terrain Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
Surface Type	Fine-Grained Soil	Coarse-Grained Soil	Mus-bog																			
Surface Strength (CI or RCI)	>280	221-280	161-220	101-160	61-100	41-60	33-40	26-32	17-25	11-16	0-10											
Left Approach Angle (deg)	175-180	180.1-185	170.1-175	185.1-190	160.1-170	190.1-200	150.1-160	200.1-210	140.1-150	210.1-220	125.1-140	220.1-235	110.1-125	235.1-250	100.1-110	250.1-260	95.1-100	260.1-265	90-95	265.1-270	MA	
Differential Bank Height* or Differential Vertical Magnitude (ft)	0	0.1-3.3	3.4-6.6	6.7-13.1	>13.1	0.1-3.3	3.4-6.6	6.7-13.1	>13.1													
Right Approach Angle (deg)	175-180	180.1-185	170.1-175	185.1-190	160.1-170	190.1-200	150.1-160	200.1-210	140.1-150	210.1-220	125.1-140	220.1-235	110.1-125	235.1-250	100.1-110	250.1-260	95.1-100	260.1-265	90-95	265.1-270		
Low Bank Height or Least Vertical Magnitude (ft)	0-1.6	1.7-3.3	3.4-6.6	6.7-9.8	9.9-13.1	13.2-16.4	16.5-19.7	>19.7														
Base Width or Top Width (ft)	NA	0	0.1-9.8	9.9-19.7	19.8-29.5	29.6-39.4	39.5-49.2	49.3-59.0	59.1-68.9	69.0-78.8	78.9-88.6	88.7-98.4	98.5-114.8	114.9-131.2	131.3-147.6	147.7-164.0	164.1-180.4	180.5-196.8	196.9-213.2	213.3-229.6	>229.6	
Water Depth (ft)	NA	0	0.1-3.3	3.4-6.6	6.7-11.4	>11.4																
Water Velocity (fps)	NA	0	0.1-3.3	3.4-6.6	6.7-11.4	>11.4																

* Classes 2-5 occur when left bank is higher than right bank; classes 6-9 occur when right bank is higher than left bank.

Legend for Areal Terrain Map Units for FRI

2405 0401

[illegible]

NOTE: Soil strengths shown on this table for dry and average strength are not valid since only wet season condition was mapped.

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PAGE 0002

(Continued)

Table A10 (Concluded)

USER ID F728

FILE - MN021

PAGE 0003

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 172 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 173 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 174 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 175 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 176 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 177 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 178 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
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 180 1. 0. 0. 0.1. 1.1.1.1.1.1.0.0.0.0.1.1.1.1.3.
 181 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.

182 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
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 185 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
 186 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
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 188 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
 189 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
 190 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
 191 1. 0. 0. 0.2. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.
 192 1.10.10.10.1. 1.1.1.1.1.1.1.1.1.1.1.1.1.1.2.

Legend for Areal Terrain Map Units for FV2

Page 1101

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1 of 3 sheets

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2 of 3 sheets

Page 0045

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USER ID F727

INXMI7 - 2712

PAGE 0001

LINEAR TERRAIN UNITS

<<<<<< FACTOR COMPLEX >>>>>>

<<<<<< FACTOR COMPLEX >>>>>>

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NOTE: Soil strengths shown on this table for dry and average strengths are not valid as only wet season condition was mapped.

Lograd for Linear Terrain Units for PK2

USE 10 1727

5145 - 5713

100 5972

SLIM MIVBBI EV3417

<<<<<<< FACTOR COMPLEX >>>>>>>

)))) FACTOR COMPLEX))))

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NOTE: Soil strengths shown on this table for dry and average strengths are not valid since only wet season condition was mapped.

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6 of 13 Sheets

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This image is a high-resolution, abstract pattern composed of numerous small, black and white dots and lines. The pattern is dense and irregular, filling the entire frame. It resembles a high-resolution scan of a textured surface, a complex digital data visualization, or a stylized representation of a natural phenomenon like a forest canopy or a star field. The overall effect is one of intense detail and complexity, with no discernible text or recognizable objects.

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Table A13

Legend for West German Linear Terrain Units

10000 10 23000 FILE - 00000 0000-0000

LINEAR TERRAIN UNITS

<<<<<<< FACTOR COMPLEX >>>>>>>

<<<<<<< FACTOR COMPLEX >>>>>>>

UNIT	MAP	SURF	DRY	AVG	WET	APPROACH	RELEVANCE	STRENGTH	VELOCITY	GRADIENT	VELOCITY
1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15	15	15	15	15
16	16	16	16	16	16	16	16	16	16	16	16
17	17	17	17	17	17	17	17	17	17	17	17
18	18	18	18	18	18	18	18	18	18	18	18
19	19	19	19	19	19	19	19	19	19	19	19
20	20	20	20	20	20	20	20	20	20	20	20
21	21	21	21	21	21	21	21	21	21	21	21
22	22	22	22	22	22	22	22	22	22	22	22
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Table A15 (Continued)

WATER 12 FMAA FILE - WAGES PAGE 0003

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Table A15 (Continued)

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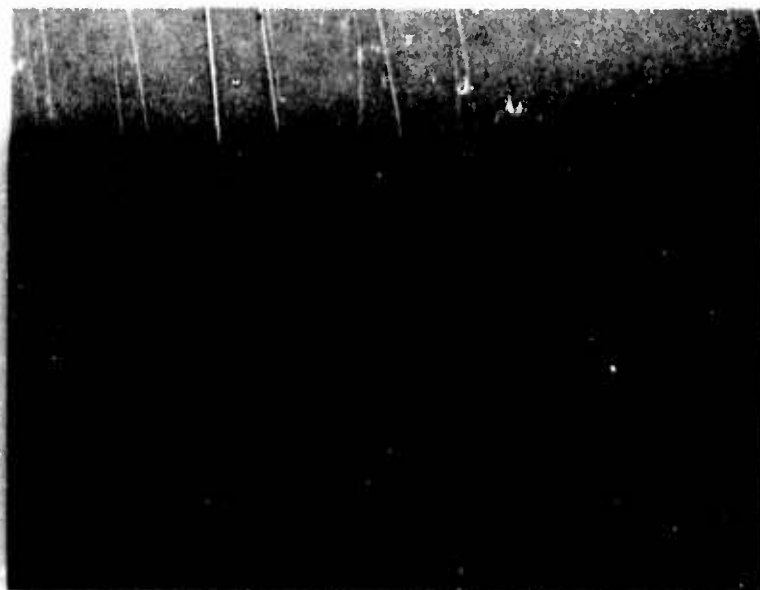
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Photograph A1. Small diameter hardwood trees
in FKI Areal Terrain Unit 60



Photograph A2. Hardwood trees with scattered
logs in FKI Areal Terrain Unit 122



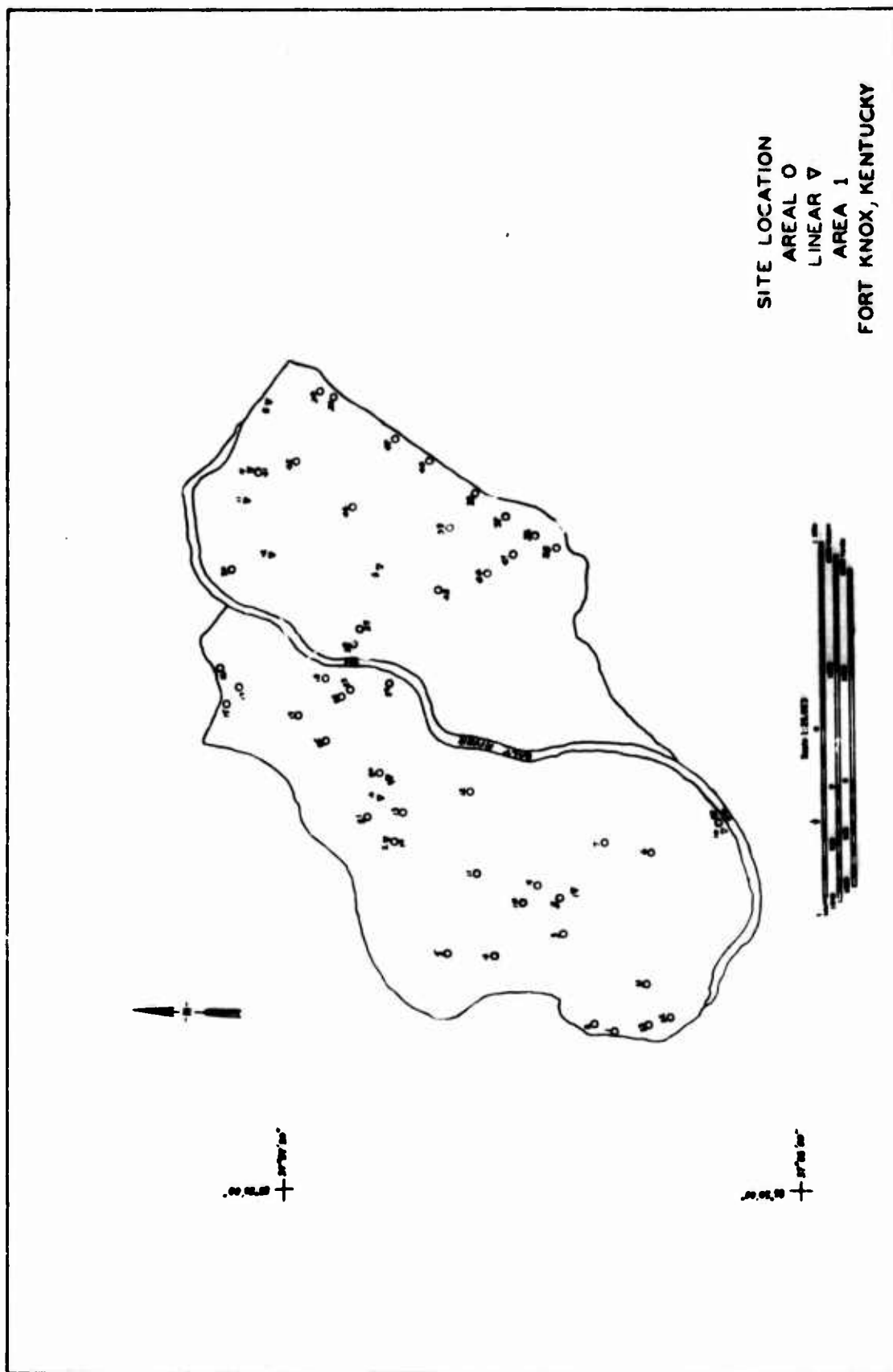
Photograph A3. Open grassland in FKL Areal
Terrain Unit 192

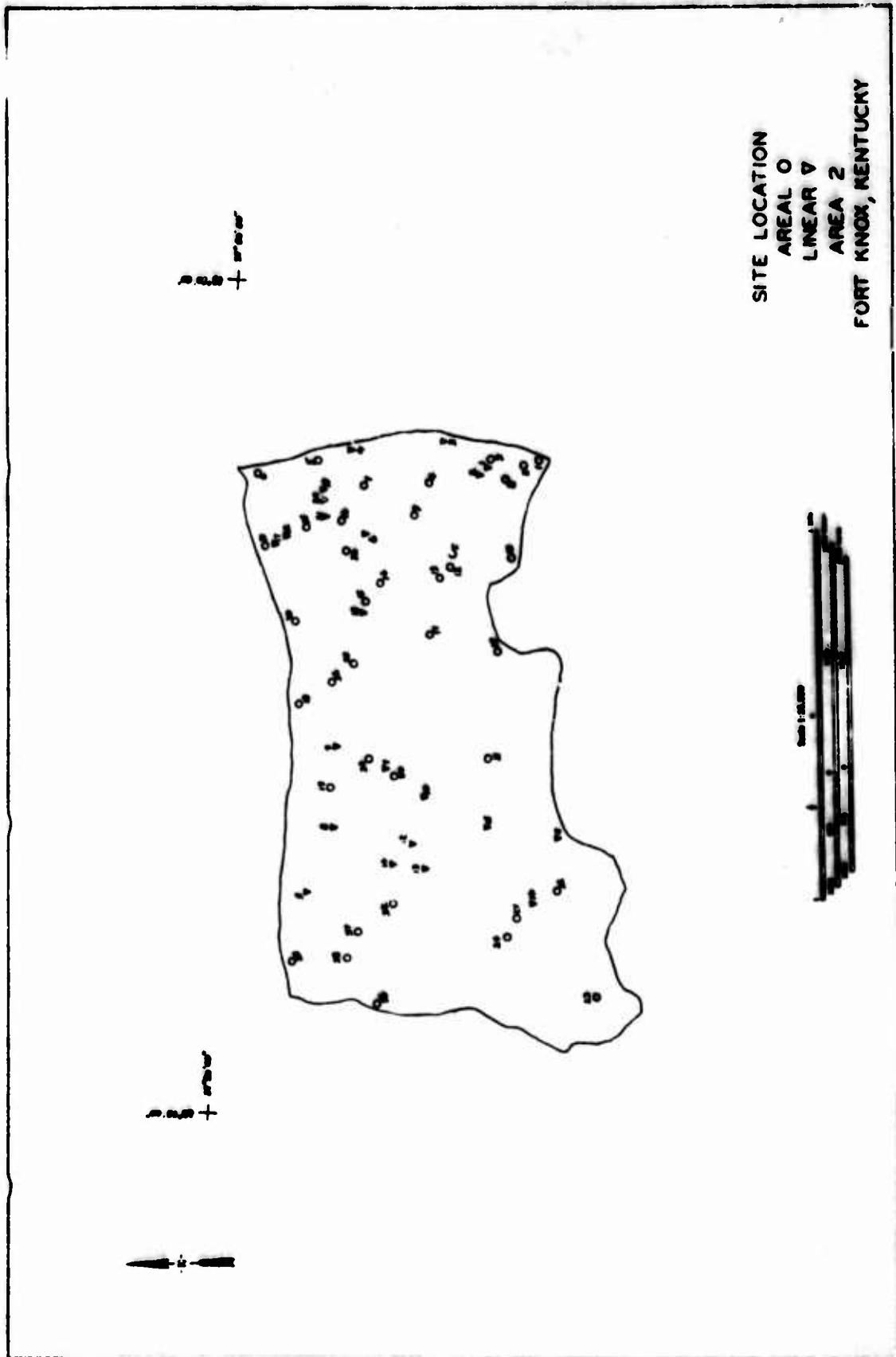


Photograph A4. Small drainage ditch at upper end
of Hudic Lake in FKL, Linear Terrain Unit 11



Photograph A5. Salt River in Fkl Linear
Terrain Unit 6





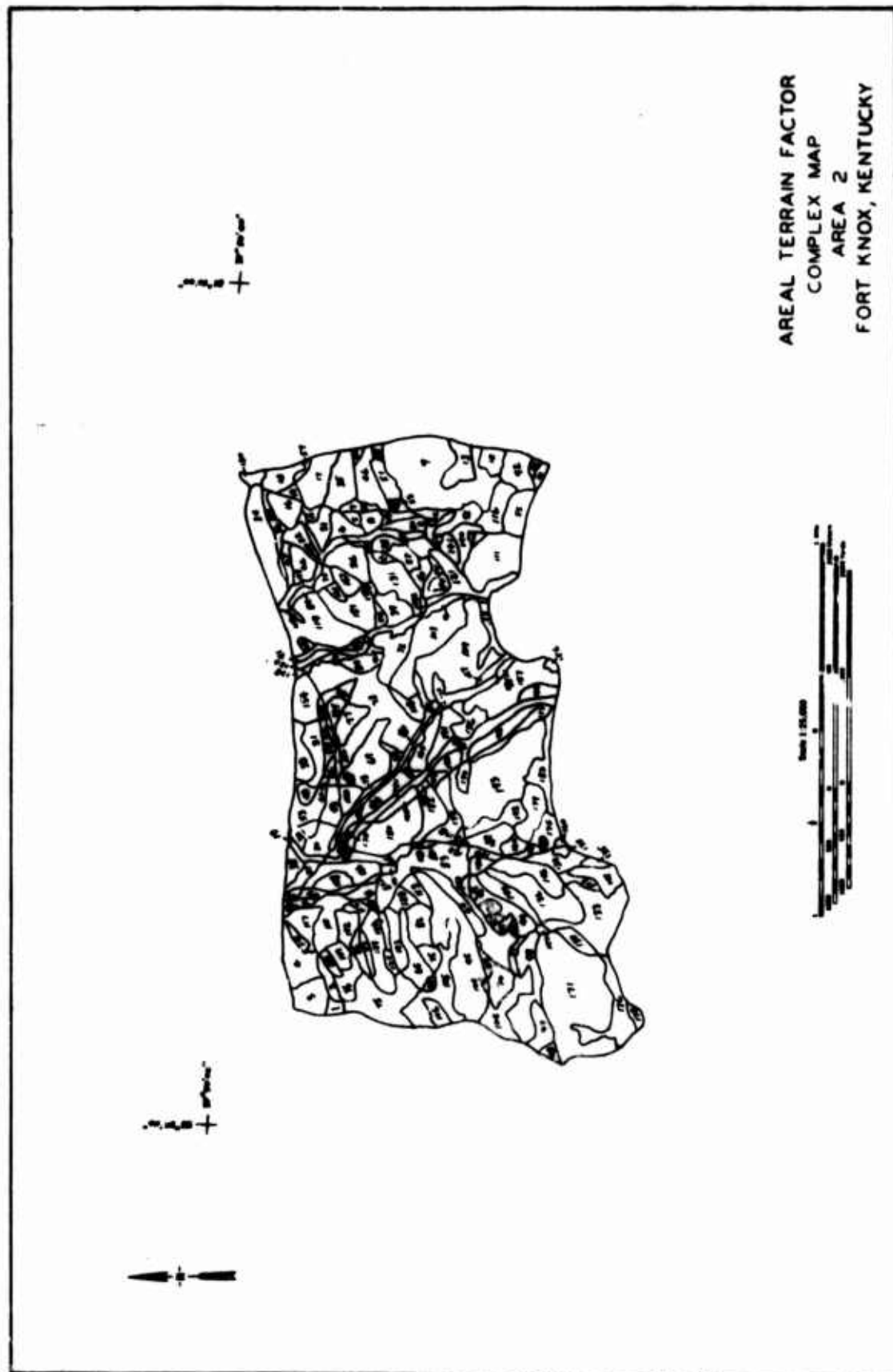
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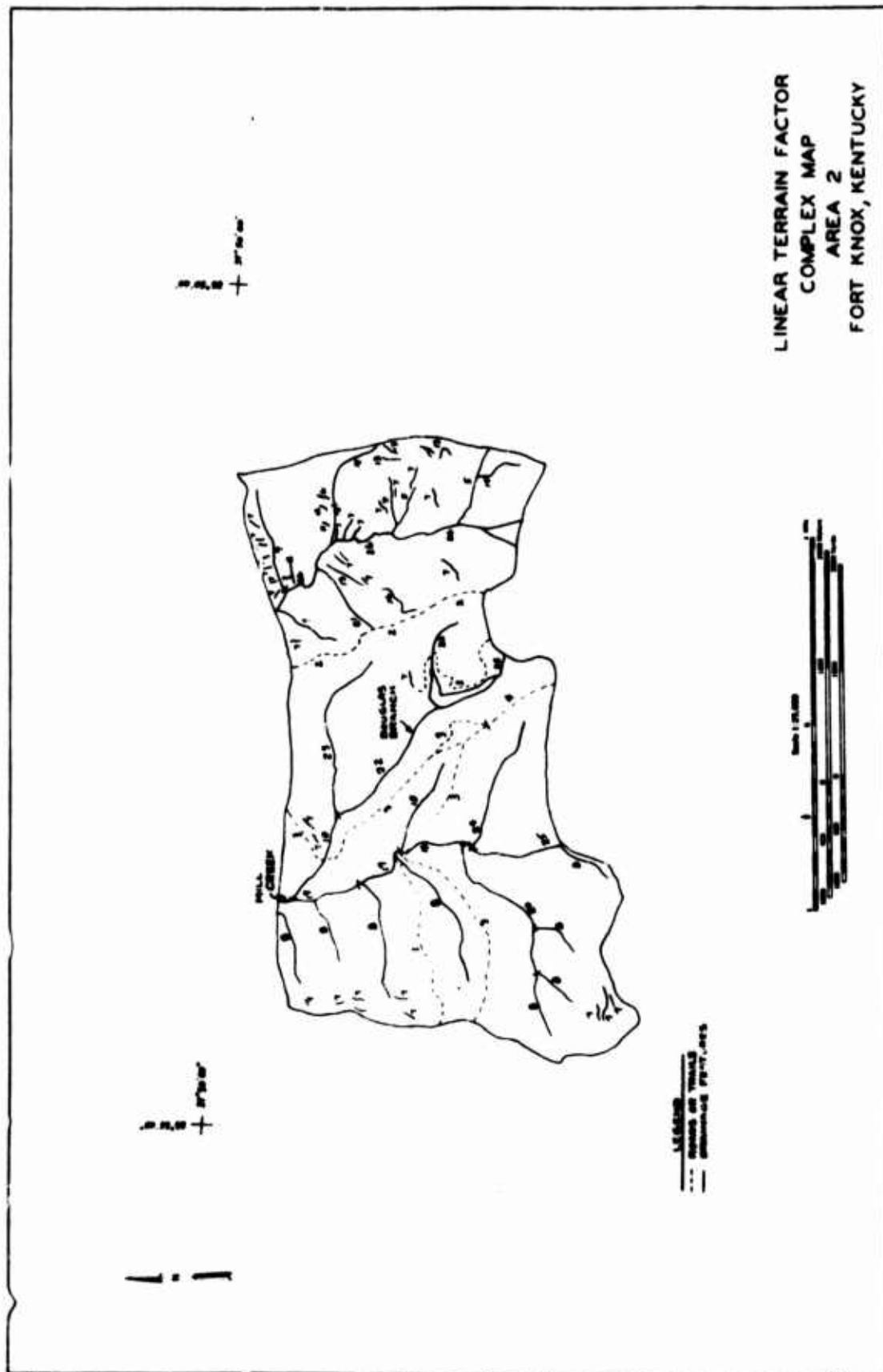


AREAL TERRAIN FACTOR
COMPLEX MAP
AREA 1
FORT KNOX, KENTUCKY

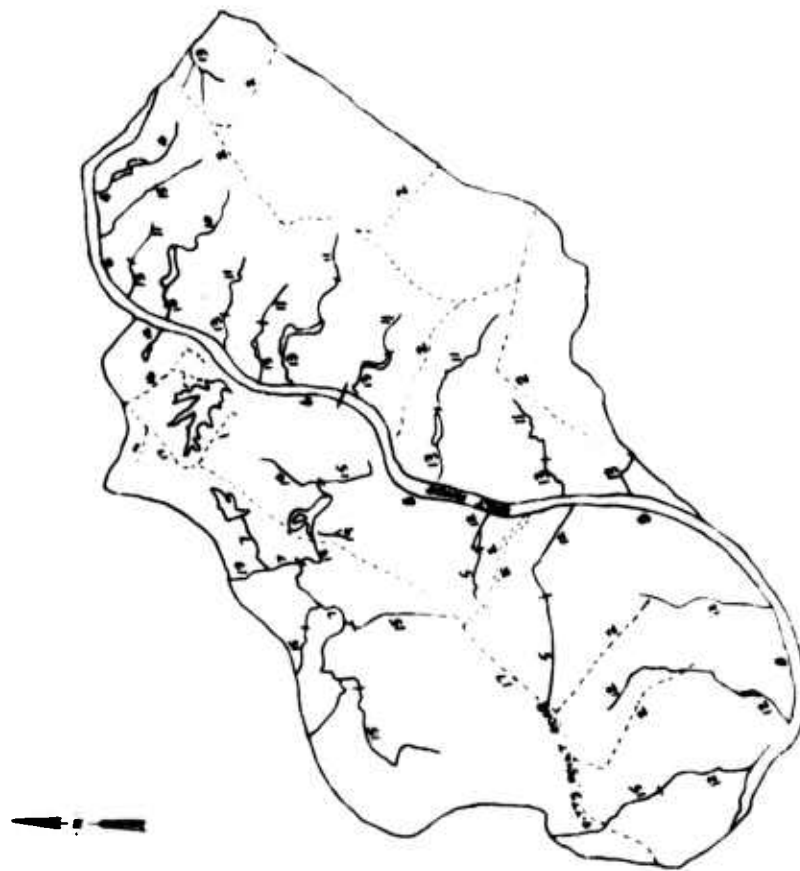


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LINEAR TERRAIN FACTOR
COMPLEX MAP
AREA 1
FORT KNOX, KENTUCKY



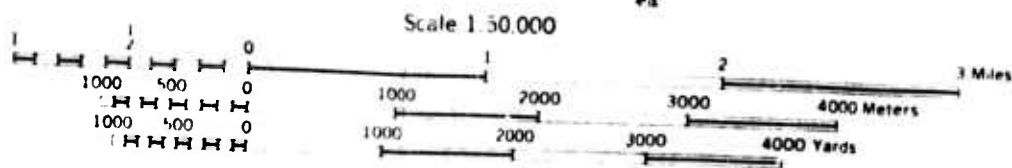
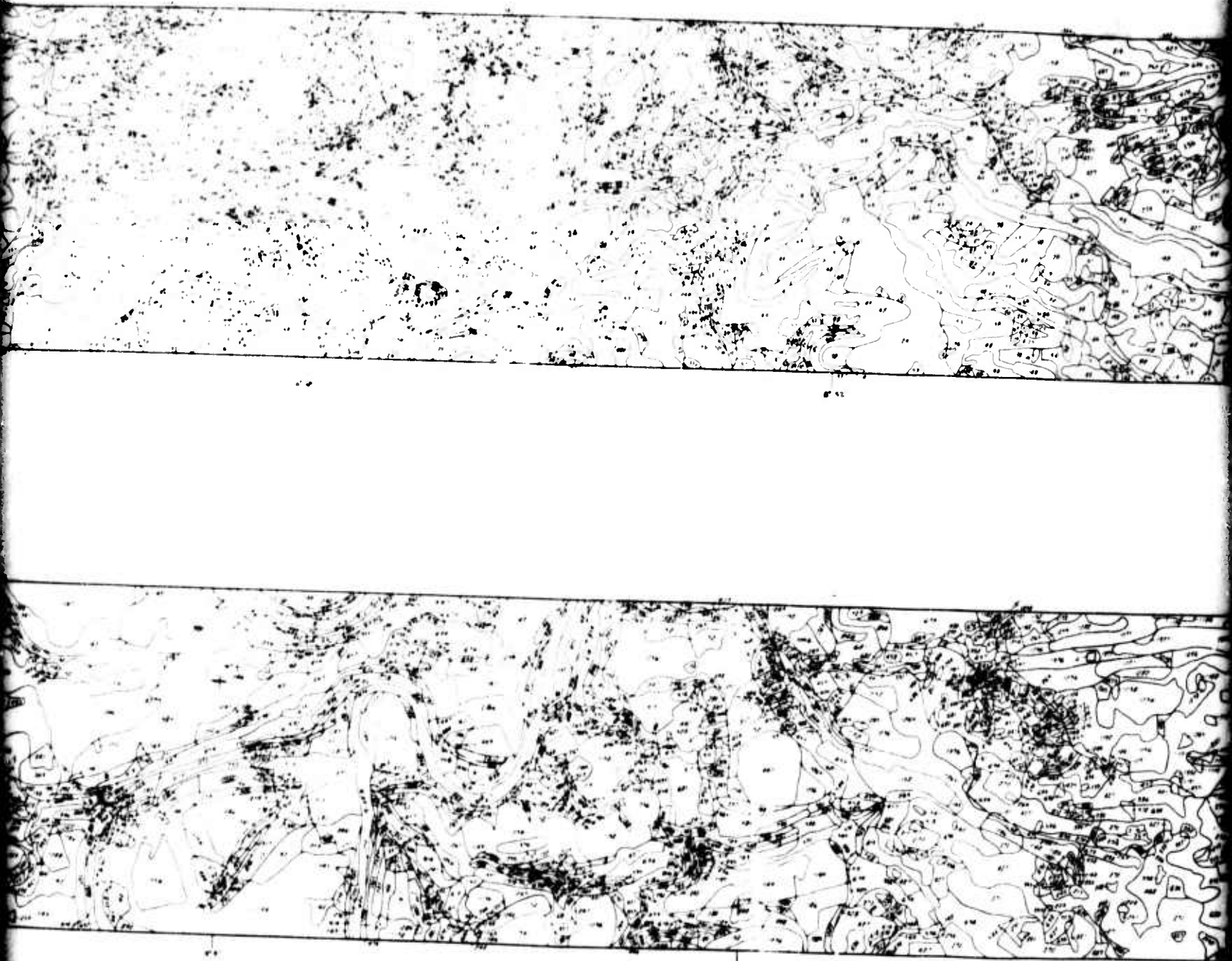
LEGEND
--- ROADS OR TRAILS
--- TERRAIN FEATURES

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0 1/2 1 1 1/2 2

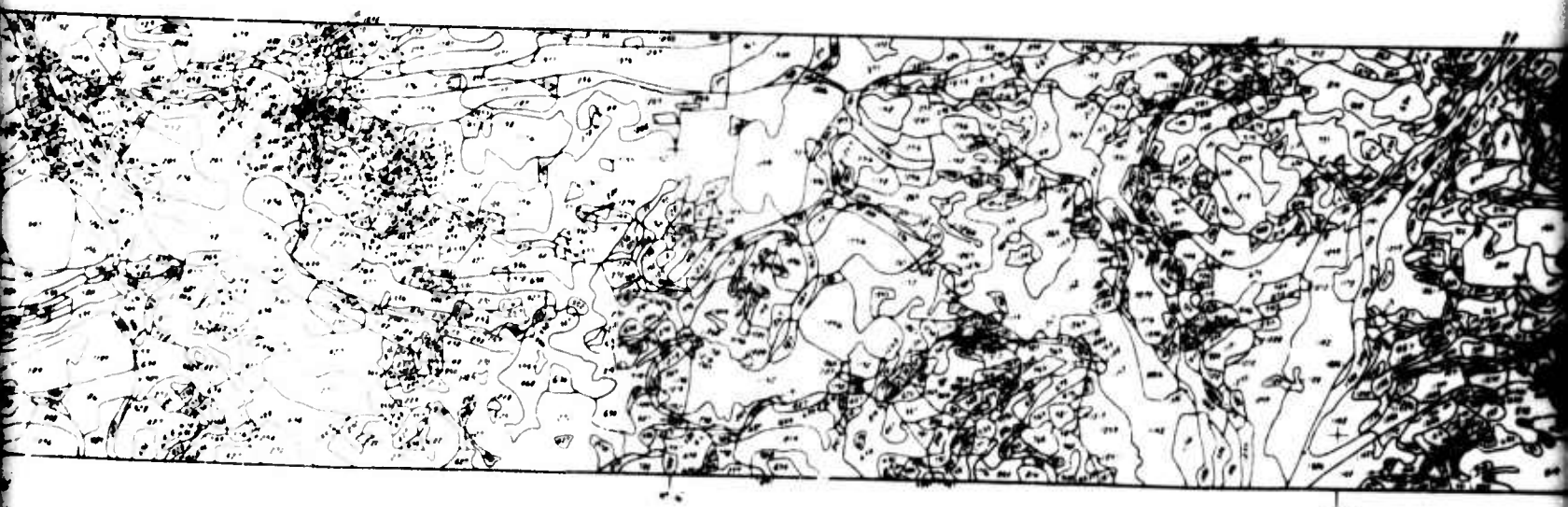
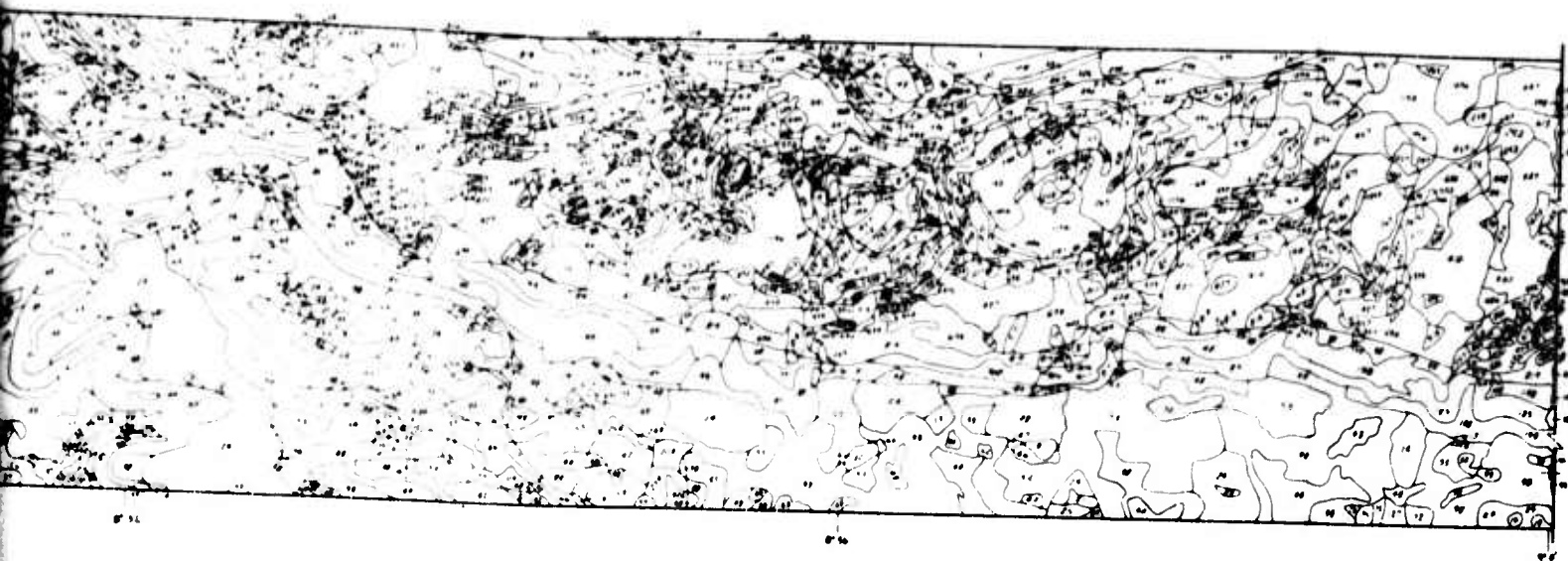


A



B

C

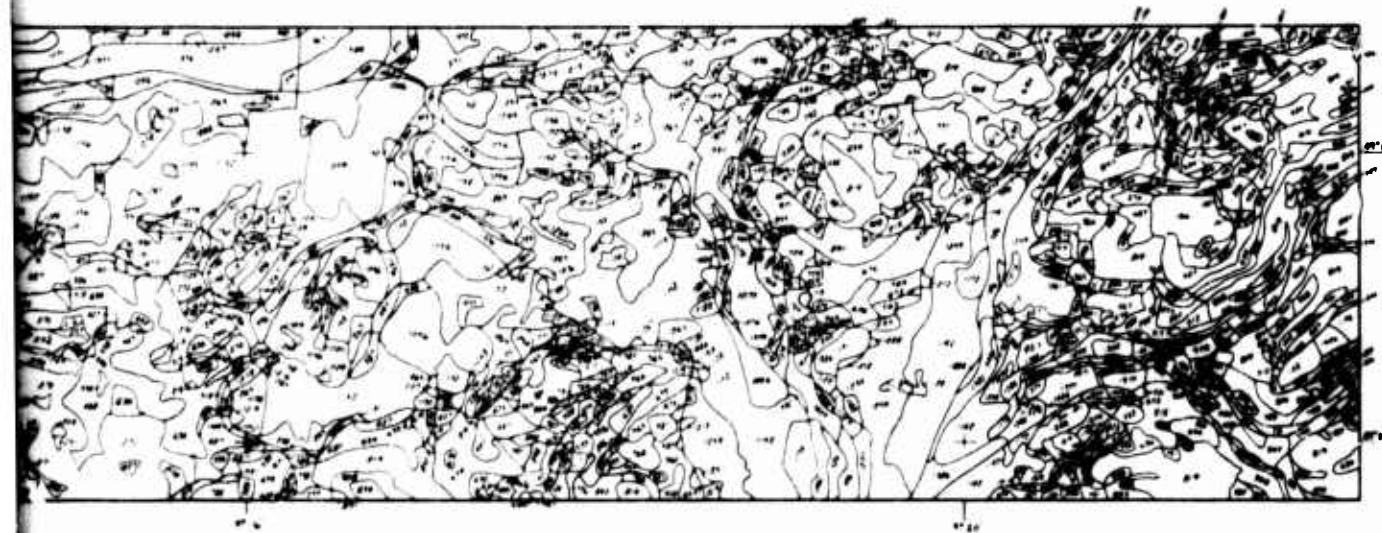
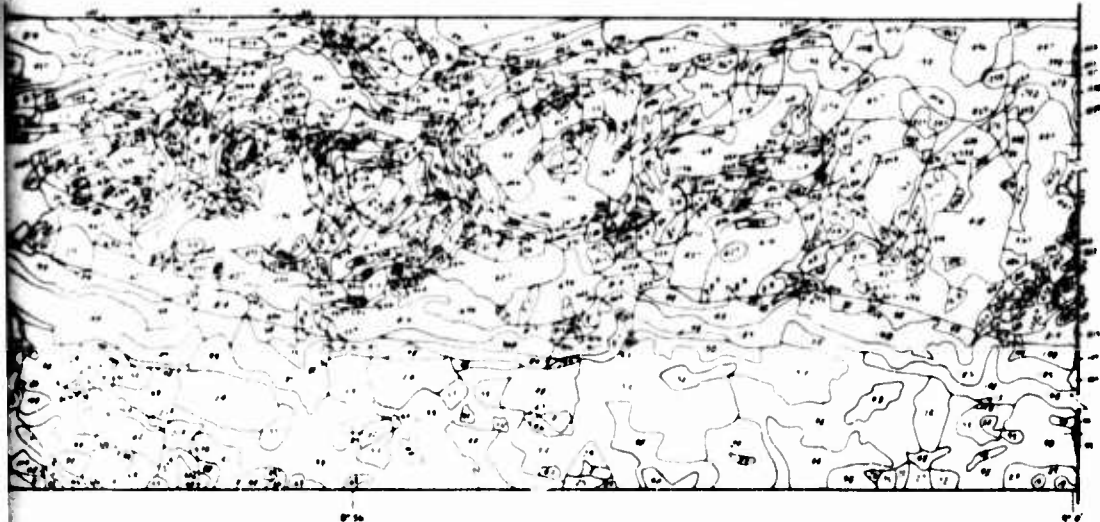


2
3000 4100 Meters
4000 Yards
1 Miles

**AREAL TERRAIN FACTOR COMPLEX
FOR
SELECTED TERRAIN IN WEST GERM**

C

PLA



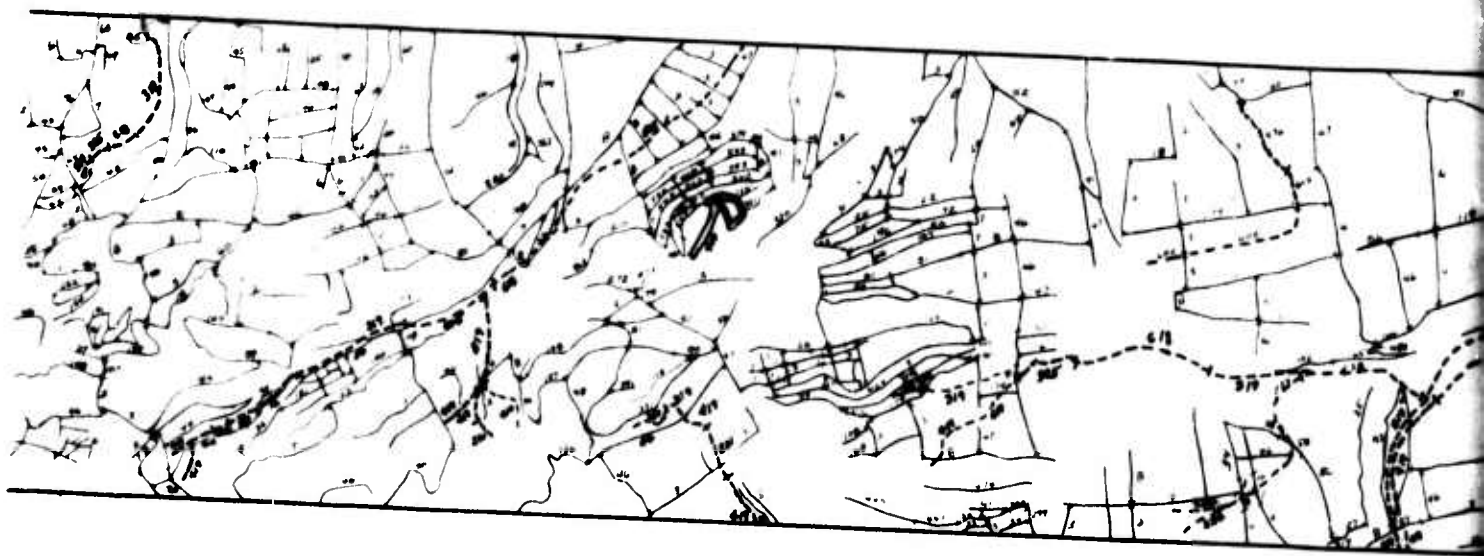
AREAL TERRAIN FACTOR COMPLEX MAP
FOR
SELECTED TERRAIN IN WEST GERMANY

PLATE A7

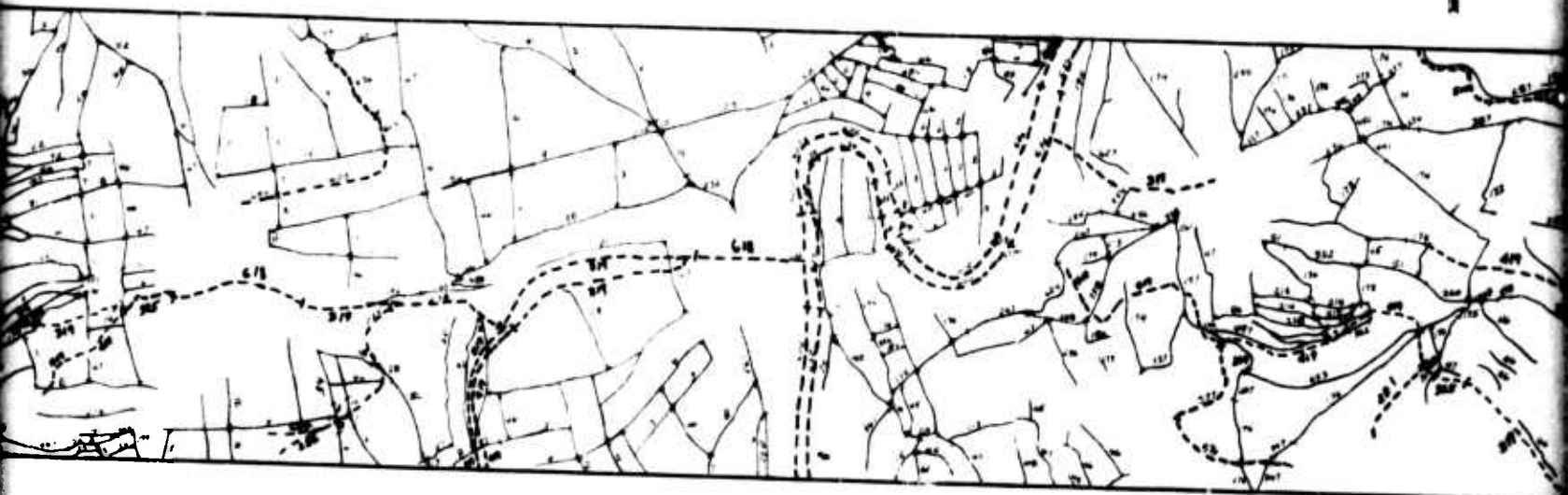
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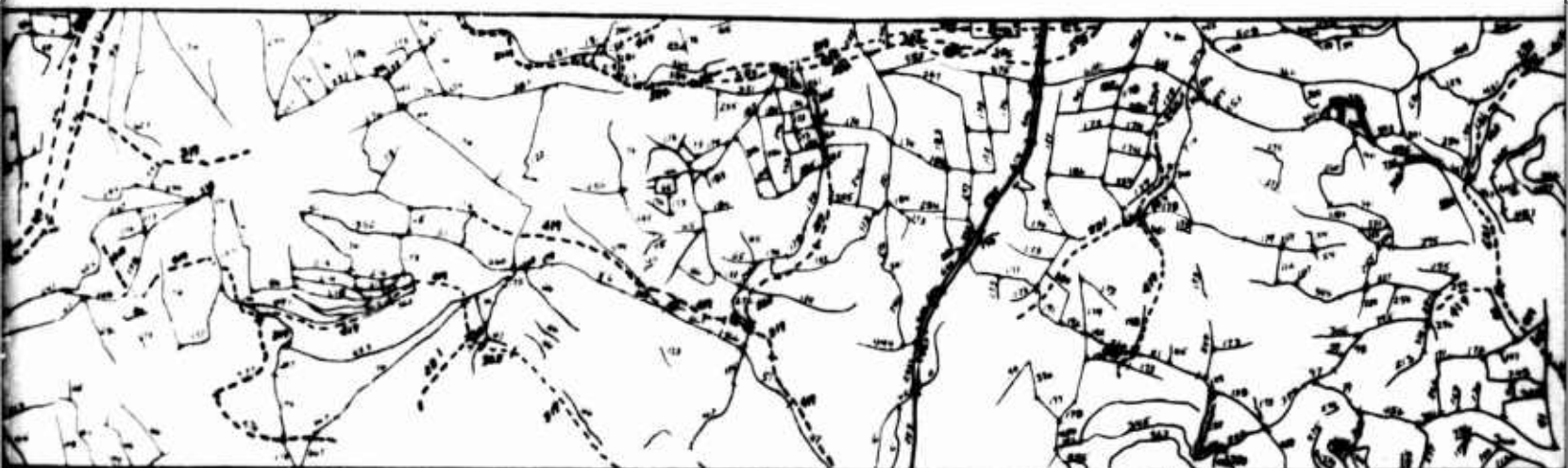


A



LEGEND
— ROAD EMBANKMENT
--- ROAD CUT
... DRAINAGE FEATURE

B

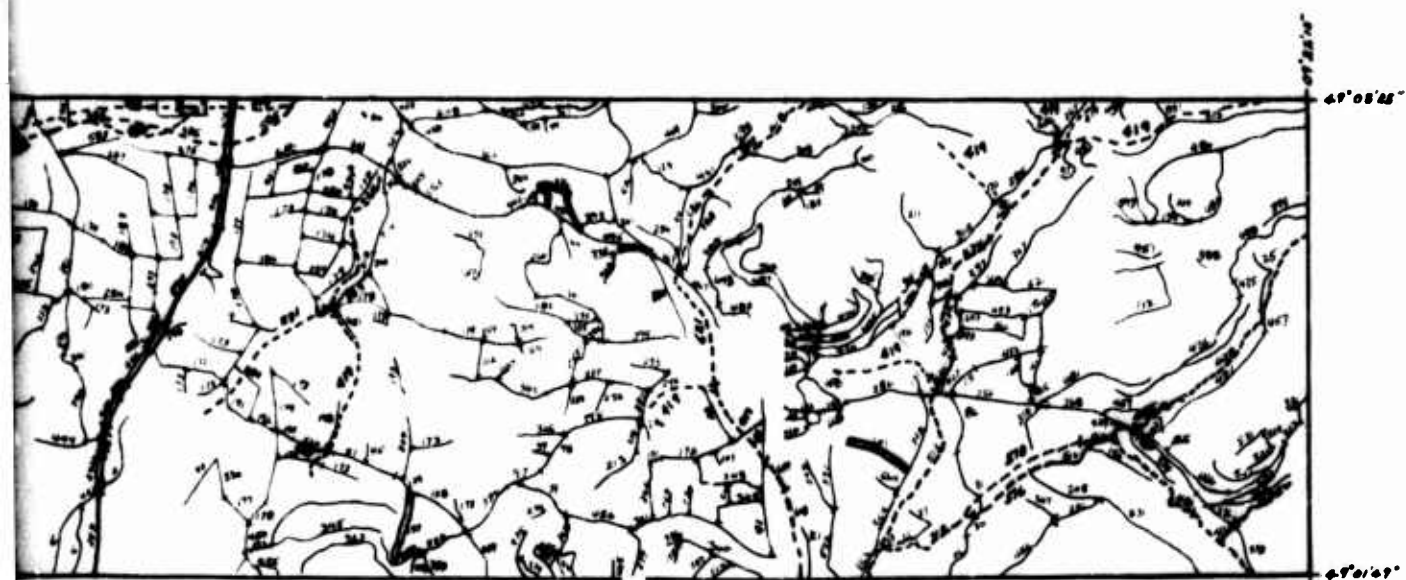


LEGEND
— ROAD EMBANKMENT
— ROAD CUT
--- DRAINAGE FEATURE



B

C



LINEAR TERRAIN FACTOR
COMPLEX MAP
WEST GERMANY (EAST END)
MOBILITY TRANSECT

PLATE 28

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D

APPENDIX B: COMPARISON OF SELECTED FORT KNOX AND WEST GERMAN TERRAINS

Introduction

1. This appendix presents comparisons of the terrains in the three study areas (FK1, FK2, and WGT) on the basis of the general descriptions of the areas, the areal occupancy and occurrence of terrain units and terrain factors, and on the basis of performance of two vehicles (one each wheeled and tracked) as predicted by the AMC-71 mobility model.

General Descriptions

2. The area mapped as WGT is nearly six times as large as the combined areas of FK1 and FK2. WGT and FK2 are located on plateaus; FK1 is located in a floodplain. The elevation is greater in WGT than in FK1 or FK2. Both FK1 and WGT are crossed by a large river and contain some small streams; FK2 has no large river but has numerous small streams. Drainage is excellent in WGT and FK2 throughout the year, while during much of the year drainage is poor in FK1.

3. Soils in FK1 are largely alluvial silty clays, in FK2 are usually residual silty clays, and in WGT are mostly residual silts and clays although some alluvial soils are found along the rivers and streams.

4. Climate is generally similar in the three areas, although the mean temperature and rainfall is slightly higher in FK1 and FK2 than in WGT.

5. The most important difference in the areas is the land use. Approximately 70 percent of the land in WGT is used for agricultural purposes, with grain as the principal crop. FK1 and FK2 are portions of a military reservation primarily used for training purposes; more than 80 percent of FK1 and 50 percent of FK2 are covered by deciduous or evergreen woodlands. WGT contains many towns and villages and a dense road network, whereas FK1 and FK2 contain no town or villages and only a few improved roads.

6. From this general comparison the terrain in WGT as a whole would appear significantly different from that in FK1 and FK2. However, when one considers specific areas in terms of landform, soils, climate, and land use, highly analogous areas can be found.

Terrain Units

Areal terrains

7. Because of the differences in areal extent of the study areas, the terrain units and occurrences are expressed in terms of number per square mile for comparative purposes. These values are shown in the following tabulation.

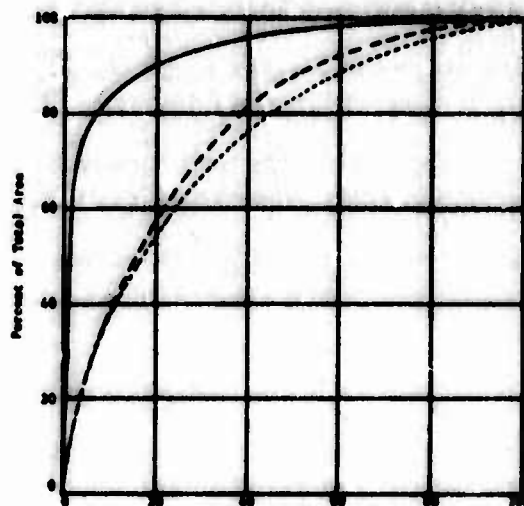
Study Area	Area sq mi	Terrain Units		Occurrences (Patches)	
		Total No.	Number per sq mi	Total No.	Number per sq mi
FK1	6.2	192	31	123	52
FK2	4.7	193	41	224	48
WGT	60.2	1408	23	5117	85

The tabulation shows a smaller number of terrain units per square mile in WGT, which may be a result of the lack of ground truth data. It also shows a larger number of patches or occurrences per square mile in WGT, which reflects the differences in land use of the areas.

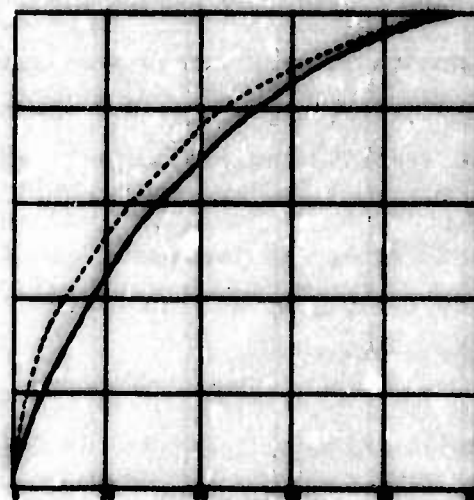
8. A complete list of the area occupied by each terrain unit, the number of occurrences of each terrain unit, the mean area per occurrence, the percent area, and the percent occurrence of each terrain unit is given in tables B1-B3, inclusive. In these tables the terrain units are arranged in descending order according to size of total area assigned.

9. The percentage distribution of the areal terrain units is shown graphically in fig. B1a. It may be seen in this figure that 90 percent of the area in WGT was described by less than 20 percent of the terrain units, while in FK1 90 percent of the area required more than 52 percent of the terrain units, and in FK2 90 percent of the area required more than 60 percent of the terrain units.

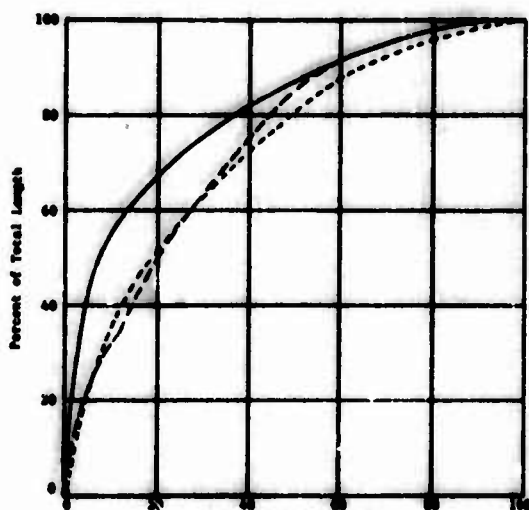
10. The frequency of occurrence is shown in fig. B1b, where it may be seen that about 65 percent of the occurrences describe 90 percent of



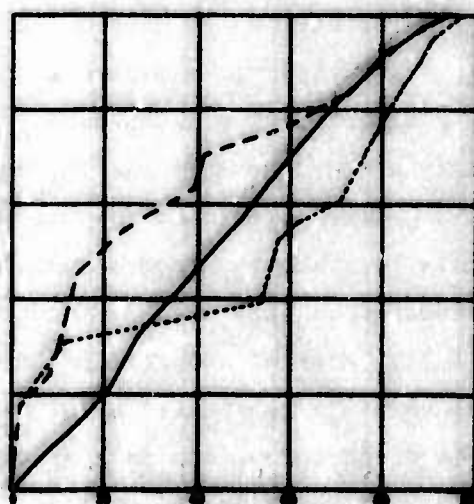
a. Distribution of Areal Terrain Units.



b. Frequency of Occurrence of Patches of Areal Terrain Units Versus Percent Area.



c. Distribution of Linear Terrain Units.



d. Frequency of Occurrence of Segments of Linear Terrain Units.

Legend
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 002

Fig. B1. Distribution and frequency of occurrence of areal and linear terrain units

of all three areas.

11. Although the frequency of occurrence of terrain units in relation to percent of total area appears similar for all three study areas, the number of occurrences per square mile, as shown in paragraph 7, is significantly higher for WGT than for FK1 or FK2. Note, however, that there are 1408 terrain units in WGT and 193 in FK2. This would suggest much greater variability in WGT. However, the largest 200 terrain units contain almost 90 percent of the WGT area. Thus, while greater variability exists, it affects little of the area and may not be significant in the mobility sense.

12. An examination of the descriptions of the terrain units given in tables A10, A11, and A14 of Appendix A reveals that while many terrain units are, indeed, quite similar and can be expected to have the same, or almost the same, effect on vehicle performance, there exists some difference between each terrain unit described in the three areas. Thus, no areal terrain unit is common to all three study areas. Terrain units usually reflect the land use. The terrain factors used to describe obstacles, vegetation, ride dynamics, visibility, and surface roughness are highly dependent upon land use. The surface strength factor may be frequently altered by land use or, when not directly affected by land use, may be generally related to a specific land use. The two remaining factors (surface type and slope), which describe a terrain unit, are seldom dependent upon land use.

13. Most of the terrain units in WGT occur in forests or croplands. Although no terrain unit in WGT was described with exactly the same combination of factor values as a specific terrain unit in FK1 or FK2, most of the terrain units in the forested areas in WGT can be associated with reasonably similar terrain units in the forested areas of FK1 and/or FK2 that yield a range of predicted speeds for the M114A1E1 that are similar to the predicted speeds of the M114A1E1 in selected vegetated terrain units in WGT.

<u>Area</u>	<u>Terrain Unit</u>	<u>M114A1E1 Speed, mph</u>	<u>Limiting Factor</u>
WGT	24	14.9	Vegetation - Soil Slope
FK1	45	15.1	Vegetation - Soil Slope
FK2	167	14.9	Vegetation - Soil Slope
WGT	98	11.7	Vegetation - Soil Slope
FK1	102	12.5	Vegetation - Soil Slope
FK2	87	11.7	Vegetation - Soil Slope
WGT	148	9.2	Vegetation - Soil Slope
FK1	138	9.2	Vegetation - Soil Slope
FK2	148	9.2	Vegetation - Soil Slope
WGT	185	5.1	Vegetation - Soil Slope
FK1	147	7.3	Vegetation - Soil Slope
FK2	141	5.3	Vegetation - Soil Slope

It should be pointed out that while soil, slope, and vegetation contributed to limiting vehicle speed in each of the above examples, the degree to which any single factor affected speed in a terrain unit may have varied. Vehicles can perform similarly in two vegetated areas with the same stem diameter-spacing values and different combinations of soil strength and slope. The vegetation stem size-spacing can also vary slightly with offsetting effects of soil and slope and yield the same vehicle performance. In addition, it should be pointed out that a change in soil strength class, slope class, or vegetation class may have no significant affect on a particular vehicle's performance. Therefore, while the above examples do not offer conclusive proof that the areas are similar, the areas are considered similar from the mobility point of view. Although there is at present no cultivation in FK1 and FK2 that would yield terrain units similar to those found in WGT, there are some areas that could easily be plowed in rows and would then be similar.

Linear terrains

14. Because of the differences in extent of linear terrain in the study areas, the linear terrain units and occurrences are expressed in terms of number per mile for comparative purposes. These values are shown in the following tabulation.

Study Area	Length mi	Terrain Units		Occurrences	
		Total No.	Number per mi	Total No.	Number per mi
FK1	29.9	17	0.6	51	1.7
FK2	25.7	26	1.0	75	2.9
WGT	421.6	641	1.5	1477	3.5

The greatest number of terrain units per mile and occurrences per mile for WGT reflect the dense road network in WGT and the scarcity of roads in FK1 and FK2. It is pointed out that road embankments or road cuts are described as linear features since they are obstacles to vehicles crossing them. Only 20 percent of the total length of the linear terrain features in WGT represented drainage features, while 61 percent of FK1 and about 70 percent of FK2 were drainage features.

15. A complete list of the length of each terrain unit, the number of occurrences of each terrain unit, the mean length per occurrence, the percent length and the percent occurrence of each terrain unit is given in tables B4-B6.

16. The linear distribution of terrain units is shown graphically in fig. B1c. In this figure it may be seen that 60 percent of the length of linear features in WGT was described by less than 10 percent of the terrain units, while in FK1 and FK2, 60 percent of the length of linear terrain features required about 26 percent of the terrain units for description. The smaller number of terrain units used to describe 60 percent of WGT results from the fact that such a large percentage of the linear features in WGT are associated with a well-developed road network. Roads are inherently more uniform than drainage features.

17. The frequency of occurrences is shown in fig. B1d where it may be seen that there is a wide difference in the percent of occurrences required to describe almost any given percent of the total length.

18. Examination of the linear terrain unit descriptions given in tables A12, A13, and A15 of Appendix A reveals that while a degree of similarity exists between some of the linear terrain units in the three areas, there is no linear terrain unit that is common to all three areas.

19. In general, the examination of the three study areas on the basis of linear occupancy and frequency of occurrence of terrain units

indicates significant differences between Fort Knox and West German terrains.

Terrain Factors

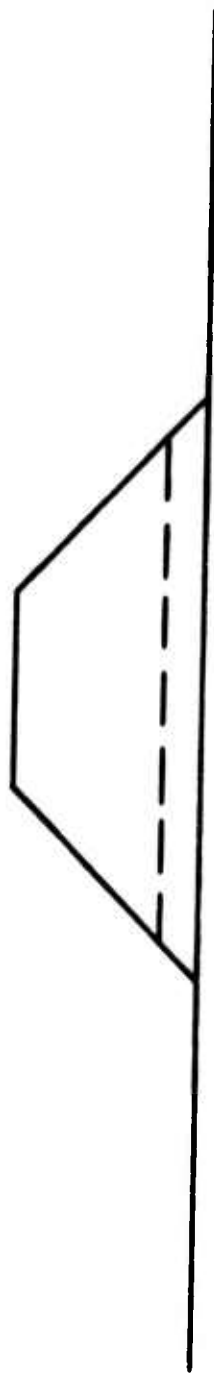
20. In describing terrain units, a particular group of terrain factors is used to describe areal terrains and a somewhat different group is used to describe linear terrains (see tables A8 and A9).

Areal terrains

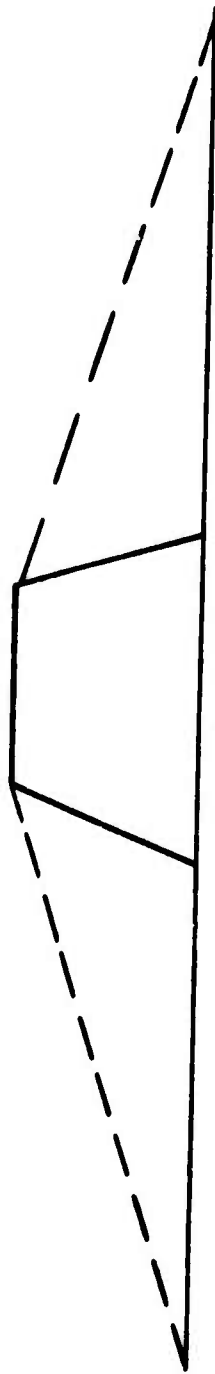
21. Some factors such as soil, slope, surface roughness, and visibility have a more or less independent effect on vehicle performance. Other factors such as those used to describe obstacles and vegetation must be coupled together to have an effect on vehicle performances. For example, the approach angle of two obstacles may be the same and yet the obstacles may have a widely different effect on vehicle performance due to the differences in other dimensions, spacing, etc. Fig. B2 illustrates geometric differences which occur when only the angle of approach and obstacle height vary. However, for the purposes of this study, comparisons were made of each terrain factor, where possible.

22. The data shown in tables B7, B8, and B9 were examined from the standpoint of both frequency of occurrence and areal occupancy. Results of this examination revealed that little difference existed between percent total area and percent occurrence of a given factor class. This is illustrated for the relatively independent terrain factors (soil strength, slope, surface roughness, and visibility) in fig. B3. Therefore, the terrain factors are discussed on the basis of areal occupancy of each factor class, and frequency of occurrence is eliminated from further discussion. However, due consideration was given to whether an individual factor class occurring in WGT also occurred in FK1 or FK2, and to the range of factor classes in each of the three areas. For convenience, the more closely related terrain factors are grouped together for discussion.

23. Soils. Soils are described by the WES descriptive system with two terrain factors--soil type and soil strength. Soil type is described by three classes:



a. Height varies; approach angle constant.



b. Approach angle varies; height constant.

Fig. B2. Example of variation of obstacles

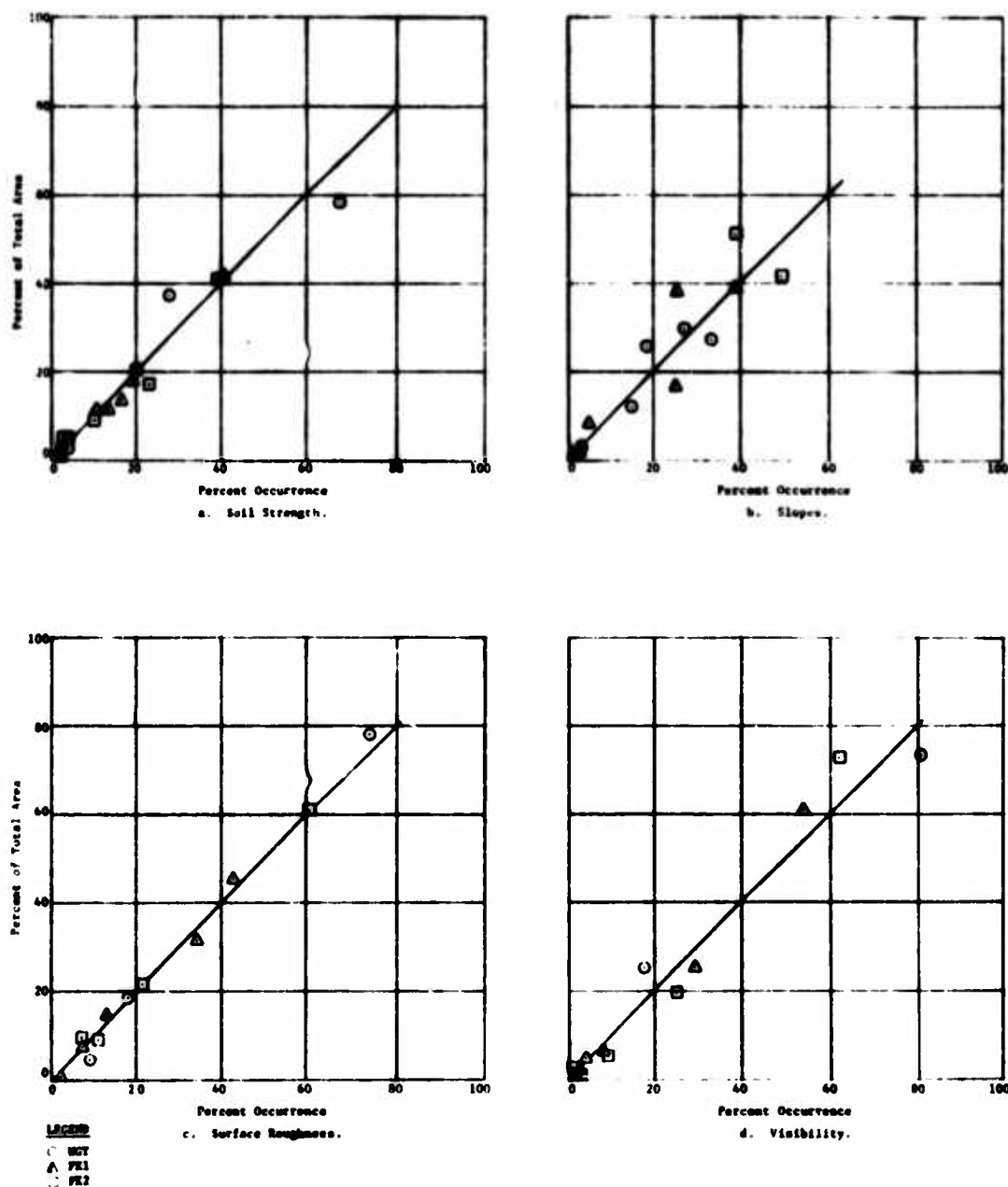


Fig. B3. Frequency of occurrence versus areal occupancy of factor classes of the independent terrain factors

- a. Class 1 - fine-grained soils.
- b. Class 2 - coarse-grained soils.
- c. Class 3 - organic soils.

In all three areas, the soil type was determined to be class 1 for all areal terrain units. Soil strength in areal terrains was described by 11 classes of rating cone index (RCI) ranging from 0 to 280. The M114A1E1 requires a minimum soil strength of 12 RCI in order to just operate; the M151A2 requires a soil strength of 19 RCI. Higher soil strengths are necessary to permit the vehicles to climb slopes, override trees and obstacles, and to gain speed.

24. Soil strength. Soil strength is normally determined for dry, average, and wet conditions, because differences in soil moisture influence soil strength. However, for this study, comparisons were made only for the wet season condition, which is generally the most unfavorable from the standpoint of vehicle performance.

25. Fig. B4 shows the areal distribution of the soil strength factor classes during the wet season for the three areas considered. In general, the soil strength in WGT was predominantly class 4 (101 to 160 RCI) and class 6 (41 to 60 RCI). The distribution of soil strength in FK1 was skewed bell-shaped with the greatest occurrence being in class 6. In FK2, soil strength ranged from class 2 to class 8 (i.e. from 208 to 26 RCI) with an erratic distribution. Generally, the soils were strongest in WGT and weakest in FK1. This figure also shows that 75 percent of the soil strengths found in WGT also occur in FK1 and that all (100 percent) of the soil strengths in WGT occur in FK2.

26. Slope. Slope was described by a single terrain factor--topographic slope in percent. It is expressed by eight classes ranging from 0 to 70 percent. Most off-road vehicles can successfully negotiate a 60 percent slope on firm soil, have difficulty on slopes between 60 and 70 percent, and cannot operate on slopes of 70 percent or greater. The areal distribution of the slope classes in the three areas is shown in fig. B5. The largest percentage of shallow slopes is found in FK1 and the steepest slopes are found in WGT. The areal distribution of slopes in WGT is nearly bell shaped and in FK1 and FK2 is somewhat skewed, with FK1

skewed to the left and FK2 skewed to the right. Note that while only 86 percent of the slope classes occurring in WGT may be found in the combined terrains FK1 and FK2, the single slope class that does not occur in either FK1 or FK2 represents only 0.2 percent of the area in WGT.

27. Surface roughness. Surface roughness was described by a single terrain factor in terms of root mean square (rms) elevation in inches. RMS is expressed in nine classes ranging from 0 to 7.6 rms. This factor does not cause immobilizations, but serves only to limit vehicle speed. A value of 0.2 rms (midpoint of class 1) has little effect on speed of the M114A1E1 and the M151A2. A value of 4.0 rms (midpoint of class 5) will severely limit speed of both vehicles. The areal distribution of the surface roughness factor classes is shown in fig. B6. Areas FK1 and FK2 show somewhat normal distributions whereas 77 percent of the surface roughness index in WGT occurs in class 2 (0.5 to 1.5 rms). This figure also shows that all of the surface roughness factor classes found in WGT occur in FK1 and FK2.

28. Visibility. Visibility is described by a single terrain factor--recognition distance in feet. It is expressed in nine classes ranging from 0 to >164 ft. The AMC-71 mobility model relates the recognition distance to the distance required to stop a vehicle. Therefore, this factor does not cause immobilizations, but serves only to limit speed. Visibility of more than 79 ft (bottom of class 2) has no effect on speed of the M114A1E1; visibility of more than 164 ft (class 1) has no effect on speed of the M151A2. The areal distribution of the visibility factor classes is shown in fig. B7. This figure shows that the largest percentage of area occupancy for all three areas occurred in class 2, indicating that, in general, visibility was good in all three areas. The small percentages in the higher classes reflect the unmanaged forests at FK1 and FK2. Note that all of the visibility factor classes occurring in WGT also occur in FK1 or FK2.

29. Obstacles. Obstacles are generally related to the cultural practices, and the dispositional and erosional processes within an area. For instance, in WGT rows are associated with cropland; in FK1 small logs are found in the unmanaged woodlands; in FK2 the ditches result from

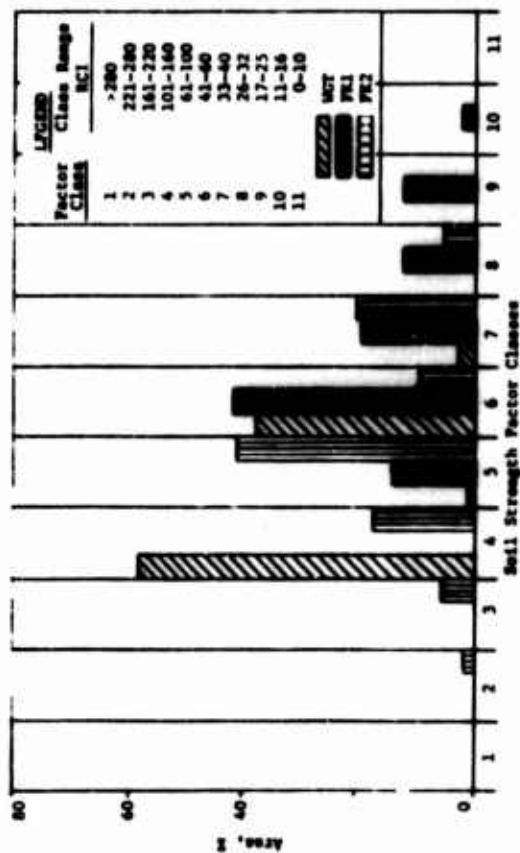


Fig. 34. Distribution of soil strength of areal terrain

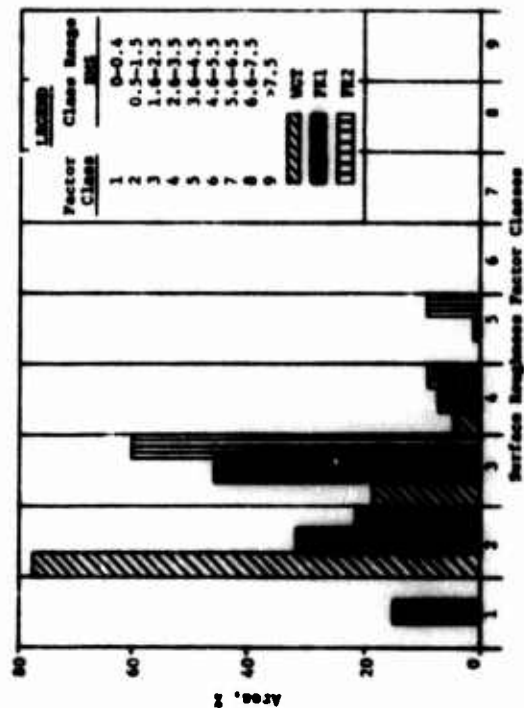


Fig. 36. Distribution of surface roughness

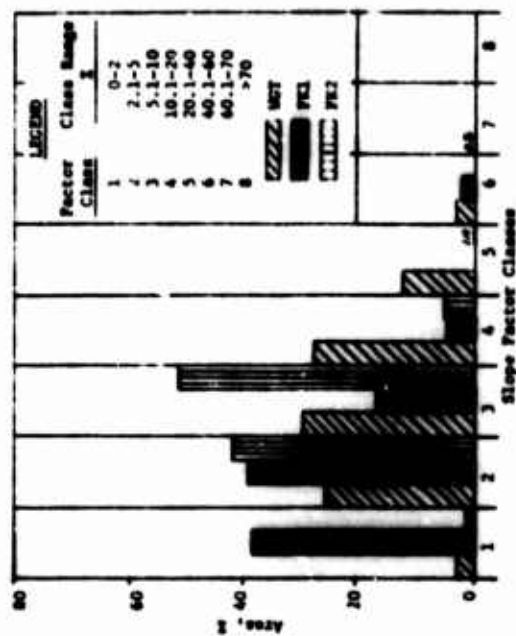


Fig. 35. Distribution of slopes

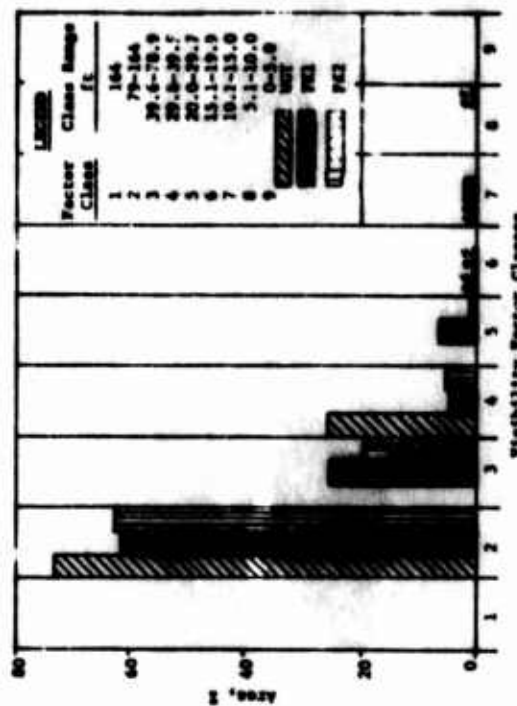


Fig. 37. Distribution of visibility

previous military activities and uncontrolled erosion. Six terrain factors are used to describe obstacles (see table A8). The areal distribution of these factors is shown in figs. B8-B12 with the caveat of paragraph 21 repeated.

- a. Approach angle. Fourteen classes are used to describe approach angle with the odd-numbered classes describing convex obstacles and the even-numbered classes describing concave obstacles. The areal distribution of obstacle approach angles (fig. B8) shows that 40 percent of FK1, 17 percent of FK2, and 41 percent of WGT have approach angles in classes 1-8 (150 to 202 deg), inclusive. Approach angles this small are considered to have little effect on mobility of current military vehicles. The approach angles in class 9 in WGT reflect the prevalence of row crops (determined by comparing other terrain factors such as obstacle spacing, obstacle width, and obstacle length), which do not occur in FK1 or FK2. Although this class of obstacle approach angles represents a large part of terrain in WGT, its absence in FK1 or FK2 is not as critical as the figures might appear to indicate for several reasons. First, rows, per se, will normally have little effect on the speed of a tracked vehicle, and small effect on the speed of wheeled vehicles with well-designed suspension systems. Second, rows are a man-made feature and can be duplicated in selected parts of FK1 with very little effort. There are no obvious patterns to the distribution of approach angles.
- b. Vertical magnitude. The areal distribution of the vertical magnitude (fig. B9) occurs largely in the first three classes (<14 in.). In all areas obstacles of this magnitude can usually be negotiated by most off-road vehicles, but may cause some reduction in speed. Distinguishable patterns are not apparent for the areal occupancy of vertical magnitudes. The figure shows that all of the obstacle vertical magnitudes found in WGT occur in both FK1 and FK2.
- c. Base width. The areal distribution of base width is shown graphically in fig. B10. There appears to be no pattern to the areal distribution of base width. The obstacles in over half of the area of WGT have base width in class 4 (12 to 25 in.), with significant occurrences in classes 1 (>47 in.) and 5 (0 to 12 in.). In FK1 and FK2 classes 1 and 5 predominate. Note that all of the base widths that occur in WGT also occur in FK1 and FK2.
- d. Length. The distribution of obstacle length in terms of areal occupancy is shown in fig. B11, which shows no obvious distribution pattern. In WGT, 42 percent of the area occurs in class 6 (20 to 49 ft) with somewhat lesser

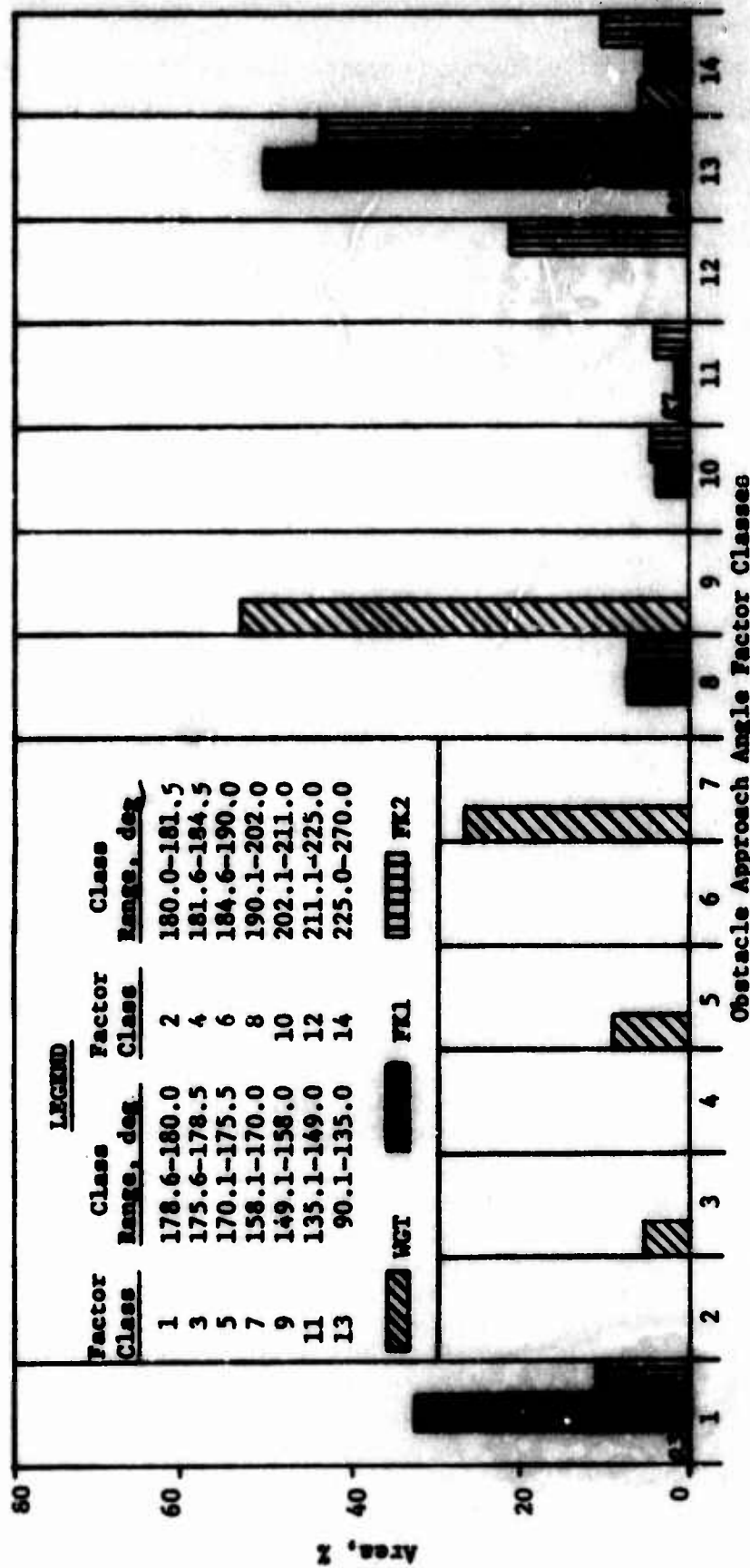


Fig. 28. Distribution of obstacle approach angles

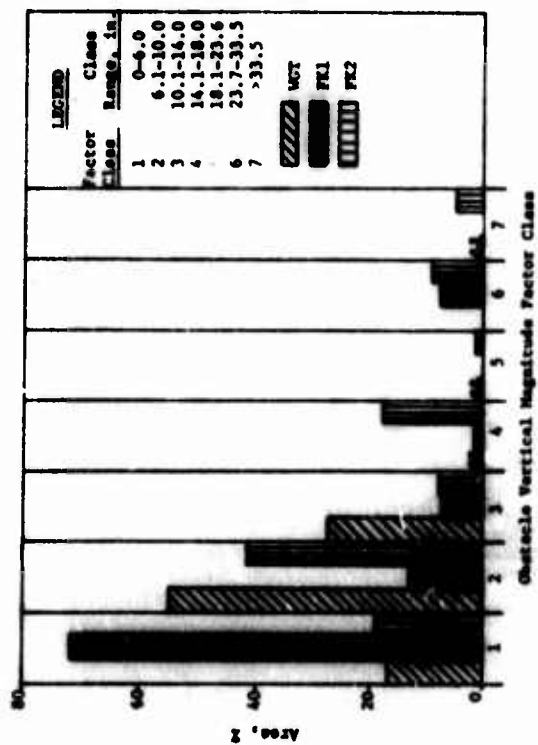


Fig. B9. Distribution of obstacle vertical magnitudes

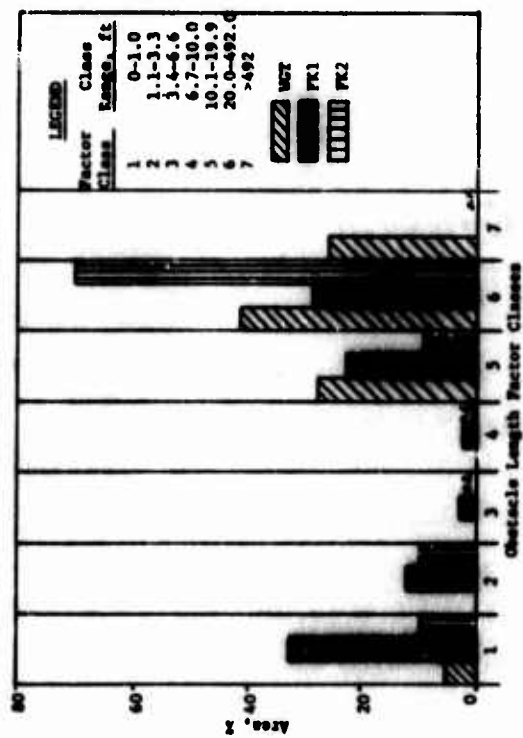


Fig. B11. Distribution of obstacle lengths

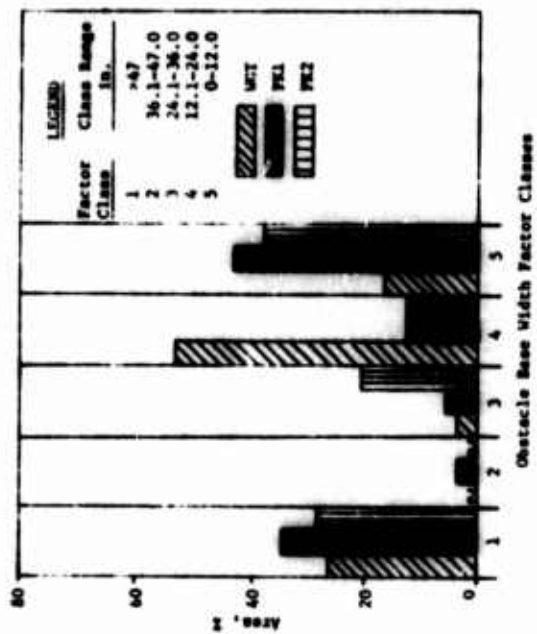


Fig. B10. Distribution of obstacle base widths

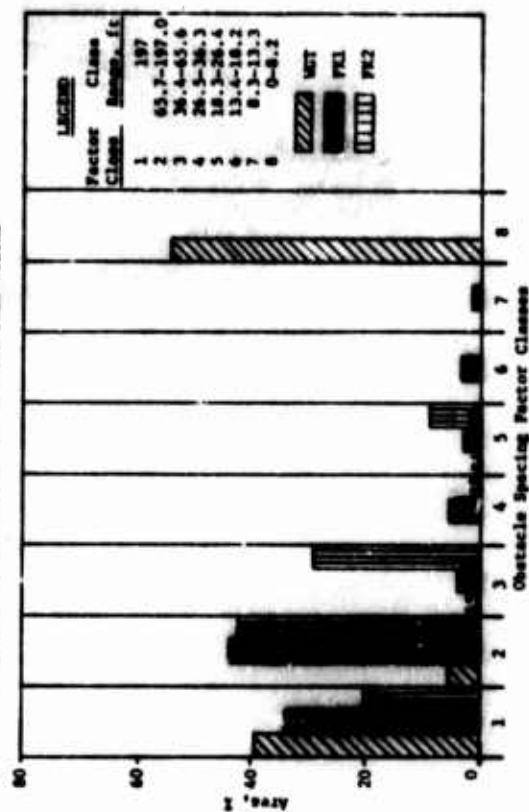


Fig. B12. Distribution of obstacle spacings

distribution in classes 5 (10 to 20 ft) and 7 (>492 ft). FK1 has similar amounts of obstacle lengths in classes 1 (<1 ft), 5, and 6; whereas in FK2, 70 percent of the lengths are found in class 6. All obstacle length factor classes occurring in WGT can be found in the combined terrain of FK1 and FK2.

- e. Spacing. Fig. B12 shows the distribution of obstacle spacing. No distribution pattern is apparent for WGT and FK1; FK2 resembles a skewed bell-shaped pattern, with 71 percent in classes 2 (66 to 197 ft) and 3 (36 to 66 ft). In WGT, 94 percent is in classes 1 (>197 ft) and 8 (0 to 8.2 ft). In FK1, more than 80 percent of the area is in classes 1 and 2. Eighty percent of the obstacle spacing classes occurring in WGT are also found in FK1 and FK2. The range of obstacle spacing in WGT is from 0 to >197 ft; the combined range of obstacle spacing in FK1 and FK2 is 8.3 to >197 ft. Obstacle spacing class 8 (0 to 8.2 ft), which does not occur in either FK1 or FK2, results from the cultivated croplands in WGT. Although this obstacle spacing class does occur in a significant percentage of the total area in WGT, its absence in FK1 and FK2 is not critical as these conditions can easily be duplicated as stated in paragraph B13.
- f. Obstacle spacing type. The areal distribution of random and linear obstacles is given in table B8. One-hundred percent of FK1, 93 percent of FK2, and 75 percent of WGT were mapped as random obstacles. Study of the air photos of WGT indicate that a much larger percentage of WGT should have been mapped as containing linear obstacles since it is felt that the obstacles in most cropland are linear.

30. In summary, WGT consists largely of cropland and forests. Intensified management practices employed in these areas result in a decrease in the occurrences of mobility significant obstacles. The obstacles commonly found in WGT are rows produced in preparing cropland, stumps and logs in forest lands, and rock outcrops on sloping, shallow soil areas. Intensive erosion control minimizes land dissection by erosion. Areas FK1 and FK2 are portions of a military reservation where the land is used essentially for training military units. No effort is devoted to management practices of these lands as yet, but conservation programs are being formulated. Logs, deadfall, and ditches are the predominant obstacles. The major differences between the obstacles in the study area is, of course, the presence of rows in WGT and the lack thereof in FK1 and FK2.

This does not constitute a formidable difference, however, since the rows in WGT may be duplicated in FK1 with little effort.

31. Vegetation. Vegetation assemblages are described by eight classes of spacing and eight stem diameter classes. Vehicle response is dependent upon characteristics of the stem size/spacing distribution which these detail. Fig. B13 shows the spacing distribution of all stems. For WGT, nonwoody vegetation (i.e. grass, crops, etc.) was arbitrarily included; thus, when all stems are considered, virtually 100 percent of the area in WGT is in class 8. For FK1 and FK2 nonwoody vegetation was not mapped; thus, a better comparison is shown in fig. B14, which eliminates consideration of nonwoody vegetation in all areas. Although the figure indicates denser vegetation in FK2 than in FK1 or WGT, little can be inferred from stem spacing without a consideration of stem size; accordingly, to compare the vegetation in the three areas, vegetation was described as follows:

- a. Open land. Areas with no vegetation or with stem spacing greater than 65 ft. (No effect on mobility.)
- b. Light woods. Areas with stems less than 3.9 in. in diameter regardless of spacing, and areas with stems greater than 3.9 in. in diameter which have spacings between 18.3 and 65 ft. (Some effect on mobility.)
- c. Heavy woods. Areas with stems greater than 3.9 in. in diameter and spacings less than 18.3 ft. (Great effect on mobility.)

32. The areal distribution of these groups is shown in fig. B15. Again, it is apparent that WGT has considerably more open land than FK1 and somewhat more open land than FK2. FK1 contains the highest percentage of light and heavy woods. The percent of area containing light and heavy woods is less for WGT than for either FK1 or FK2. Nevertheless, it is obvious that all three areas contain significant amounts of each of the three vegetation groups.

33. The distributions of the spacing of the light woods and heavy woods are shown in figs. B16 and B17. Note that the spacing of the light woods in WGT is predominantly in class 3 (36 to 66 ft), and in FK1 and FK2 is predominantly in class 7 (8.3 to 13.3 ft). This reflects the orchards in WGT and the young, denser tree growth in FK1 and FK2. Five of the six



Fig. B13. Spacing Distribution of all stems



Fig. B14. Spacing distribution of all stems >1-in. stem diameter

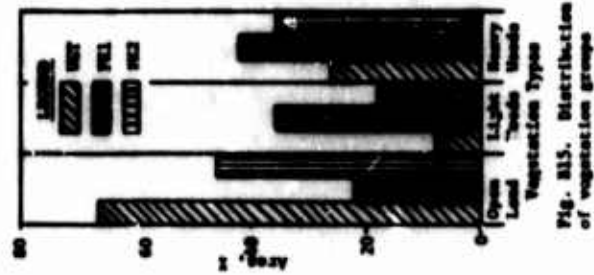


Fig. B15. Distribution of vegetation groups

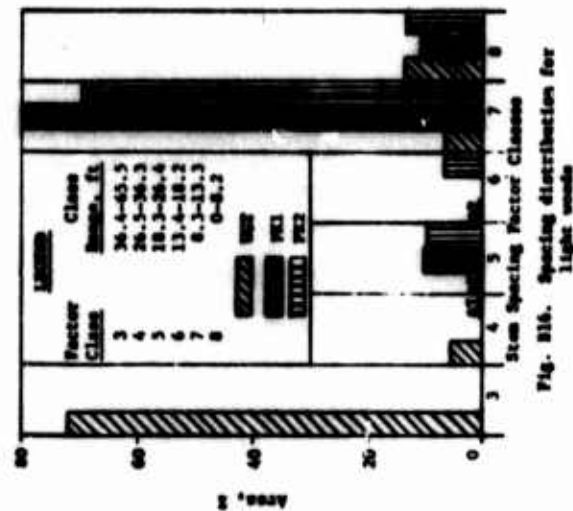


Fig. B16. Spacing distribution for light woods

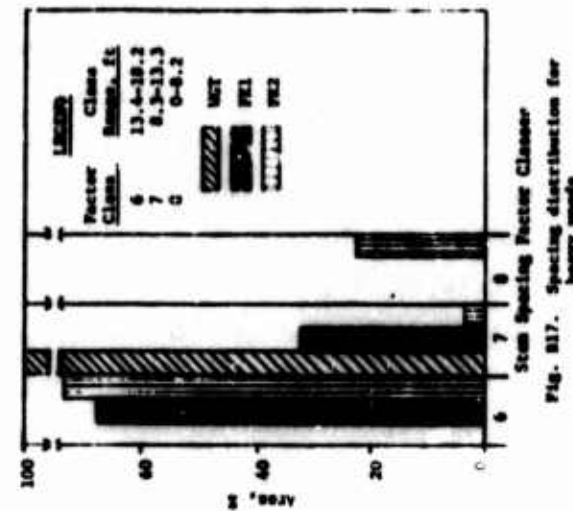


Fig. B17. Spacing distribution for heavy woods

spacing classes of light woods which occur in WGT can be found in FK1 and FK2; the one spacing class of light woods in WGT which does not occur in either FK1 or FK2 represents relatively widely spaced (36 to 66 ft) stems which would have little mobility significance. The spacing of the heavy woods in WGT is in class 7, and in FK1 and FK2 is largely in class 6 (13.4 to 18.2 ft); however, all of the spacing classes of heavy woods that occur in WGT can be found in both FK1 and FK2. This is a result of the tree management programs and harvesting practices in the respective areas. On the basis of stem spacing, the areal extent of wooded areas in WGT is different from that in FK1 and FK2; nevertheless, all significant stem spacings occurring in WGT can be found in FK1 or FK2.

Linear terrains

34. The linear terrain unit data shown in table B10 were examined from the standpoint of both linear occupancy and frequency of occurrence. Results of this examination generally indicated little difference between linear occupancy and frequency of occurrence. Therefore, the distributions of the terrain factor classes were compared on the basis of linear occupancy only.

35. Most of the linear terrain features in FK1 and FK2 were described as surface type class 1 (fine-grained material). All of the linear terrain features in WGT were described as surface type class 2 (coarse-grained material).

36. The distribution of the other eight terrain factors is discussed in the following paragraphs.

- a. Soil strength. Fig. B18 shows that all of the linear terrain features in WGT were mapped with a soil surface strength class 1 (>280 CI). More than 60 percent of the linear terrain features in FK1 and FK2 were mapped in soil strength classes 4-10 (11 to 160 RCI), indicating that more soil problems would be encountered in the Fort Knox study areas. There is no apparent distribution pattern to the data as shown in fig. B18. A significant portion of the linear features in FK1 and FK2 have soil strengths similar to those of linear features in WGT.
- b. Left and right approach angles. In figs. B19 and B20, the odd-numbered classes (except 21) indicate convex features such as road embankments, levees, dikes, etc.; the even-numbered classes indicate concave features such as streams

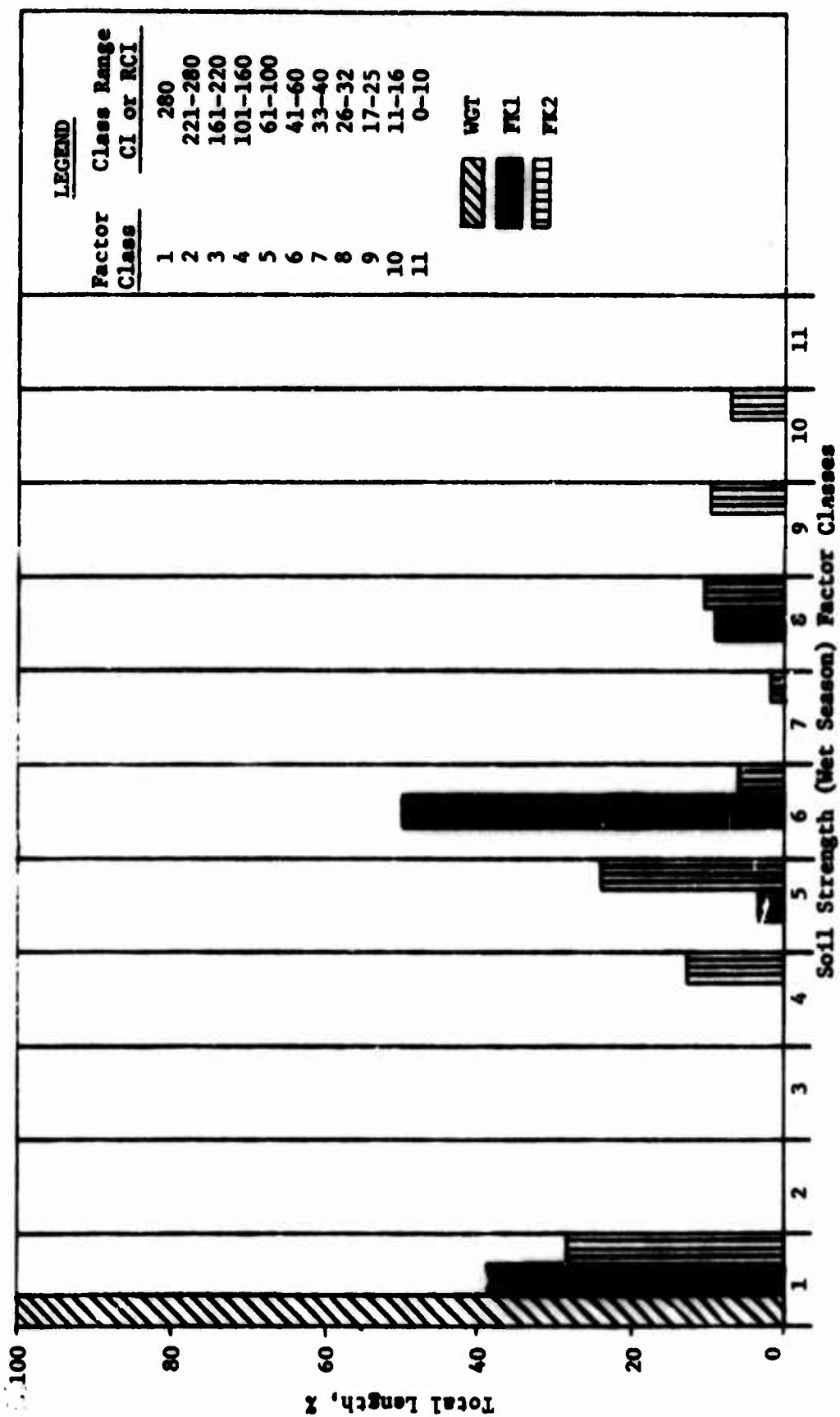


Fig. B18. Distribution of soil strengths for all linear features

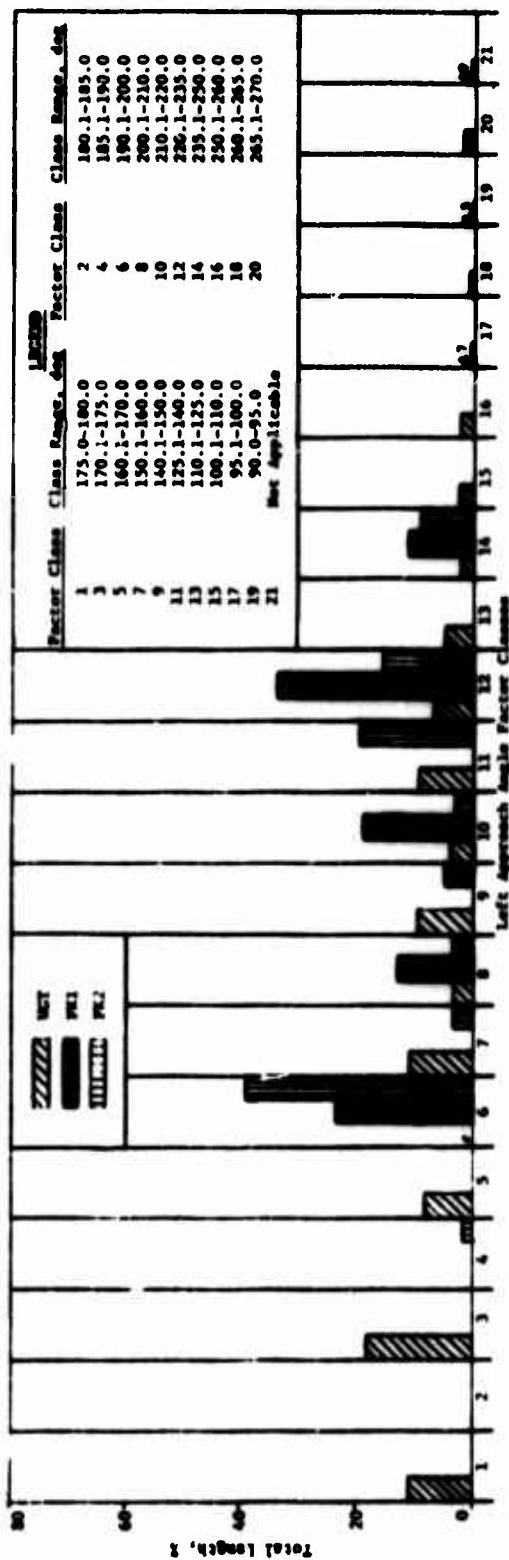


Fig. B19. Distribution of left approach angles for all linear features



Fig. B20. Distribution of right approach angles for all linear features

ditches, road cuts, etc. In WGT, odd-numbered linear terrain factor classes predominate, because of the highly developed road net that represents more than 75 percent of the total length of the linear terrain features. The lack of positive features in FK1 and FK2 is apparent, indicating the lack of improved roads in these areas. The even class numbers in FK1 and FK2 reflect the concave linear features which are drainage features; no road cuts occurred in FK1 or FK2. The steeper approach angles in the concave features in WGT represent both road cuts and drainage features. The Neckar River in WGT creates a more severe mobility problem than the Salt River in FK1 because of the steeper approach angles. Although the areal distribution of the approach angles indicate considerable differences, it should be noted that the steeper angles (90 to 110 deg and 250 to 270 deg) that occur in WGT but not in FK1 or FK2 represent less than 10 percent of WGT, and that lower approach angles (160 to 180 deg) that occur in WGT but not in FK1 or FK2 represent roads. It would seem likely that if the perimeter road around FK2 were included in the linear terrain features, some of these approach angles would occur. Seven of the remaining eight classes of approach angles which occur in WGT also occur in the Fort Knox terrains, the only one not occurring being class 13, i.e. a positive feature which might well occur if the aforementioned perimeter road were included.

- c. Differential bank height or vertical magnitude. In fig. B21 class 1 (banks of equal height) indicates that left and right bank heights are equal. Classes 2-5 (0 to >13.1 ft) indicate a higher left bank, and classes 6-9 (0 to >13.1 ft) indicate a higher right bank (see table A9). Although the data on this figure indicate that the left bank is frequently higher than the right bank in FK1 and FK2, it is believed that this is a result of the size of the sample area. Although classes 5 and 8 do not occur in FK1 or FK2, these bank heights do occur on the opposite bank, hence all bank heights in WGT occur in FK1 or FK2.
- d. Low bank height or least vertical magnitude. Fig. B22 shows that the low bank height or least vertical magnitude of the majority of the linear terrain features was generally small since 62 percent of the total length of the linear features in FK1, 83 percent in FK2, and 81 percent in WGT were less than class 3 (approximately 3.3 ft). In all areas, percentage of occurrence decreased as class number increased, except class 8 in FK1, which represents the Salt River. The three classes which occur in WGT and do not occur in FK1 or FK2 represent only 2.2 percent of the total length of linear features in WGT.

- e. Base width or top width. Fig. B23 shows that the width of most of the linear terrain features was generally small. For instance, the width of 100 percent of the total length of the linear terrain features in FK1, 96 percent in FK2, and 67 percent in WGT was less than class 7 (approximately 40 ft). Generally, as the base width or top width of a feature increased, its occurrence decreases, as one would expect. The three classes of base width which occur in WGT and do not occur in FK1 or FK2 represent only 2.5 percent of the total length of linear features in WGT.
- f. Water depth and water velocity. Figs. B24 and B25 show the distribution of water depth and water velocity for wet concave features (drainage features which may or may not contain water) only. Note that the predominant water depth in the wet concave features of all three areas falls in class 3 (>3.3 ft). The water depths in classes 5 and 6 (>6.7 ft) in the Neckar River in WGT and the Salt River in FK1, respectively, would require most vehicles to swim. No rivers that would require a vehicle to swim occurred in FK2. All of the water depth classes occurring in WGT are not duplicated in FK1 and FK2; however, the overall range of water depths occurring in WGT is encompassed by the range occurring in FK2. Moreover, since water depth varies considerably in most natural features, it is reasonable to expect that specific traverses may be selected in the Fort Knox terrains which will have all significant water depths. The distribution of the water velocity factor classes in FK1 is more similar to that in WGT than is the distribution in FK2. Again, this is probably because both FK1 and WGT contain large rivers. In WGT approximately 83 miles of the drainage features contained water and approximately 2 miles of the drainage features had no water. In FK1 approximately 14.6 miles had water and 1.8 miles had no water. In FK2 approximately 9.9 miles had water and approximately 3.3 miles were dry. All water velocity classes occurring in WGT are duplicated in FK1 and FK2.

General

37. Although it has been shown that significant differences exist between terrains in FK1 and FK2 and terrains in WGT, specific conditions can be found in which the terrains are generally similar, but their relative extent and occurrence differ. Nevertheless, most of the individual factor classes occurring in WGT can be found in the Fort Knox terrains.

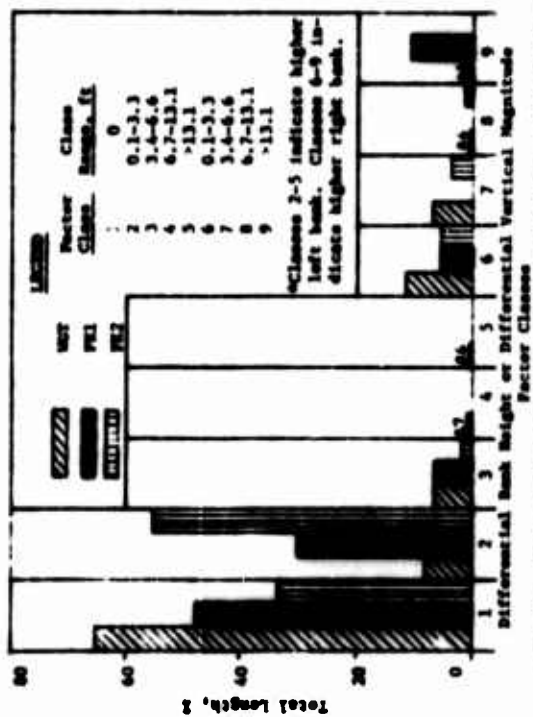


Fig. B21. Distribution of differential bank height or differential vertical magnitude of all linear features

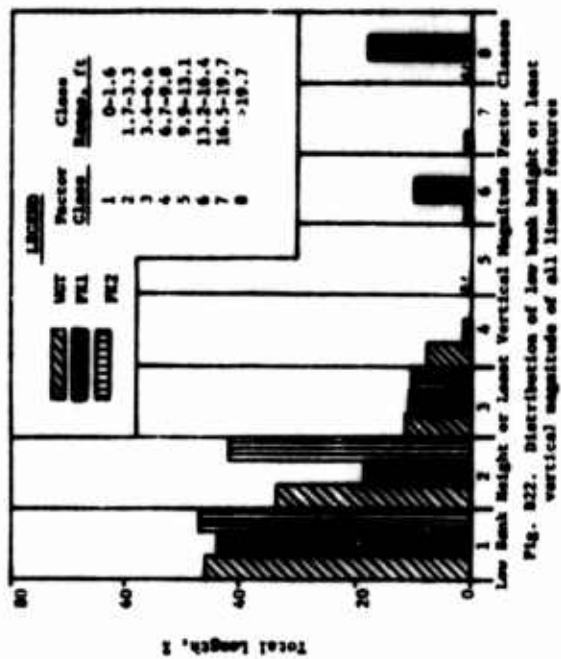


Fig. B22. Distribution of low bank height or least vertical magnitude of all linear features

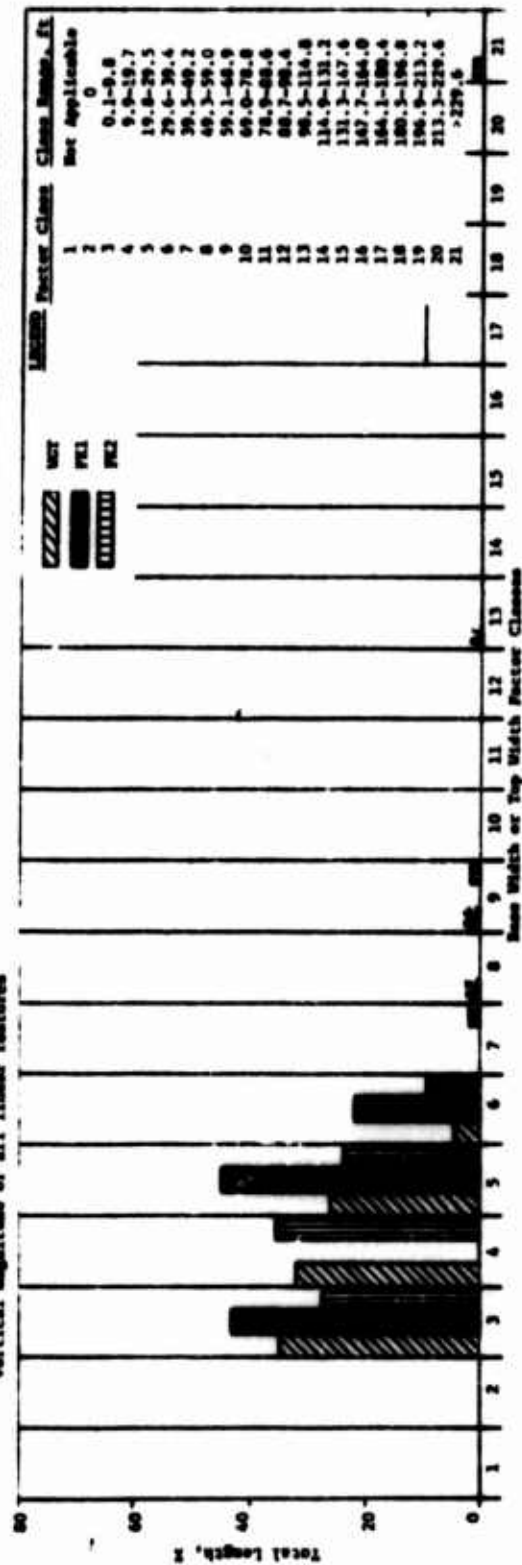


Fig. B23. Distribution of bank width or top width for all linear features

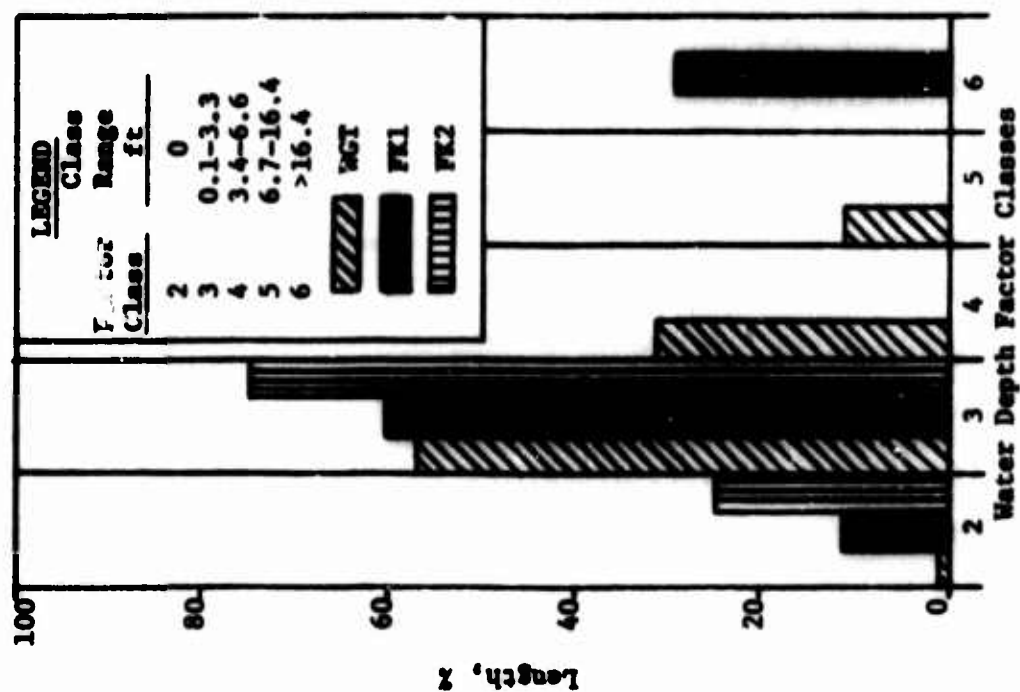


Fig. B24. Distribution of water depth of wet concave features

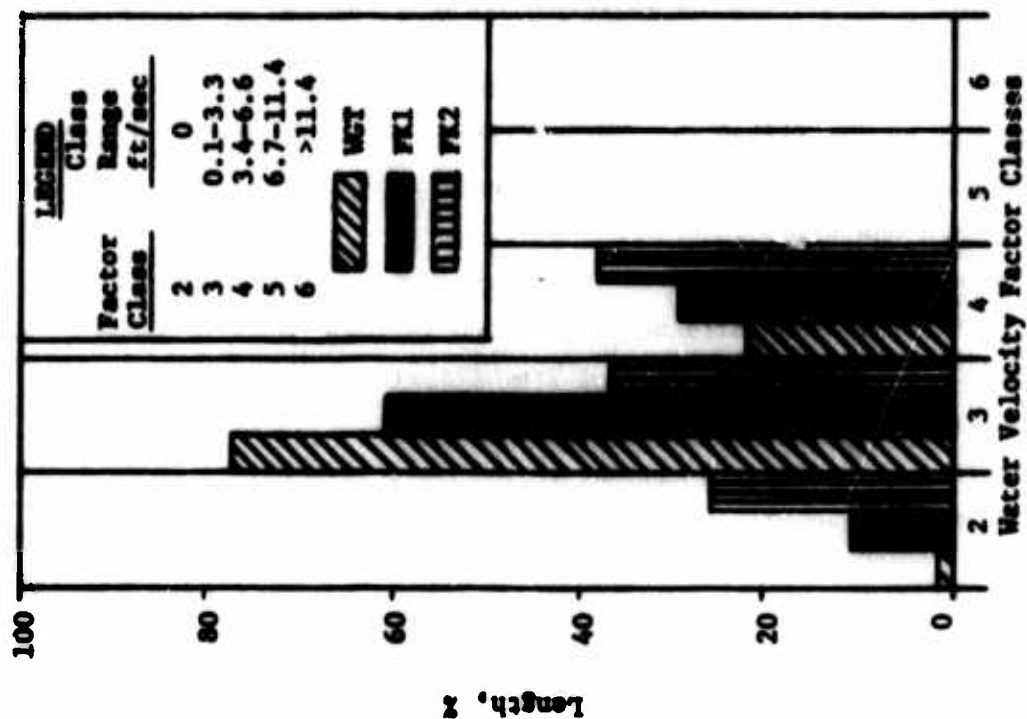


Fig. B25. Distribution of water velocity of wet concave features

Vehicle Performance

38. The three study areas were compared on the basis of the predicted performance of the M141A2 4x4, 1/4-ton truck and the M114A1E1 armored command and reconnaissance carrier. Photographs of these vehicles are given in figs. B26 and B27.

39. The performance predictions were made with the AMC-71 mobility model, which predicts performance in areal terrain units in terms of speed and identifies the factors causing immobilizations or limiting speed. It also predicts performance in linear terrain units in terms of "go-no go" and identifies the factors causing immobilization where applicable. Basic data required as input to the model are given in tables B11-B14.

Performance in Areal Terrains

40. An example of the primary output of the AMC-71 mobility model is given in table B15. In this table the terrain units (second column) are given in order of decreasing speed. As a secondary consideration, when two or more terrain units yield the same speed, the terrain units are given in order of decreasing size. The third column shows the total size of the terrain unit (i.e. combined area of all patches) in terms of percent of the total study area. The fourth column gives the cumulative area of the terrain units in order from the highest speed to the lowest speed. The fifth column indicates the speed predicted for each terrain unit. A speed of 0.1 mph was arbitrarily assigned to all of the no-go predictions to give some idea of the engineering effort that would be required to cross these areas. The sixth column indicates the average speed considering the indicated terrain unit and all terrain units yielding higher speeds. The seventh, eighth, and ninth columns list the controlling factors (see paragraph 47) when the vehicle is traveling upslope, on a level, and downslope, respectively. Similar data were determined for each vehicle in each of the study areas and provide the basis for the discussions in the following paragraphs.

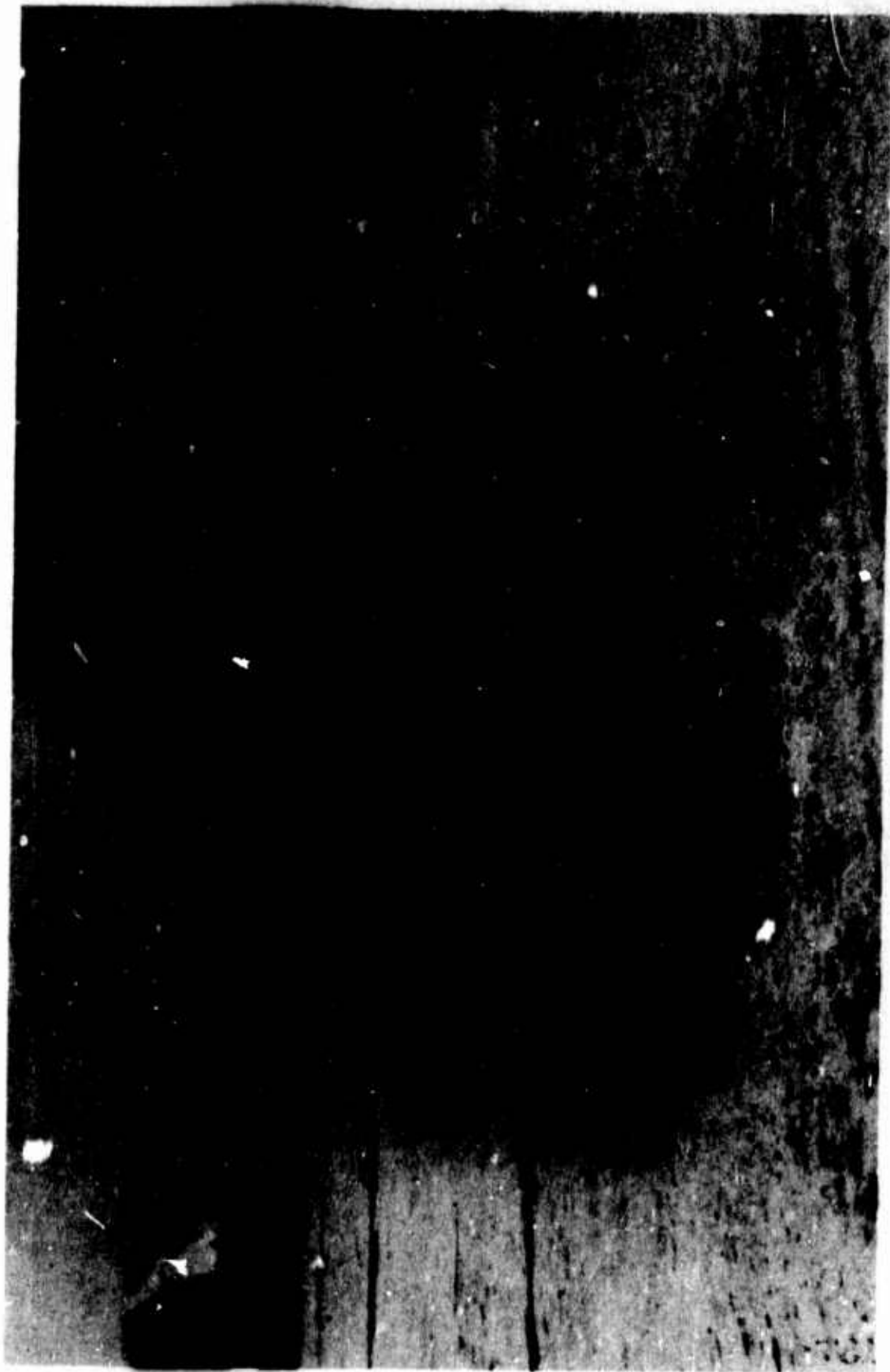


Fig. B26. M51A2, 4x4, 1/4-ton truck

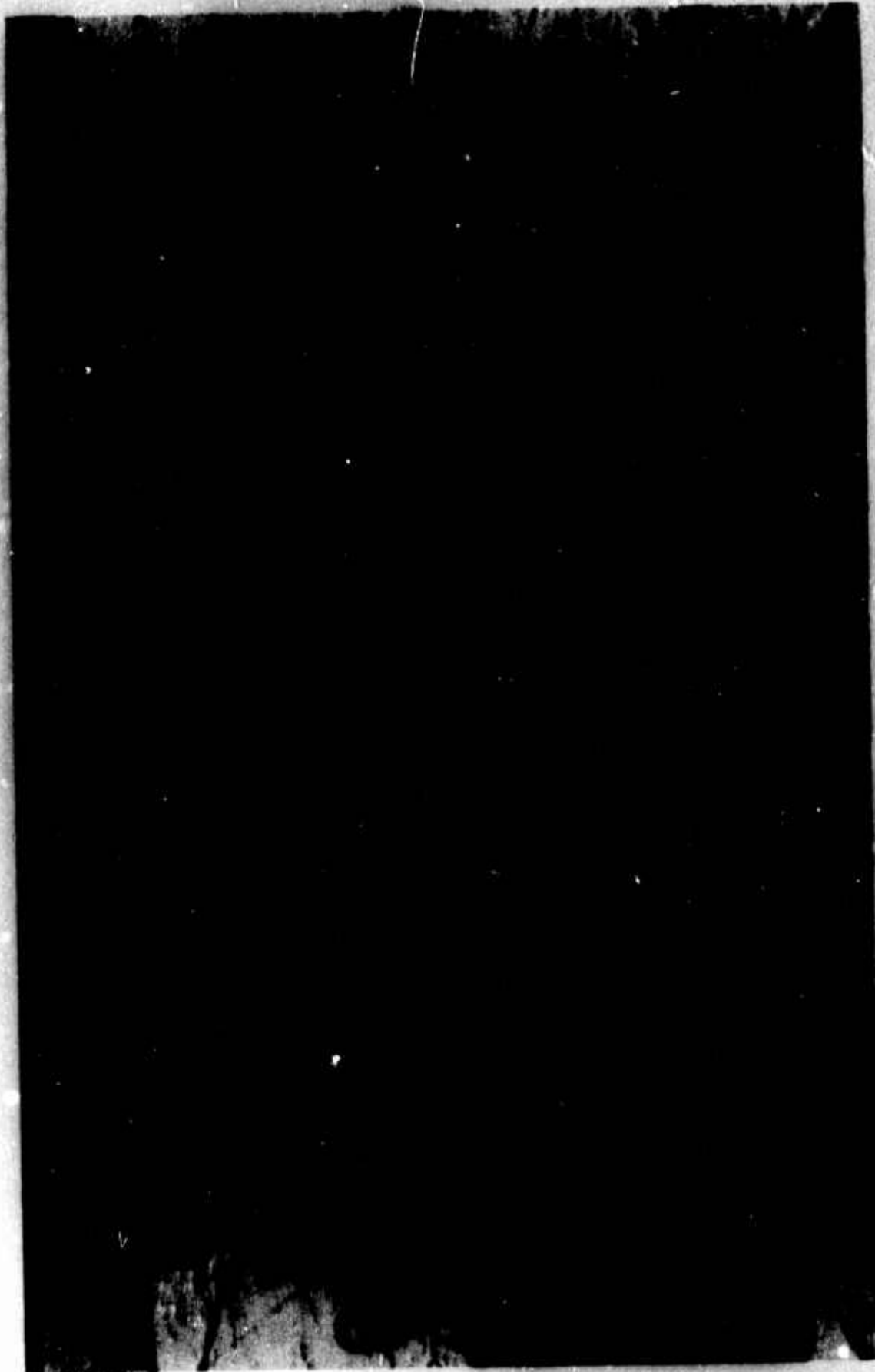


Fig. 227. M114A1E1 armored command and reconnaissance carrier

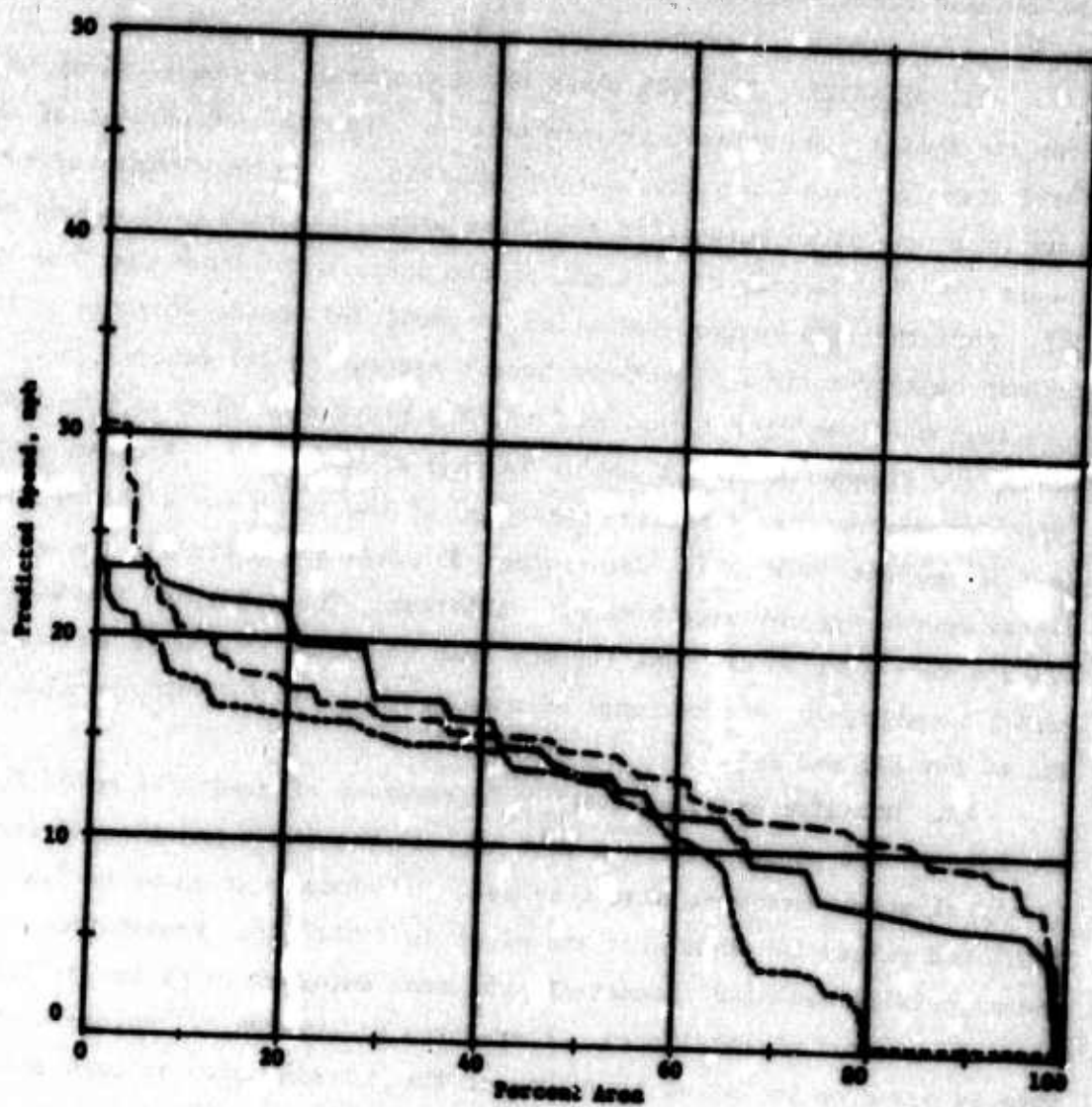
41. The above data were examined from the standpoint of both areal occupancy and frequency of occurrence of speed in terrain units. Mobility profiles were arranged to show the degradation in speed from the best to the poorest terrain units.

Predicted speed

42. M114A1E2. Fig. B28 shows the degradation in predicted speed from the best to the poorest terrain unit as a function of percent of the total area for each study area for the M114A1E1. For the terrain units comprising any given percent of the three areas, the predicted speeds were lowest for FK2, largely as a result of the obstacles (eroded ditches) in FK2. Note that the largest variation in predicted speeds occurred in the terrain units comprising about the best 6 percent (0-6%) (where the surface roughness was very low in FK1) and the poorest 30 percent (70-100%) (where the ditches were most severe in FK2) of each area. For the terrain units comprising approximately 35 percent of the three areas [between the best 30 percent (0-30%) and the poorest 35 percent (65-100%)], the predicted speeds are not significantly different. The predicted speeds for FK1 are more similar to those for WGT than to those for FK2 on an areal basis; however, the entire range of speeds predicted for WGT was also predicted for FK1 and FK2.

43. Mobility profiles showing degradation of predicted speed from the best to the poorest terrain unit in each area as a function of frequency of occurrence were also prepared. An example is shown in fig. B29; tabulated values for this plot are given in table B16. Examination of these profiles revealed essentially the same information as the profiles based on percent of total area. Therefore, discussion of vehicle performance is based on the areal occupancy of the terrain units in each study area.

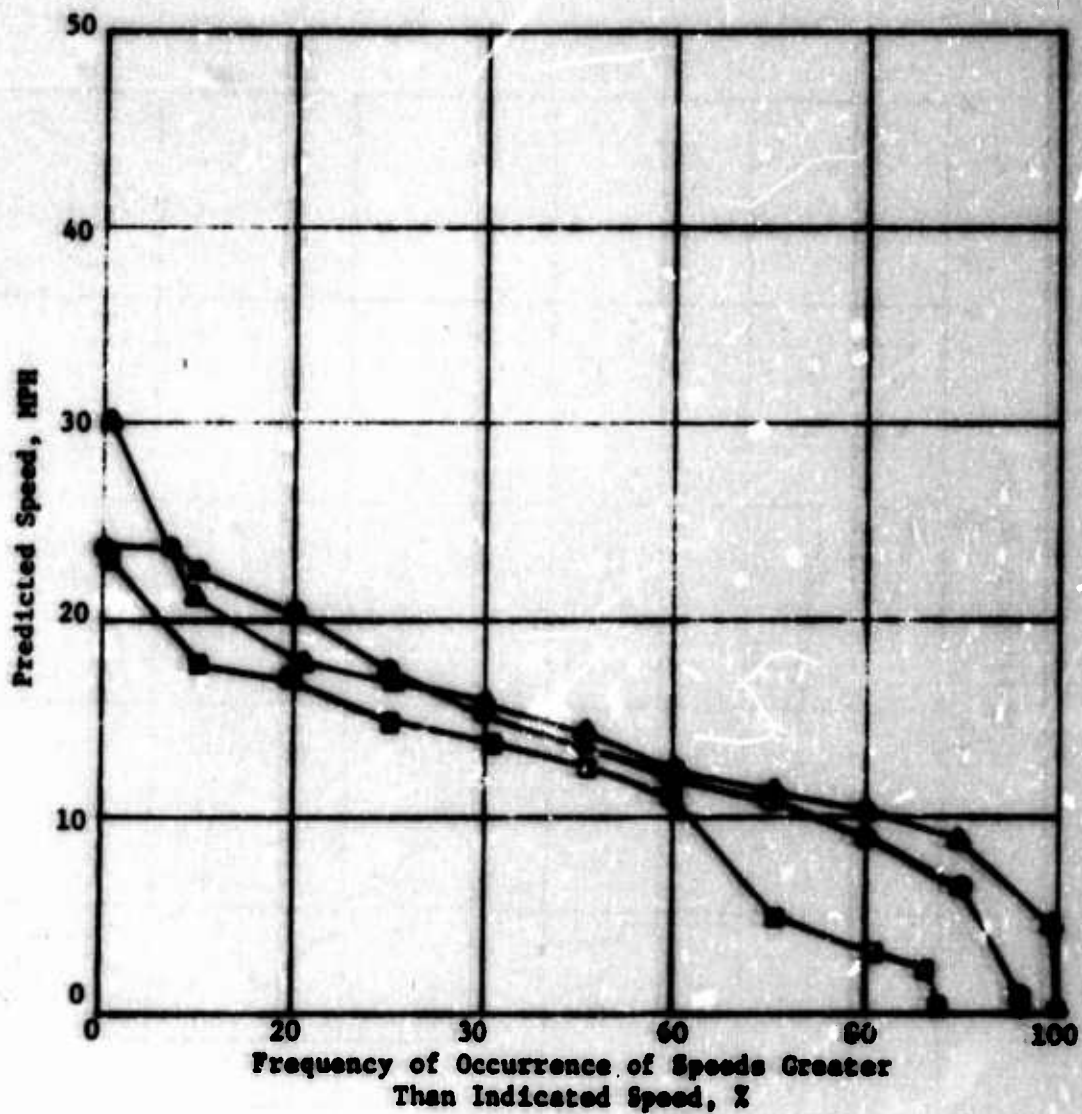
44. M151A2. The mobility profile (fig. B30) for the M151A2 shows that the predicted speed in the terrain units for any given percentage of the three study areas is highest for FK1, generally because the obstacles were less severe and the surface was smoother. The predicted speed in the best 10 percent of the area and about the poorest 30 percent of the area was higher for WGT than for FK2, again because of the eroded ditches in



LEGEND

GUT ———
 FK1 - - - -
 FK2

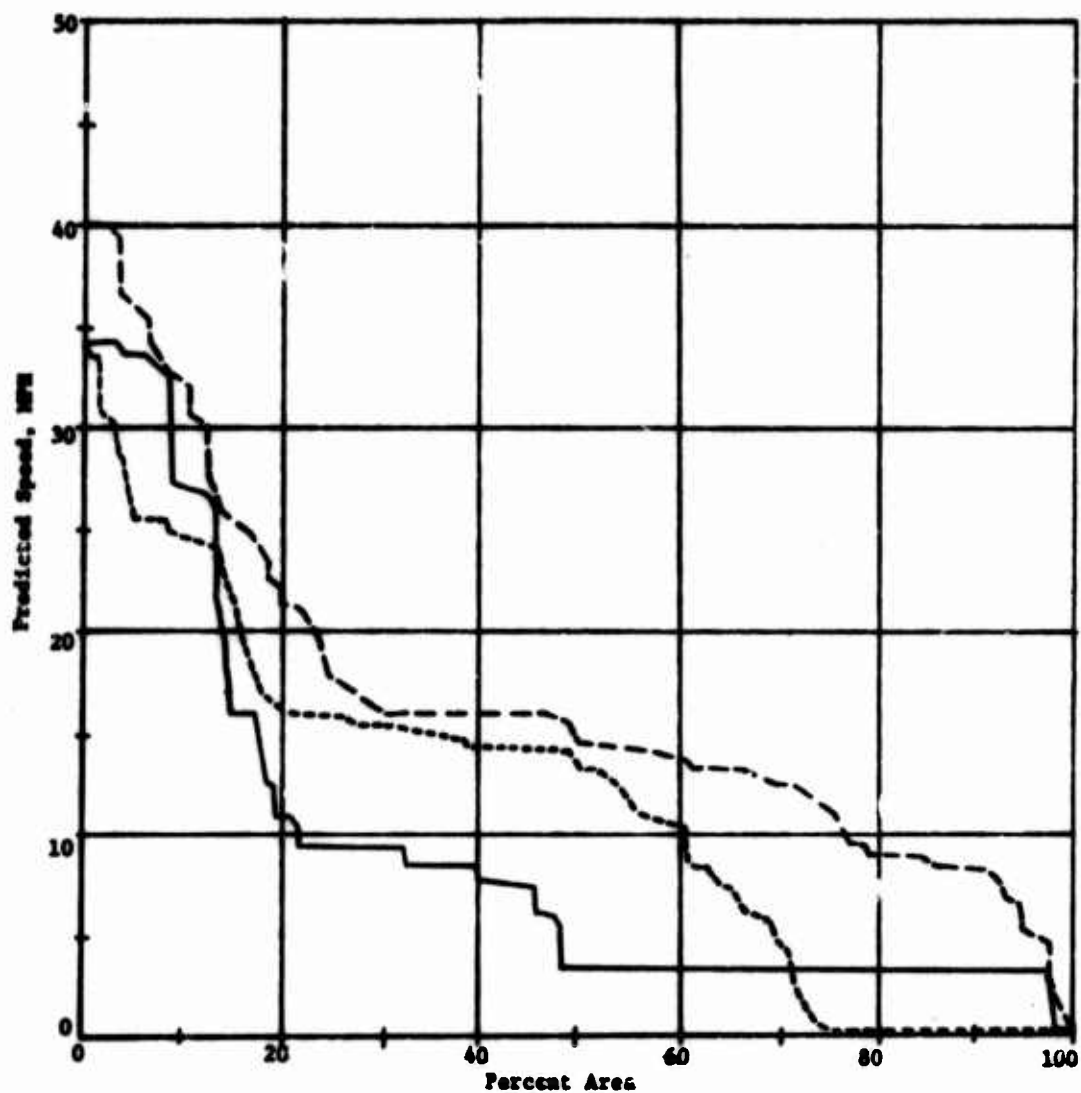
Fig. 226. Predicted speed versus percent area for N114A1R1



LEGEND

- - WGT
- △ - FK1
- - FK2

Fig. B29. Predicted speed versus frequency of occurrence of speeds greater than indicated speed for M114A1E1



LEGEND

WGT ———
 FK1 - - - -
 FK2

**Fig. B30. Predicted speed versus percent area
 for M151A2**

FK2. For the remaining 55 percent of the area, the predicted speed was higher for FK2 than for WGT, largely due to the row crops in WGT. Overall, the predicted speeds for the M151A2 in WGT are less similar to those in FK1 and FK2 than the predicted speeds for the M114A1E1 because the M151A2 was more sensitive to the obstacles in the areas. This sensitivity was brought about because the M151A2 was considered to have to cross the crop rows in WGT, whereas the M114A1E1 was considered to ride on top of the crop rows.

Cumulative average speed

45. The cumulative average speed is the weighted average of the predicted speeds for the best terrain unit, then the best two terrain units, the best three terrain units, etc., as shown in table B15. It is computed as follows:

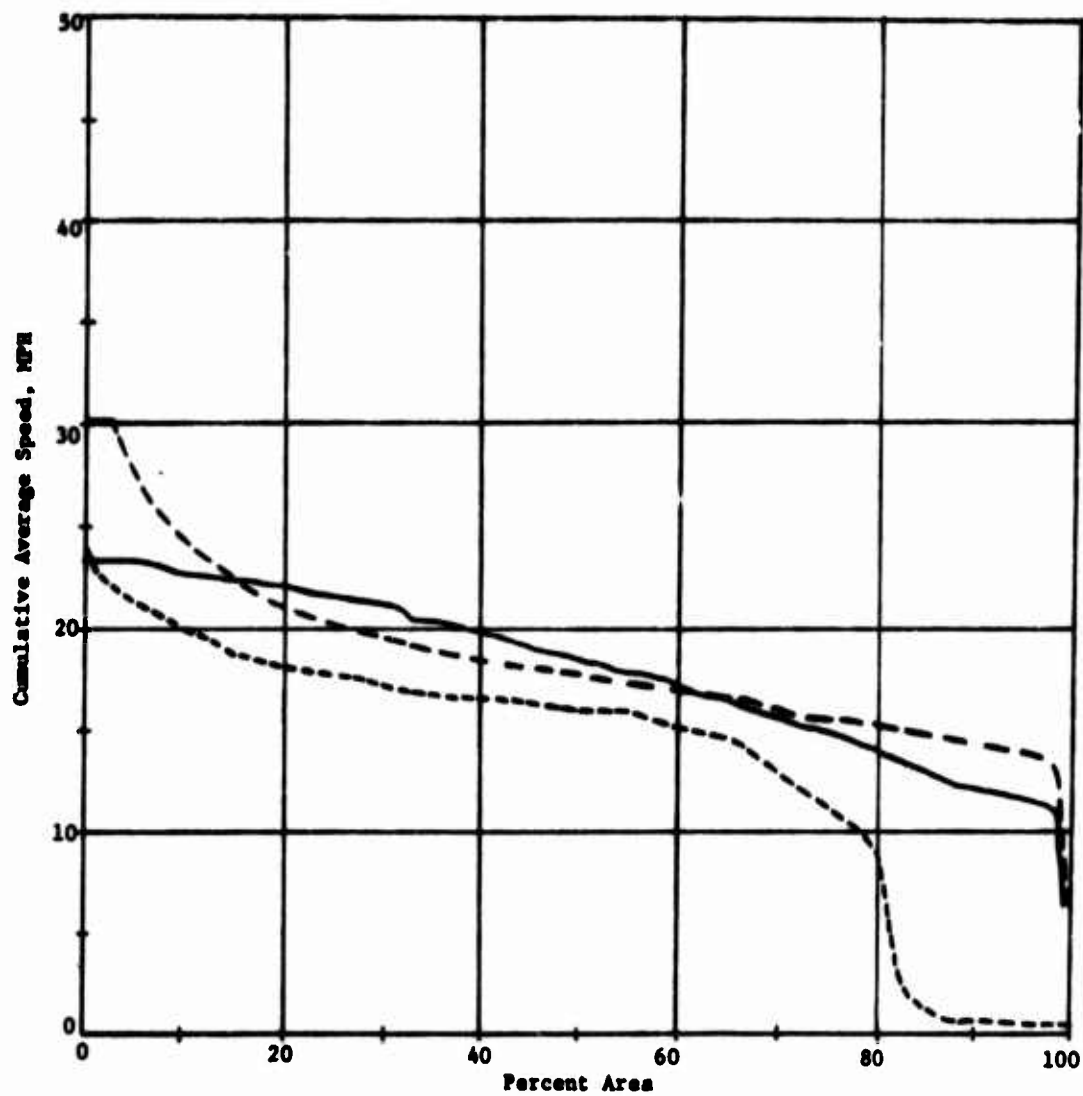
$$\text{Cumulative Average Speed} = \frac{\sum_0^x [\text{speed in unit}_1 \times \text{unit area}_1]}{\sum_0^x \text{unit areas}}$$

Note that immobilizations are assigned a speed of 0.1 mph (see table B15). This is reflected in the cumulative average speed curves. It should be emphasized, however, that when an immobilization is predicted for a terrain unit, this prediction is applicable to the terrain unit as a whole, and it is realized that careful reconnaissance might disclose a path for crossing the area. For instance, a path might be found between linear obstacles such as erosion ditches which would permit traffic in a single direction.

46. M114A1E1. Fig. B31 shows the degradation in cumulative average speed for the M114A1E1 from the best to the poorest terrain unit in each study area.

47. The cumulative average speed in the best 15 percent of the area is highest for FK1. When greater than 15 percent and less than 60 percent of the area is considered, the cumulative average speed is higher for WGT. When greater than 60 percent of the area is considered, the cumulative average speed is highest for FK1. The cumulative average speed for any given percentage of the area is lowest for FK2. For most of the area, the average speeds for the M114A1E1 are similar for FK1 and WGT.

48. M151A2. The cumulative average speed profile for the M151A2



LEGEND

WGT ———
 FK1 - - - -
 FK2 ······

Fig. B31. Cumulative average speed versus percent area
 for M114A1E1

(fig. 332) shows that the cumulative average speed for any given percentage of the area traversed is higher in FK1 than in FK2 or WGT. The cumulative average speed in the best 20 percent of the area is higher for WGT than for FK2. When greater than 20 percent and less than 75 percent of the area is considered, the average speed is higher for FK2 than for WGT. When greater than 75 percent of the area is considered, the average speed for WGT is higher than that for FK2. Again, the cumulative average speeds for the M151A2 show less similarity between the study areas than the cumulative average speeds for the M114A1E1.

Summary of areal terrain performance

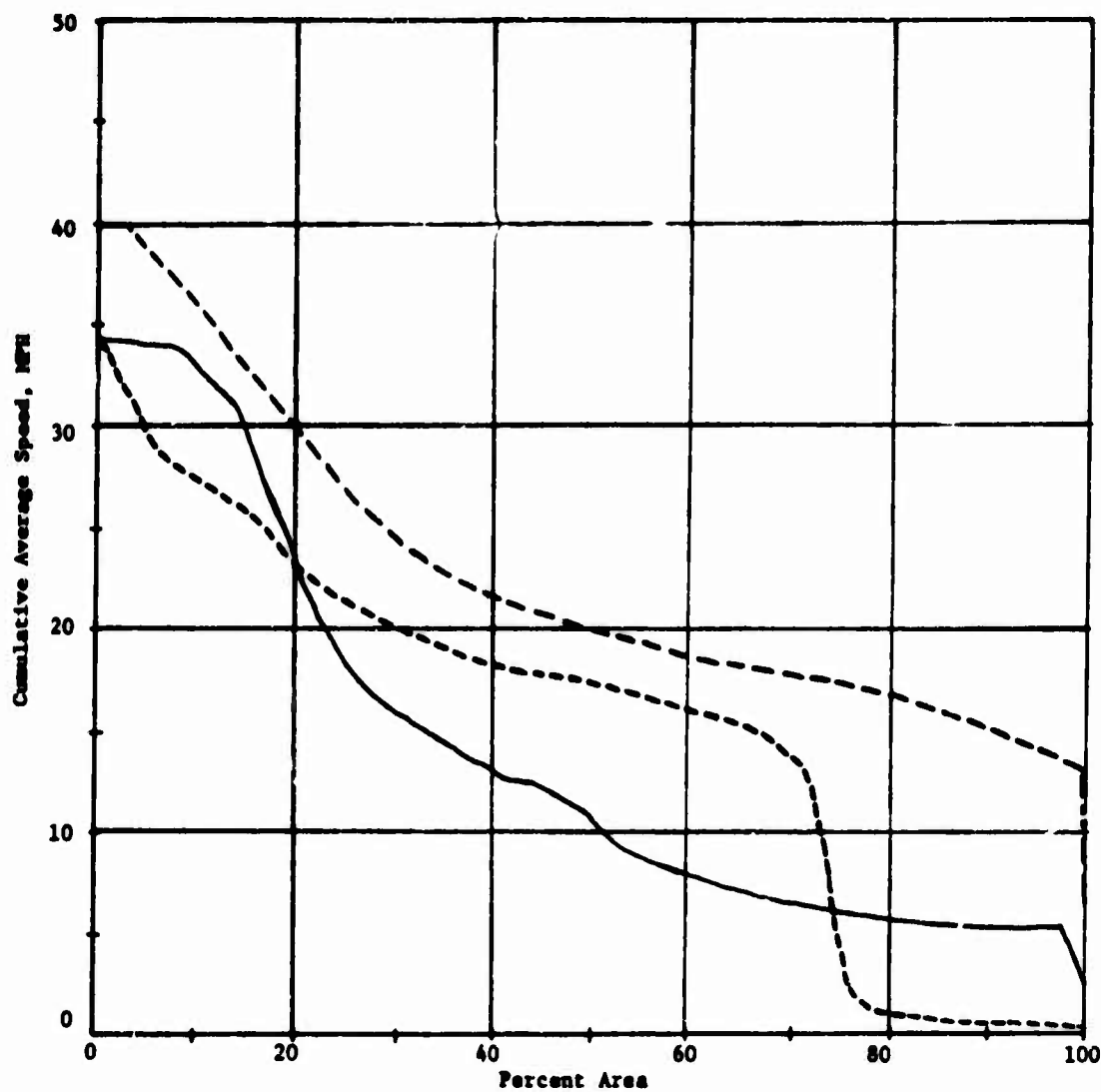
49. A summary of vehicle performance in terms of cumulative average predicted speed of the tracked M114A1E1 and the wheeled M151A2 in the areal terrains of FK1, FK2, and WGT for the best 50 percent (V_{50}) and the best 90 percent (V_{90}) of the respective areas, the ranking of the vehicles (M151A2 speed/M114A1E1 speed), and the predicted percent no go is shown in the following tabulation:

		<u>M114A1E1</u>	<u>M151A2</u>	<u>Ranking</u>
V_{50}	FK1	17 mph	20 mph	118%
	FK2	16 mph	17 mph	106%
	WGT	18 mph	11 mph	61%
V_{90}	FK1	15 mph	17 mph	113%
	FK2	1 mph	1 mph	100%
	WGT	12 mph	6 mph	50%
No Go	FK1	0.8%	2.1%	
	FK2	20.6%	27.7%	
	WGT	0.7%	1.8%	

While the tabulation shows that the ranking of the two different vehicles based on relative speed and percent no go is fairly consistent, the speed performance on an areal basis differs among the three areas.

Controlling Factors in Areal Terrains

50. One of the outputs of the AMC-71 mobility model is the percent of the area at which each of 10 factors either causes an immobilization or limits speed. The 10 controlling factors are identified by number as follows:



LEGEND

WGT ———
 FK1 - - - -
 FK2

Fig. B32. Cumulative average speed versus percent area
 for M151A2

<u>Controlling Factor No.</u>	<u>Description</u>
<u>Factors Causing Immobilization</u>	
1	Surface strength less than minimum required for one pass
2	Available traction less than total of surface and slope resistances
3	Obstacle interference
4	Available traction less than total of surface, slope, obstacle, and vegetation resistances
<u>Factors Limiting Speed</u>	
5	Ride dynamics
6	Total of surface and slope resistance
7	Visibility
8	Maneuvering
9	Total of surface, slope, obstacle, and vegetation resistances
10	Acceleration and deceleration between obstacles

51. It must be emphasized that controlling factors 5 through 10 given above are those that limit speed in the AMC-71 mobility model and do not indicate the degree of effect of individual terrain factors. Nevertheless, they do provide a useful diagnostic tool, subject to certain limitations. For instance, ride dynamics (5) reflects the effects of small-scale surface irregularities, but does not include the effects of overriding obstacles. Surface and slope resistance (6) indicates the effects of surface strength and gravity. Visibility (7), per se, does not directly affect vehicle speed, but limits the driver's vision and hence his ability to avoid obstacles, thus indirectly limiting speed. Factors 8 and 9 indicate the effects of vegetation, soil, slope, and obstacles and are considered together in this analysis as the effects of vegetation-soil-slope combination. The minor effect of obstacles included in factor 9 is not considered. Factor 10 indicates the major effects of obstacles; this includes the speed reduction due to shock when overriding an obstacle, and the effects of acceleration and deceleration between obstacles when applicable.

52. The factors controlling speed were examined at increasing intervals of 20 percent of each area in which the predicted speeds were highest, i.e. the best 20 percent, the best 40 percent, 60 percent, 80 percent, and finally for 100 percent of each study area. These data are given

in tables B17 and B18.

M114A1E1

53. WGT. Fig. B33 shows that ride dynamics (factor 5) is the most significant single factor limiting speed of the M114A1E1 in WGT for all intervals, reflecting the effects of cropland. However, in the 0- to 100-percent interval, the vegetation-soil-slope combination (factors 8 and 9) had a slightly larger effect. Another factor which limited speed in at least 10 percent of WGT was obstacles (10). Fig. B34 shows that immobilizations of the M114A1E1 occurred in less than 1 percent of WGT. These resulted from soil-slope (2), obstacle interference (3), and lack of sufficient traction (4).

54. FK1. In FK1 the two factors (8 and 9) which are associated with vegetation, soil, and slope are the most significant factors limiting speed of the M114A1E1 for all intervals. This was not unexpected since 76 percent of FK1 is wooded. Other factors which limited speed in at least 10 percent of FK1 were ride dynamics (5), soil-slope (6), and obstacles (10). Immobilizations of the M114A1E1 occurred in less than 1 percent of FK1. They resulted from a lack of sufficient traction (4).

55. FK2. For the best 20 percent of FK2, ride dynamics (5) is the most significant factor limiting speed of the M114A1E1; for all other intervals, obstacles (factor 10) were the most significant as a result of the erosion ditches in FK2. Other factors which limited the speed of the M114A1E1 in at least 10 percent of FK2 were ride dynamics (5) and vegetation-soil-slope combination (8 and 9). Immobilizations of the M114A1E1 in 12.6 percent of FK2 were caused by obstacle interference (3) and in 7.9 percent of FK2 were caused by lack of sufficient traction (4).

56. It is noteworthy that not only do all of the factors limiting speed in WGT occur in FK1 and FK2, but they occurred in most speed ranges, indicating a wide range of effects.

M151A2

57. WGT. Fig. B35 shows that ride dynamics (factor 5) was the most significant factor limiting speed of the M151A2 in the best 20 percent of WGT. In the best 40 and best 60 percent of WGT, vegetation-soil-slope combination (factors 8 and 9) was the most significant; in the best

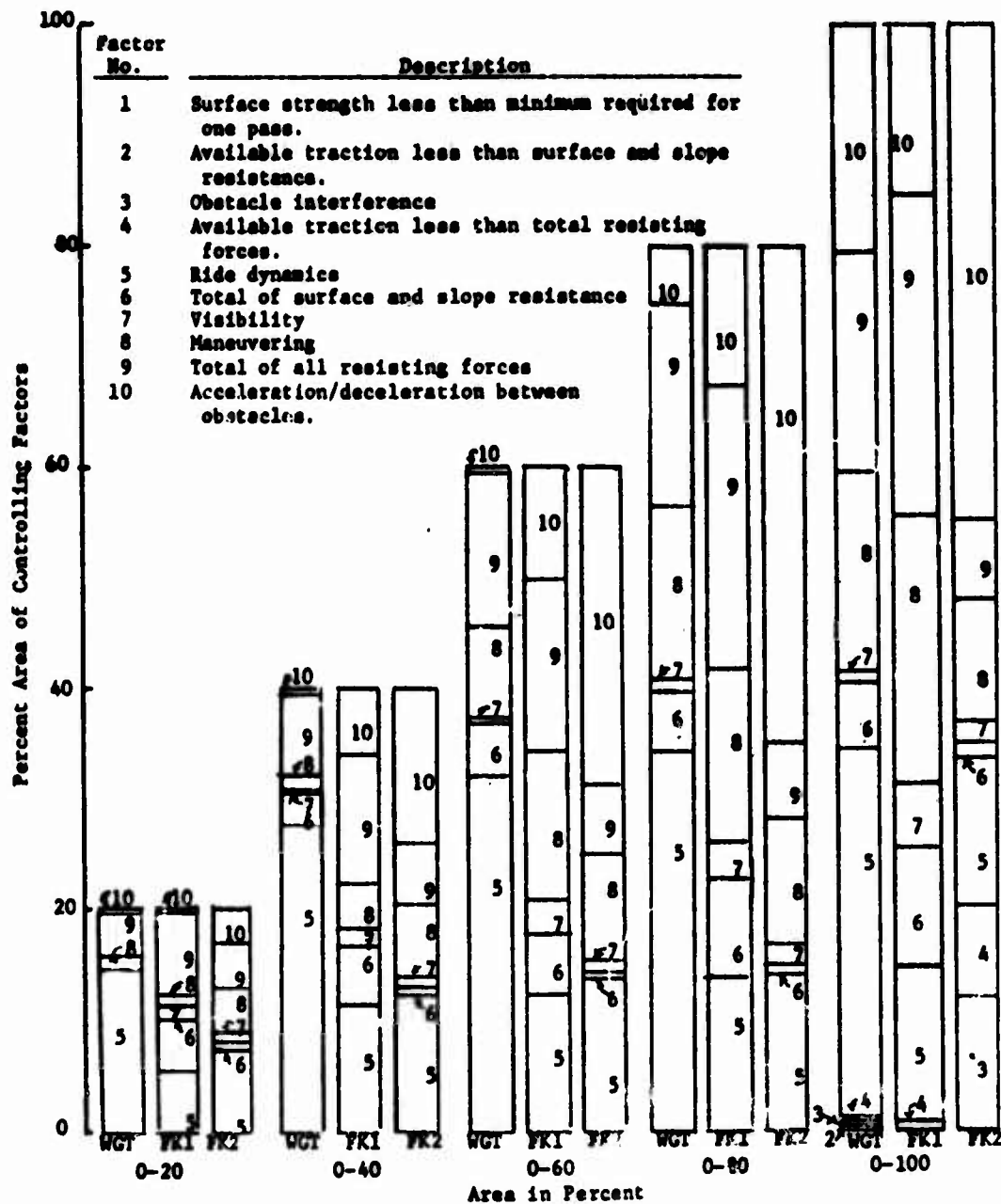


Fig. B33. Controlling factors for the M114A1E1

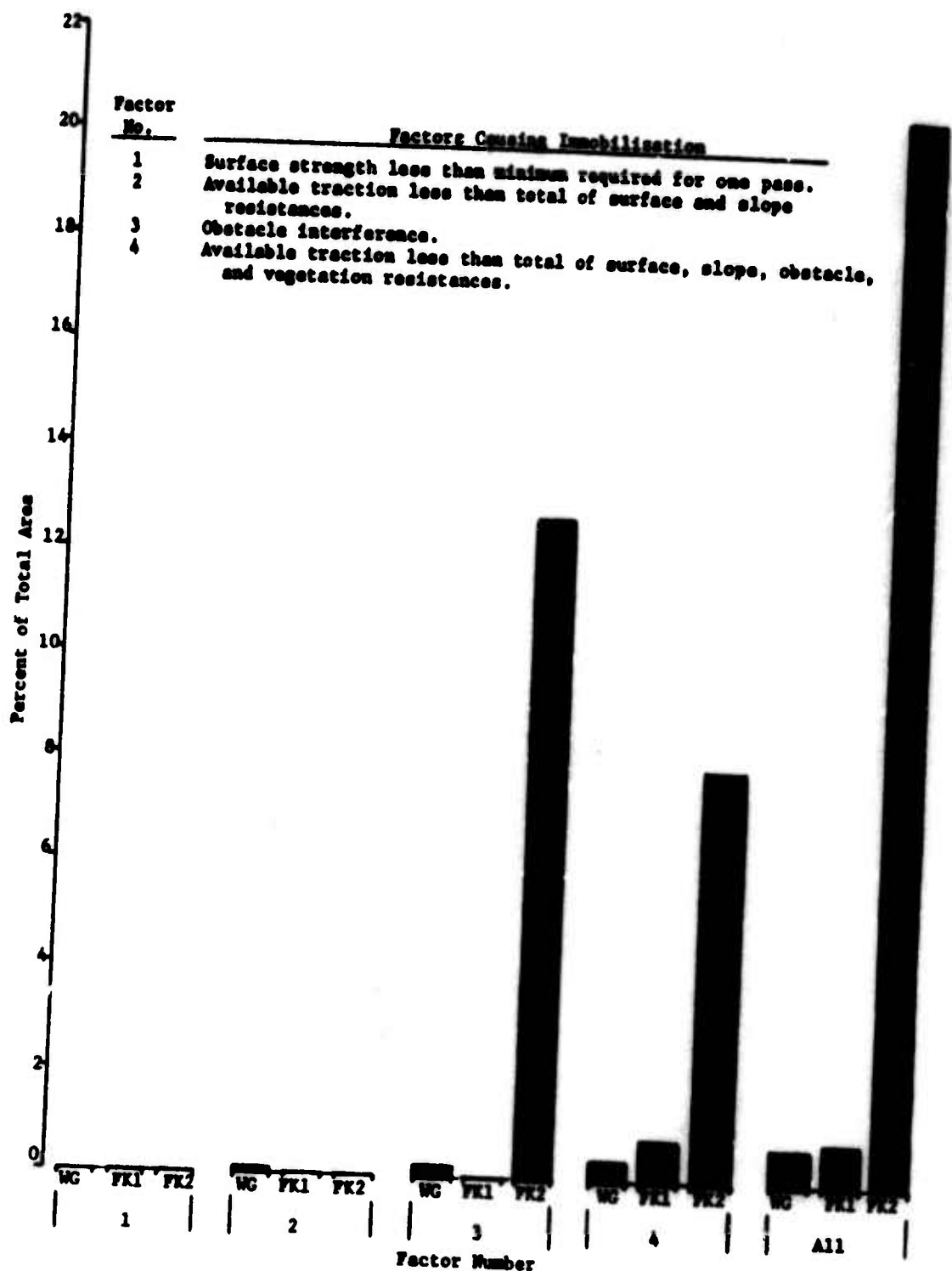


Fig. B34. Factors causing immobilization for the M114A1E1

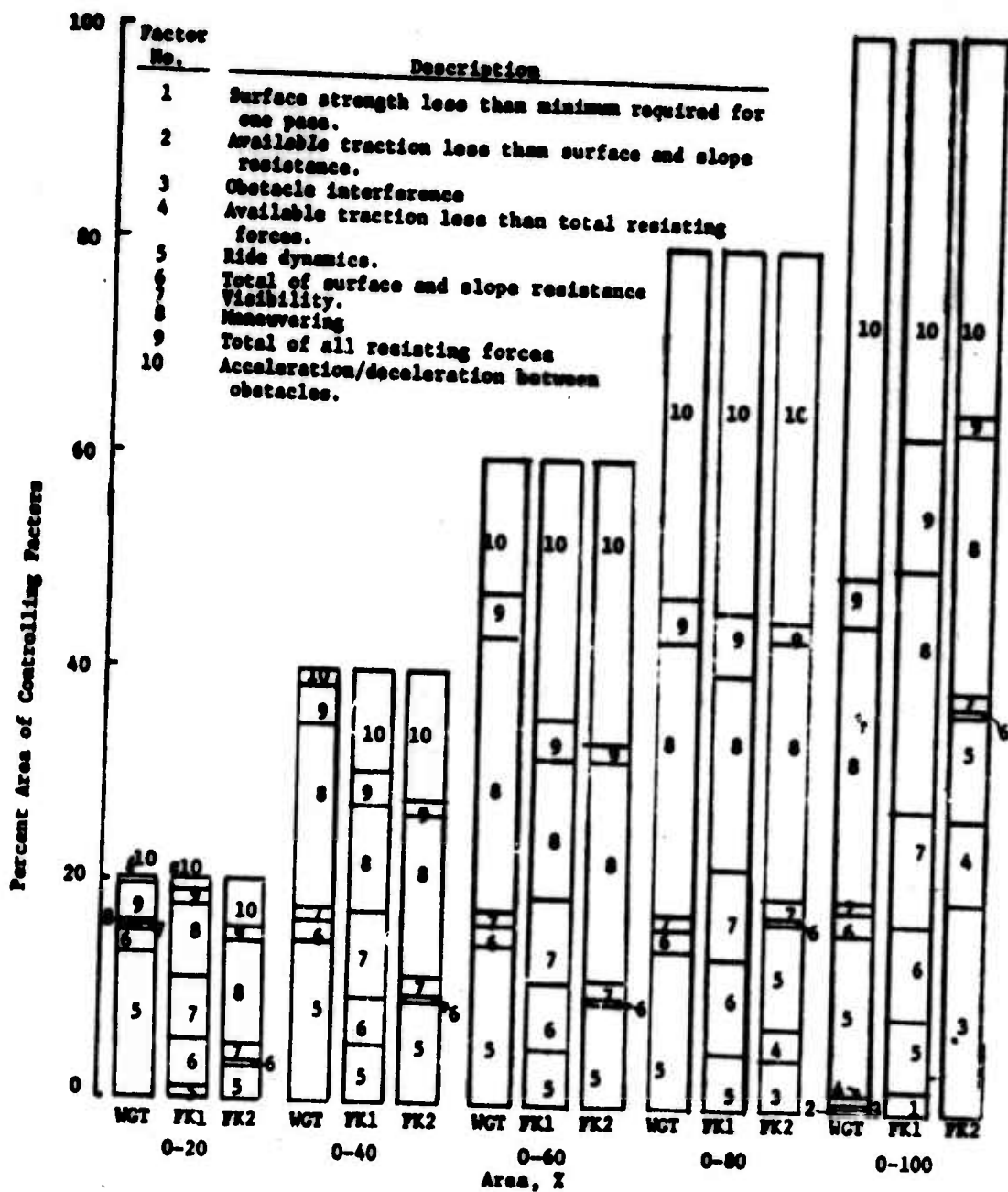


Fig. B35. Controlling factors for the M151A2

80 percent and when 100 percent of WGT was considered, obstacles (factor 10) were most significant. These results reflect the effects of the croplands and forests in WGT. Fig. B36 shows that immobilization of the M151A2 were predicted in less than 2 percent of WGT. They were caused by soil-slope (2), obstacle interference (3), and lack of sufficient traction (4).

58. FK1. In FK1, vegetation-soil-slope combination (8 and 9) limited speed of the M151A2 most frequently in the best 20 and best 40 percent of the area. In the best 60 and 80 percent, and when 100 percent is considered, obstacles (10) most frequently limited speed. The only other factor which limited speed of the M151A2 in at least 10 percent of FK1 was visibility (7). Again, the preponderance of wooded area in FK2 is shown. All immobilizations, which amounted to 2.1 percent of FK1 were due to soft soils (1).

59. FK2. In the best 20 and best 40 percent of FK2, the speed of the M151A2 was most frequently limited by the vegetation-soil-slope combination (8 and 9). In the best 60 and 80 percent, and when the entire area was considered, obstacles (10) limited the speed most frequently. Immobilizations were caused by obstacle interference in 20 percent of FK2 and 7.9 percent of FK2 by lack of sufficient traction (4). Both the factors limiting speed and the factors causing immobilization indicate the range of severity of erosion ditches in FK2.

Effects of Vehicle Characteristics

60. To show the relative overall importance of vehicle ride, traction, and power train, and other vehicle characteristics more clearly, separate plots were made for each factor limiting speed.

61. Ride dynamics (fig. B37) limited speed for the M114A1E1 much more frequently than for the M151A2 in WGT and slightly more often in FK1 and FK2. Most of the effect of ride dynamics occurs in the best 40 percent of the areas (i.e. that 40 percent in which the highest speeds occurred). This reflects the better suspension characteristics of the M151A2 at higher speeds as shown in table B14 where an 1.0 rms allows 34.0 mph for the M151A2 and 23.5 mph for the M114A1E1.

62. Surface and slope resistance (fig. B38) generally limited the

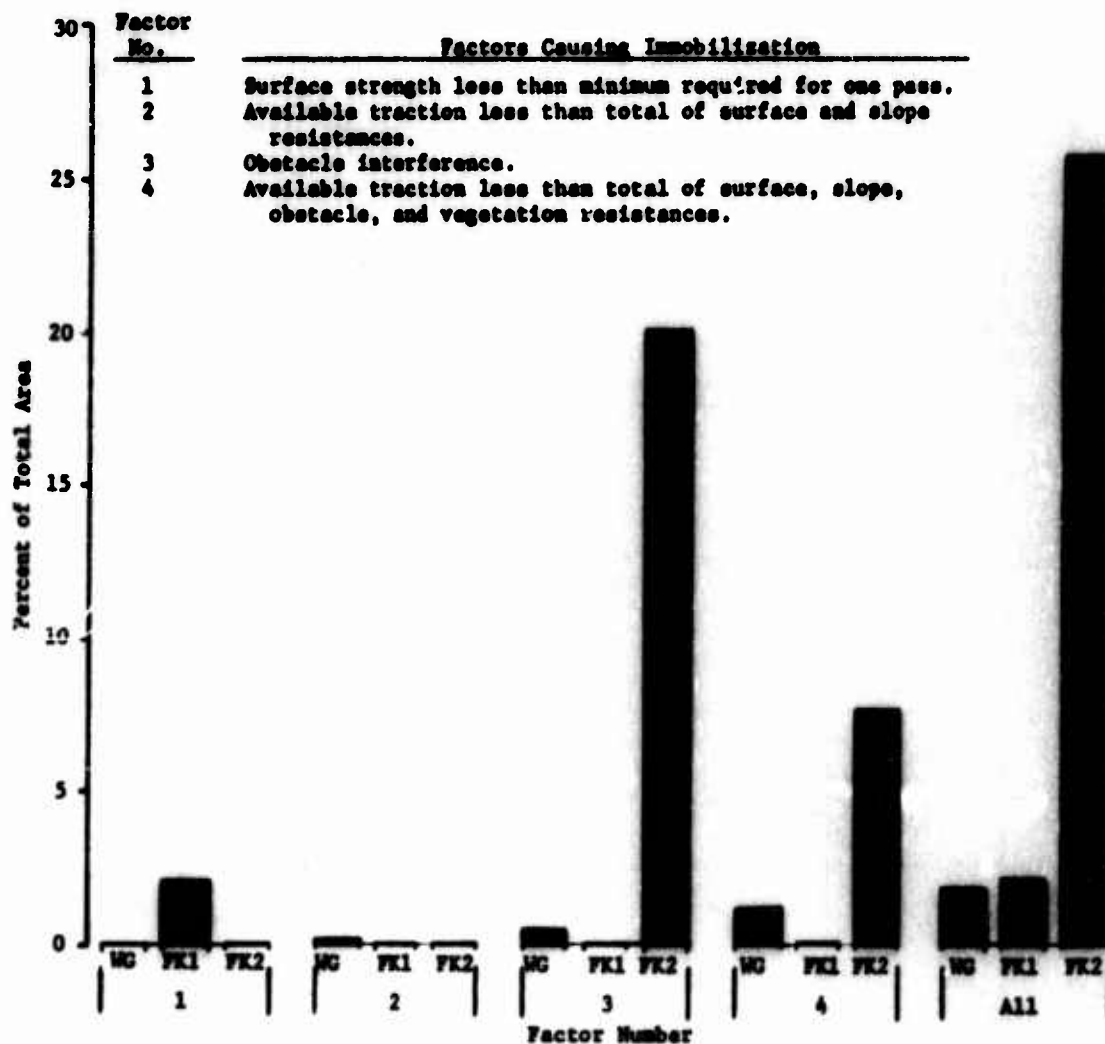


Fig. B36. Factors causing immobilization for the M151A2

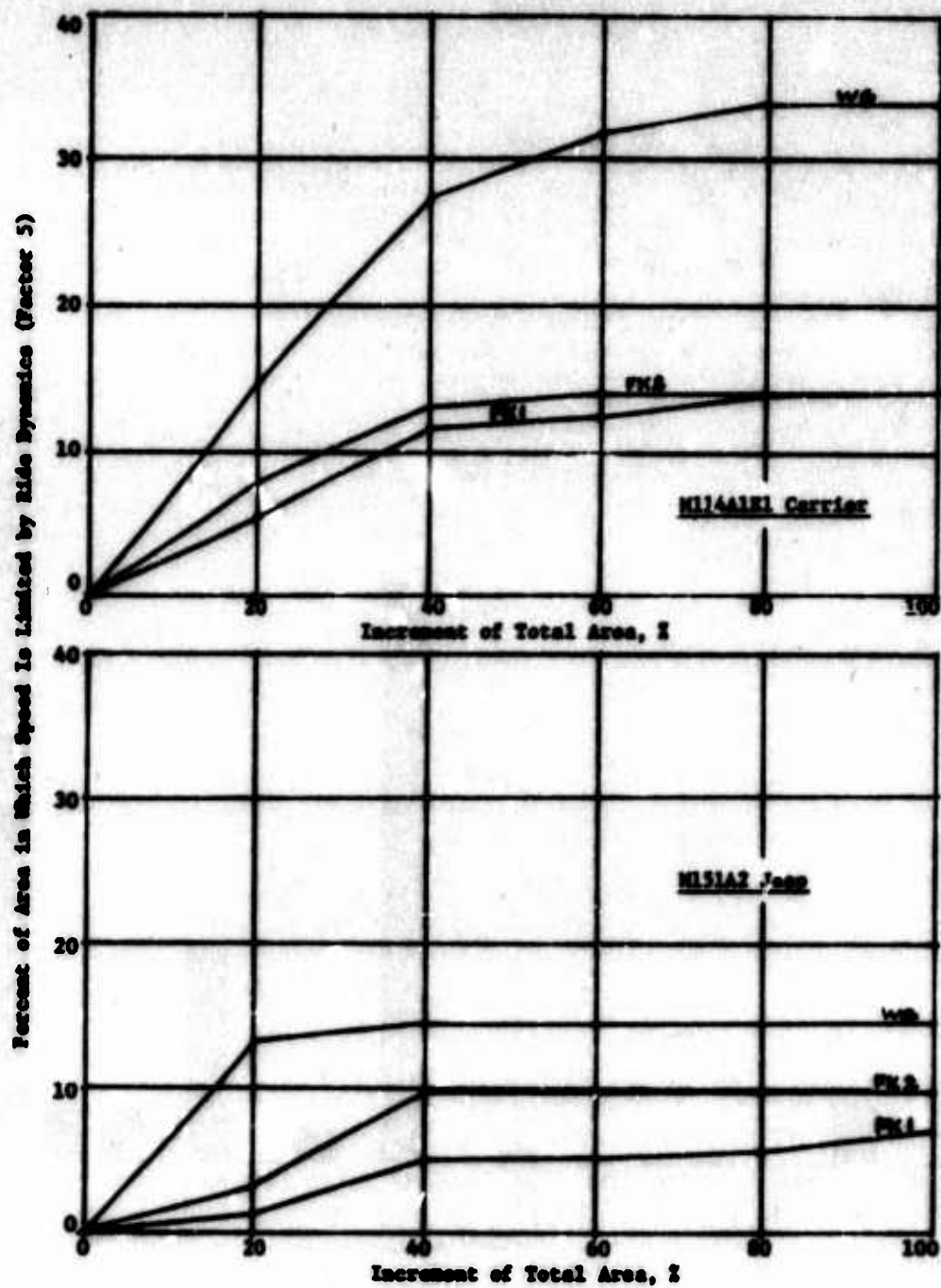


Fig. 837. Effects of ride dynamics on speed

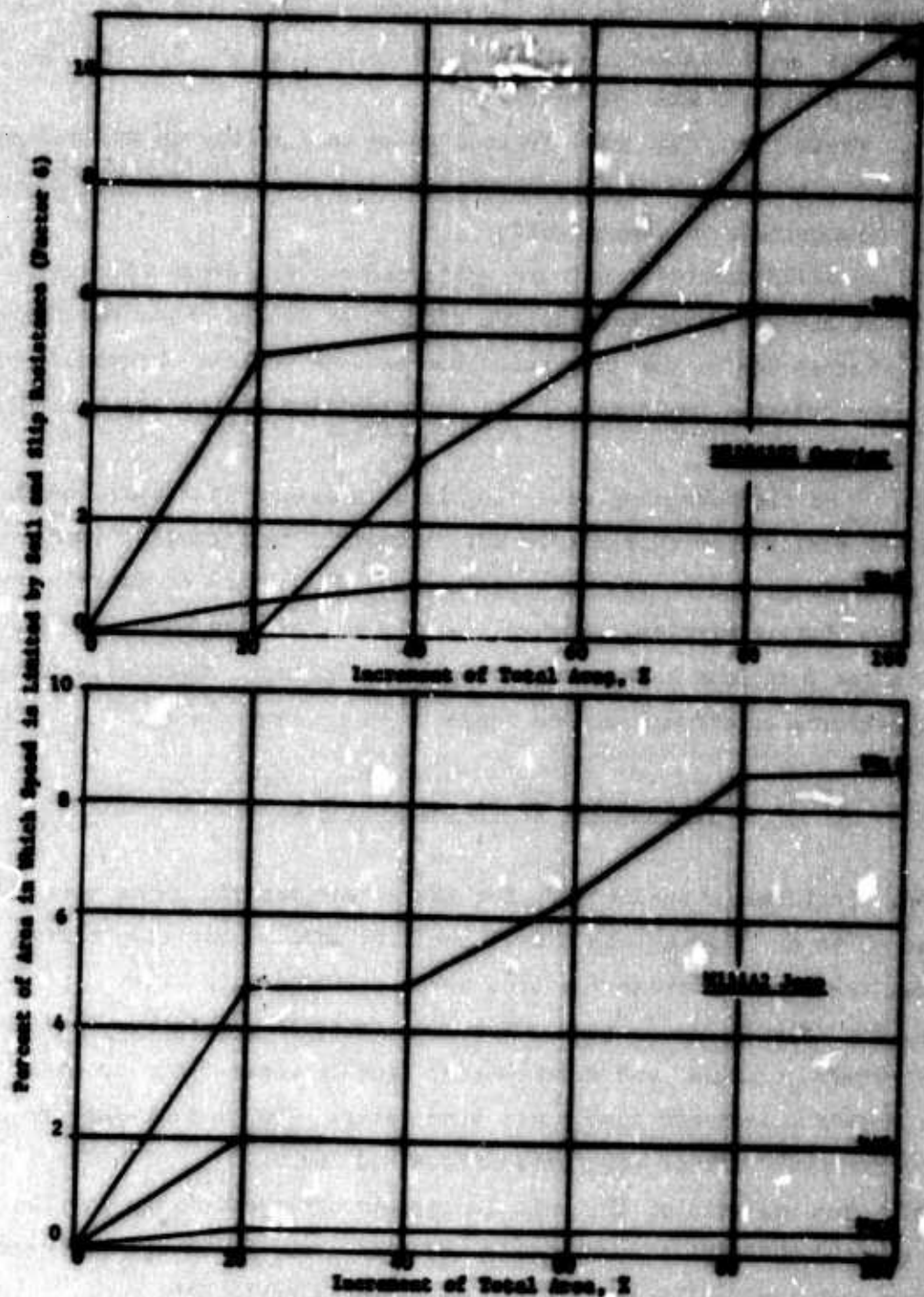


Fig. 136. Effects of soil strength and slope on speed

speed for the M114A1E1 more frequently than for the M151A2, although the differences are small. In the best 20 percent of WGT surface and slope resistance was not a limiting factor for the M114A1E1, but limited the speed of the M151A2 to some extent.

63. Visibility (fig. B39) limited speed only rarely in FK2 and WGT. The difference in FK1 is probably due to the fact that the tracked M114A1E1 can stop more quickly in weaker soils.

64. Similar examinations were performed for the other diagnostic factors, but are not shown because the effects of design characteristics are more obscure due to the interrelations between vehicle characteristics. However, the relative importance of each controlling factor can be seen in figs. B33 and B35.

65. From the foregoing analysis, it is apparent that terrains in FK1 and FK2 differ from terrains in WGT in respect to potential immobilizing situations, and to the relative overall importance of vehicle and power train characteristics. However, individual terrain units can be formed in the Fort Knox study areas by plowing up rows, which will affect vehicle performance throughout the range to be expected in WGT.

Performance in Linear Terrains

66. Performance predictions for the linear terrain units were made in terms of go or no go by the AMC-71 mobility model. For comparative purposes, the linear terrain features were separated into three types--wet concave, dry concave, and convex. Wet concave denotes negative features such as rivers, streams, and ditches that contain water. Dry concave denotes negative features that contain no water. Convex features are positive features such as road embankments and levees.

67. The analysis of the vehicle performance predictions for the M151A2 and the M114A1E1 in each study area in terms of mileage and percent of go for each type of linear feature is shown in table B19.

68. In the wet concave features, both vehicles had a higher percentage of go in FK1 and FK2 than in WGT. This is primarily because there are more large rivers in WGT than in FK1 and FK2.

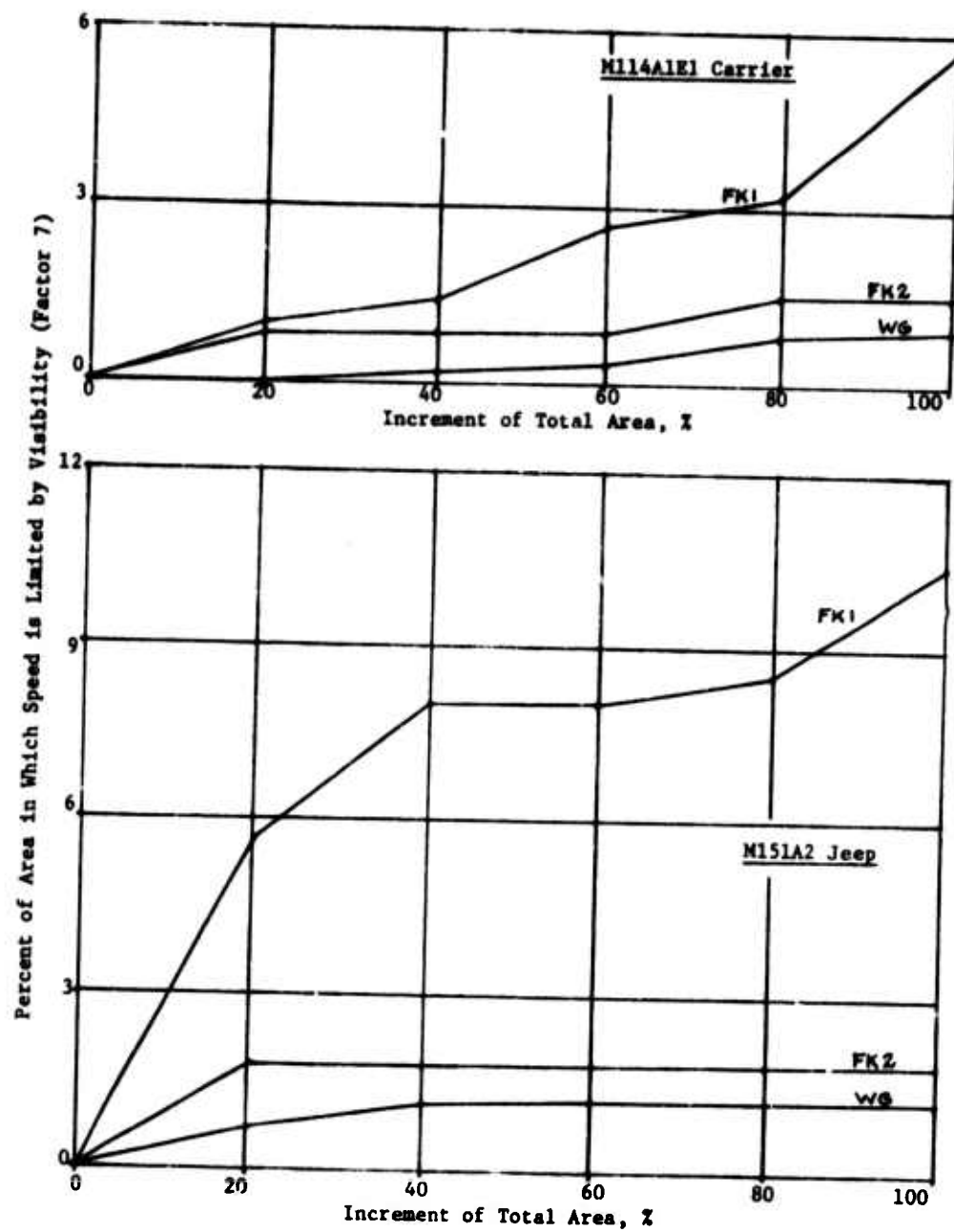


Fig. B39. Effects of visibility on speed

69. In the dry concave features, both vehicles had a higher percentage of go in FK1 than in WGT because of the steep road cuts in WGT. The performances in FK2 and WGT were, in general, similar. While there were no road cuts in FK2, there were several erosion ditches.

70. There were no convex linear features in FK1, and the convex features in FK2 created no difficulty for the vehicles because of the small size of these features. The convex features in WGT comprised a large percent of the total linear features, reflecting the road embankments which would cause some difficulty for both vehicles.

71. If all dry features are considered, the predicted performance of both vehicles in the three study areas appear to be relatively similar. In all types of linear features the percentage of go was higher for the M114A1E1 than for the M151A2, except for the convex features in FK2 where the predictions indicated no difficulty for either vehicle. This is probably a result of the superior traction and swimming capabilities of the M114A1E1.

Factors Causing No-Go Performance in Linear Terrains

72. The output of the AMC-71 mobility model includes the reasons for no-go predictions in linear terrain units. These diagnostic factors are as follows:

<u>Factor No.</u>	<u>Description</u>
1	Water depth greater than fording depth.
2	Water velocity greater than maximum allowable (allowable water velocity based on control of vehicle while crossing stream and exiting).
3	Bank angle-height combination.
4	Surface strength less than minimum required for one pass.
5	Traction available less than surface and slope resistances.
6	Vehicle geometry-linear feature interference.

The reasons for no-go performance are listed in the order in which the applicable terrain and vehicle characteristics are considered in the AMC-71 mobility model, and must be viewed in that light; i.e. once a no go has been predicted for a linear terrain unit, no further determinations are

made. For example, if the water depth exceeds the fording limit for a nonamphibious vehicle, no determination is made for water velocity, bank angle, or soil strength. Thus, when a factor is given for causing no go, it may be correctly assumed that the preceding factors predicted go, but it may not be assumed that the subsequent factors would predict go. In order to reduce the number of computations involving soil strength and traction, the bank angle-height combinations which would yield a no-go condition for both vehicles regardless of soil strength were established. The following values were used:

	<u>Bank Angle, deg</u>	<u>Height, ft</u>
For wet concave features	30 or greater	13
For dry concave features	40 or greater	13
For convex features	40 or greater	13

Note that this is always a special case of factor 5 and may be a special case of factor 4 or factor 6. The immobilizations due to water depth and water velocity (table B20) reflect the presence of the Salt River in FK1 and the Neckar River in WGT. Note that the predictions indicate the amphibious M114A1E1 would do no better in the Salt River (and only slightly better in the Neckar River) than the nonamphibious M141A2. For this study the M141A2 was considered to be operating without a fording kit; however, the depths of the Salt and Neckar Rivers were such that use of the fording kit would not have made them passable.

73. A summary of the vehicle performance diagnostics is given in table B20. Since the M114A1E1 is an amphibious vehicle, water depth caused immobilizations only for the M151A2. For this study the M151A2 was considered to be operating without a fording kit. Fording depth is given in table B11.

74. The lengths of the no go's due to the bank angle-height combination are different for the two vehicles in WGT because the effects of water depth and velocity are considered first in the AMC-71 mobility model.

75. No linear terrain units caused immobilization as a result of insufficient soil strength; i.e. RCI less than VCI_1 .

76. The M114A1E1 had fewer no go's from traction failure in FK1 than the M151A2.

77. Vehicle geometry-linear feature geometry interference caused immobilizations only for the M151A1 in WGT. These resulted from the steeper approach angles in WGT than in FK1 or FK2.

78. In general, the diagnostics show that the percentages of the linear terrains affected by each of the factors causing immobilizations were generally similar in all three areas, with FK1 and WGT being more similar due to the presence of large rivers; the major exception being that FK1 and FK2 lacked the steeper approach angles which caused immobilizations were generally similar in all three areas, with FK1 and WGT being more similar due to the presence of large rivers; the major exception being that FK1 and FK2 lacked the steeper approach angles which caused immobilization for the M151A2 in WGT.

Evaluation

Areal distribution

79. The tabulation of the comparative data describing each parameter shown in fig. B40 was used to consider at several levels of detail the relative importance of the parameters compared in the foregoing paragraphs. Each item was evaluated in terms of the similarity of WGT to FK1 and FK2 according to the following scale: high, som, low, and very low. For instance, the size of WGT was considered to have very low similarity to FK1 and high similarity to FK2, etc. In order to summarize the results at the level shown in the table below, the similarity evaluations of the items listed in the last column were arbitrarily assigned numerical values (High - 4, Same - 3, Low - 2, and Very Low - 1). The values given to the comparative data items were summed and averaged. The average values were used to assign the similarity ratings as follows:

General Description	Comparative Data			WST Similarity To							
	WST			PE1							
	WST	PE1	PE2	High	Same	Low	Very Low	High	Same	Low	Very Low
General Description											
Star	60.2 sq mi	6.2 sq mi	4.7 sq mi								
Topography	Plateau	Flood plain	Plateau			X		X			X
Elevation	600-1250 ft	600-600 ft	600-800 ft			X			X		
Drainage	Good	Poor	Good				X	X			
Soils	Residual silty and clays	Alluvial silty clays	Residual silty clays			X			X		
Climate	Temperate	Temperate	Temperate	X				X			
Land use	Agricultural	Military training	Military training				X				X
Demography	Cities and villages	Bivouac areas	Bivouac areas				X				X
Roads	Improved roads	Trails	Trails				X				X
Hydrology	Large river, streams and canals	Large river, low small streams	Numerous small streams		X				X		
Areal Terrain Units											
Areal occupancy	23/sq mi	31/sq mi	41/sq mi			X					X
Frequency of occurrence	85/sq mi	52/sq mi	40/sq mi				X				X
Linear Terrain Units											
Linear occupancy	1.5/mi	0.6/mi	1.0/mi				X			X	
Frequency of occurrence	3.5/mi	2.9/mi	1.7/mi		X				X		
Areal Terrain Factors											
Soil type	Fine grained	Fine grained	Fine grained	X				X			
Surface strength	502-100 RCI	1002-100 RCI	242-100 RCI				X			X	
	32-40 RCI	442-40 RCI	262-40 RCI								X
Slope	282-52	772-52	432-52				X		X		
	152-202	22-202	0.42-202				X				X
Surface roughness	772-1.5 RMS	482-1.5 RMS	212-1.5 RMS			X					X
Visibility	732-80 ft	612-80 ft	732-80 ft		X			X			
Vegetation	662 open	222 open	662 open				X		X	X	
	82 light	362 light	182 light				X				
	262 heavy	422 heavy	362 heavy			X			X		
Obstacles	Rare	Large	Large and ditches				X				X
Linear Terrain Factors											
Soil type	Coarse grained	Fine grained	Fine grained				X				X
Surface strength	1002-100 RCI	392-100 RCI	202-100 RCI				X				X
	92-40 RCI	92-40 RCI	272-40 RCI				X				X
Approach angles	632-20°	782-20°	632-20°			X		X			
Low bank height	792-in	622-in	882-in			X			X		
Water depth	562-in	702-in	1002-in			X				X	
Water velocity	762-in/sec	712-in/sec	622-in/sec	X		X			X		
Performance of M14A1B1											
No Go (areal)	0.72	0.82	20.62	X							X
No Go (linear)	302	322	202	X					X		
Predicted speed for best 50% of area	14-24 mph	15-30 mph	13-23 mph		X			X			
Weighted average speed for best 50% of area	18 mph	17 mph	16 mph	X				X			
Performance of M151A2											
No Go (areal)	1.02	2.12	27.72	X							X
No Go (linear)	442	552	322		X			X			
Predicted speed for best 50% of area	4-34 mph	14-40 mph	13-34 mph			X				X	
Weighted average speed for best 50% of area	11.3 mph	20.2 mph	17.3 mph			X			X		
Factors Causing No Go for M14A1B1 in Areal Terrain											
Insufficient traction	0.42	0.82	7.92	X							X
Obstacle interference	0.22	—	12.62	X							X
Soil-slope	0.12	—	—	X				X			
Factors Causing No Go for M14A1B1 in Linear Terrain											
Insufficient traction	21.72	5.62	17.32			X		X			
Bank severity	4.82	8.62	3.02	X				X			
Water velocity	3.62	18.02	—			X				X	
Significant Factors Limiting Speed of M14A1B1											
Vegetation-soil-slope	37.62	52.92	17.92		X					X	
Ride dynamics	34.02	14.02	14.02			X				X	
Obstacles	21.02	15.62	44.92		X					X	
Soil-slope	1.02	11.02	5.92		X		X			X	
Factors Causing No Go for M151A2 in Areal Terrain											
Insufficient traction	1.22	—	7.72	X						X	
Obstacle interference	0.42	—	20.02	X							X
Soil-slope	0.22	—	—	X				X			
Soft soil	—	2.12	—	X				X			
Factors Causing No Go for M151A2 in Linear Terrain											
Insufficient traction	31.72	28.82	29.02	X			X				
Bank severity	4.02	8.62	3.02	X				X			
Water depth	4.82	18.02	—		X					X	
Bank interference	4.02	—	—			X				X	
Significant Factors Limiting Speed of M151A2											
Vegetation-soil-slope	30.12	34.82	25.82	X				X			
Ride dynamics	14.62	6.92	9.82			X				X	
Obstacles	30.22	37.02	34.42		X				X		
Visibility	1.12	10.42	1.82			X		X			

Fig. B40. Tabulat. of comparative data

Evaluation Parameter	WGT Similarity To:							
	FK1				FK2			
	High	Some	Low	Very	High	Some	Low	Very
				Low				Low
1. General description			X				X	
2. Areal terrain units			X					X
3. Linear terrain units			X				X	
4. Areal terrain factors				X			X	
5. Linear terrain factors			X				X	
6. Performance of M114A1E1	X					X		
7. Performance of M151A2		X					X	
8. Factors causing no go's for M114A1E1		X						
9. Significant factors limiting speed for M114A1E1			X			X		
10. Factors causing no go's for M151A2	X					X		
11. Significant factors limiting			X			X		

NOTE: Nos. 6, 7, 8, and 10 include both areal and linear terrains.

80. General description. The tabulation shows that the general description of the areas indicate low similarity of WGT to FK1 and FK2.

81. Terrain units and terrain factors. The second, third, fourth, and fifth parameters show low or very low similarity of WGT to FK1 and FK2 as would be expected since these parameters summarize measurements of specific factors used to describe terrain.

82. Mobility performance. The mobility parameters, i.e. 6-11, show the similarity in vehicle performance factors causing no go and factors limited speed for the M114A1E1 and M151A2.

83. The predicted performance of the M114A1E1 was highly similar in WGT and FK1. The factors causing no go's for the M114A1E1 were only somewhat similar in WGT and FK1, and the factors limiting speed of the M114A1E1 show a low similarity between WGT and FK1. The performance of the M114A1E1 in WGT and FK2 was somewhat similar, the factors causing no go and the factors limiting speed were also somewhat similar.

84. The predicted performance of the M151A2 was somewhat similar in WGT and FK1, the factors causing no go for the M151A2 were highly similar between WGT and FK1, and the factors limiting speed showed low similarity between WGT and FK1. The performance of the M151A2 in WGT showed low simialrity to that in FK2; the factors causing no go for the

M151A2 showed some similarity between WGT and FK2; and the factors limiting speed were somewhat similar.

85. When considered together, the predicted performance of the two vehicles indicated more similarity between WGT and FK1, the factors causing no go indicate more similarity between WGT and FK1, and the factors limiting speed indicate more similarity between WGT and FK2.

86. Overall, the mobility parameters indicate that the terrain in FK1 and FK2 is somewhat similar to that in WGT in terms of vehicle response.

Occurrences

87. Although the areal and linear distributions in the terrains are significantly different, examination of the terrain units and the terrain factors individually showed that most of the terrain conditions in WGT that affect mobility can either be found or reproduced with little effort in FK1 and FK2.

88. Areal terrain units. Areal terrain units representative of those in the forested areas of WGT can be selected in FK1 or FK2, although their relative size and frequency of occurrence will differ. Terrain units can be found in FK1 or FK2 which are similar to those in the croplands in WGT except for the obstacles (crop rows), and since these are man made, they can easily be duplicated.

89. Linear terrain units. Generally, linear terrain units similar to those in WGT can be found in FK1 or FK2 except for the linear terrain units comprising the roads. Adding the perimeter road in FK2, which was not mapped, would increase the number of similar terrain units.

90. Areal terrain factors. Although the areal occupancy and frequency of occurrence of individual terrain factor values do differ, generally the factor values which occur in WGT can be found in FK1 or FK2, for example:

- a. Soil strength. All of the soil strength classes occurring in WGT can be found in FK1 or FK2.
- b. Slopes. The slopes which occur in WGT and not in FK1 or FK2 represent only 0.2 percent of WGT.
- c. Surface roughness. All of the surface roughness classes which are in WGT can be found in FK1 or FK2.
- d. Visibility. All of the visibility classes occurring in WGT can be found in FK1 or FK2.

- e. Obstacles. The major obstacles in WGT which are not found in FK1 or FK2 are the crop rows, which can be easily duplicated.
- f. Vegetation. All of the stem diameter classes found in WGT occur in some terrain units of FK1 or FK2. The spacing classes which are not duplicated represent areas of widely spaced trees which have little or no effect on vehicle performance. In any event, these spacing classes could conceivably be duplicated at Fort Knox by removing a few trees.

91. Linear terrain factors. Most of the linear terrain factor values occurring in WGT can be found in FK1 or FK2 except values for low bank height and approach angle terrain factors. However, the overall range of low bank heights in WGT is duplicated in FK1 or FK2, and the missing classes represent only 2.0 percent of the WGT linear features. Most of the approach angles that do not occur in FK1 or FK2 as presently mapped (except the steeper approach angles which resulted from the large cuts and fills along the primary roads in WGT) would be found if the perimeter road around FK2 were included.

92. Vehicle speed. The ranges of vehicle speed for both vehicles that were predicted for WGT were also predicted for FK1 or FK2, although the relative areas for which these speeds were predicted did, in some cases, significantly differ.

93. Factors causing immobilization. The only immobilizing factor in areal terrains which occurred in the predictions for WGT and not in those for FK1 or FK2 was the surface strength-slope combination which represents only 0.2 percent of WGT for the M151A2 and 0.1 percent of WGT for the M114A1E1. The only immobilizing factor in linear terrains which occurred in WGT predictions and not in those for FK1 or FK2 was vehicle geometry-linear feature geometry interference for the M151A2.

94. Factors limiting speed. All of the factors limiting speed that occurred in the WGT predictions also occurred in those for both FK1 and FK2.

Summary of local Spanish White, Arab, Portuguese, and Portuguese Data for B. From Study Area 1 (2011)

(Continued)

166<

167<

(2 of 2 sheets)

Table B2
 Sources of Annual Sectoral Real Gross Domestic Product for P. R. from 1960 to 1982

[illegible]

accumulative total.
 represents the total
 area occupied by all of the occurrences (patches) of the indicated terrain unit.
 represents the total
 number of occurrences (patches) of the indicated terrain unit.

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169<

[illegible]

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Cumulative total.

Table B3 (Continued)

[illegible]

(2 of 14 sheets)

((Cont. Forward))

Table B3 (Continued)

Table B3 (Continued)

[illegible]

(Cont. from p. 1)

(4 of 14 sheets)

Table B1 (Continued)

ITEM NO.	TERMINAL UNIT	TOTAL SO. MI.	NO. OF RECOR	MEAN AREA SO. MI.	OCCURRENCES			
					AREA	OCCURRENCES		
					AREA	OCCURRENCES		
					AREA	OCCURRENCES		
484	384	709	3	0.003	0.014	94.713	0.059	77.050
485	786	709	1	0.009	0.014	94.727	0.020	77.078
486	153	709	2	0.005	0.014	94.741	0.020	77.097
487	367	709	2	0.005	0.014	94.756	0.030	77.936
488	222	709	2	0.005	0.014	94.770	0.030	77.975
489	222	709	2	0.005	0.014	94.784	0.030	78.014
490	879	709	1	0.009	0.014	94.798	0.020	78.034
491	1442	709	3	0.003	0.014	94.813	0.050	78.093
492	183	709	1	0.009	0.014	94.827	0.020	78.112
493	19.4	709	2	0.005	0.014	94.841	0.020	78.131
494	71	709	2	0.004	0.014	94.855	0.030	78.190
495	1336	709	1	0.009	0.014	94.869	0.020	78.210
496	471	709	2	0.004	0.014	94.882	0.020	78.269
497	1233	709	1	0.009	0.014	94.896	0.020	78.269
498	1237	709	3	0.003	0.014	94.910	0.050	78.277
499	744	709	5	0.002	0.014	94.923	0.090	78.925
500	1136	709	2	0.003	0.014	94.937	0.050	78.983
501	721	709	1	0.009	0.014	94.951	0.020	78.983
502	426	709	2	0.004	0.014	94.965	0.030	78.982
503	594	709	1	0.009	0.014	94.978	0.020	78.982
504	1414	709	2	0.004	0.014	94.992	0.020	78.982
505	186	709	1	0.009	0.014	95.006	0.020	78.982
506	160	709	2	0.003	0.014	95.019	0.030	78.959
507	149	709	3	0.003	0.014	95.033	0.050	78.710
508	184	709	1	0.009	0.014	95.047	0.020	78.738
509	753	709	3	0.003	0.013	95.061	0.050	78.796
510	346	709	2	0.004	0.013	95.075	0.030	78.835
511	366	709	2	0.004	0.013	95.089	0.030	78.874
512	436	709	1	0.008	0.013	95.109	0.020	78.894
513	46	709	2	0.004	0.013	95.112	0.030	78.933
514	8	709	3	0.003	0.013	95.125	0.050	78.992
515	639	709	2	0.004	0.013	95.138	0.030	79.031
516	308	709	2	0.004	0.013	95.151	0.020	79.070
517	874	709	1	0.008	0.013	95.165	0.020	79.089
518	6	709	1	0.008	0.013	95.178	0.020	79.180
519	1419	709	1	0.008	0.013	95.191	0.020	79.126
520	279	709	2	0.004	0.013	95.204	0.030	79.167
521	1374	709	1	0.008	0.013	95.217	0.020	79.167
522	1727	709	1	0.008	0.013	95.230	0.020	79.267
523	223	709	2	0.004	0.013	95.243	0.030	79.266
524	80	709	2	0.008	0.013	95.256	0.020	79.245
525	278	709	2	0.004	0.013	95.268	0.030	79.304
526	734	709	2	0.004	0.013	95.281	0.030	79.343
527	894	709	1	0.008	0.013	95.293	0.020	79.363
528	48	709	2	0.004	0.013	95.306	0.030	79.462
529	15	709	1	0.008	0.013	95.318	0.020	79.422
530	157	709	3	0.003	0.013	95.331	0.050	79.490
531	1893	709	1	0.008	0.013	95.343	0.020	79.500
532	1574	709	2	0.004	0.013	95.356	0.020	79.510
533	1771	709	1	0.008	0.013	95.368	0.030	79.558
534	1869	709	1	0.008	0.013	95.381	0.020	79.570
535	155	709	2	0.004	0.013	95.393	0.030	79.617
536	1924	709	1	0.008	0.013	95.406	0.020	79.637
537	826	709	1	0.008	0.013	95.418	0.020	79.694

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(5 of 14 sheets)

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ITEM NO.	TERMINAL UNIT	TOTAL AREA SQ. MI.	NO. OF OCCUR.	MEAN 50-MI.	OCCURRENCES				
					1	2	3	4	5
238	1286	1.000	1	0.00	0.019	95.431	0.020	78.076	
239	356	1.000	2	0.04	0.013	95.443	0.339	78.715	
240	422	1.000	2	0.04	0.013	95.456	0.339	78.734	
241	1035	1.000	1	0.00	0.013	95.468	0.020	78.773	
242	949	1.000	1	0.00	0.013	95.481	0.020	78.782	
243	411	1.000	1	0.00	0.013	95.493	0.020	78.812	
244	137	1.000	3	0.003	0.012	95.505	0.339	78.871	
245	705	1.000	3	0.003	0.012	95.517	0.339	78.901	
246	46	1.000	1	0.00	0.012	95.529	0.020	78.949	
247	1325	1.000	2	0.04	0.012	95.541	0.339	79.068	
248	296	1.000	2	0.04	0.012	95.553	0.339	80.037	
249	19	1.000	1	0.00	0.012	95.565	0.020	80.047	
250	715	1.000	2	0.04	0.012	95.577	0.339	80.066	
251	323	1.000	2	0.04	0.012	95.589	0.339	80.135	
252	1237	1.000	1	0.00	0.012	95.600	0.020	80.145	
253	652	1.000	2	0.004	0.012	95.612	0.339	80.164	
254	1249	1.000	1	0.00	0.012	95.624	0.020	80.184	
255	296	1.000	3	0.003	0.012	95.636	0.339	80.242	
256	417	1.000	2	0.04	0.012	95.648	0.339	80.311	
257	778	1.000	2	0.04	0.012	95.660	0.339	80.349	
258	1514	1.000	3	0.004	0.012	95.672	0.339	80.438	
259	253	1.000	1	0.00	0.012	95.684	0.020	80.457	
260	422	1.000	2	0.004	0.012	95.696	0.339	80.497	
261	1149	1.000	3	0.004	0.012	95.708	0.339	80.536	
262	43	1.000	1	0.00	0.012	95.720	0.020	80.595	
263	1135	1.000	4	0.001	0.012	95.731	0.137	80.693	
264	949	1.000	1	0.00	0.012	95.743	0.020	80.672	
265	1361	1.000	1	0.00	0.012	95.755	0.020	80.692	
266	128	1.000	1	0.00	0.012	95.767	0.020	80.711	
267	676	1.000	2	0.004	0.012	95.779	0.339	80.750	
268	1347	1.007	1	0.007	0.011	95.790	0.020	80.770	
269	1345	1.007	1	0.007	0.011	95.802	0.020	80.788	
270	1230	1.007	1	0.007	0.011	95.813	0.020	80.809	
271	129	1.007	1	0.007	0.011	95.824	0.020	80.829	
272	902	1.007	1	0.007	0.011	95.836	0.020	80.848	
273	313	1.007	1	0.007	0.011	95.847	0.020	80.868	
274	916	1.007	1	0.007	0.011	95.858	0.020	80.887	
275	1241	1.007	1	0.007	0.011	95.870	0.020	80.907	
276	957	1.007	3	0.002	0.011	95.881	0.050	80.965	
277	326	1.007	1	0.007	0.011	95.892	0.020	80.985	
278	226	1.007	1	0.007	0.011	95.904	0.020	81.004	
279	1223	1.007	1	0.007	0.011	95.915	0.020	81.024	
280	1253	1.007	2	0.004	0.011	95.926	0.339	81.043	
281	1028	1.007	1	0.007	0.011	95.937	0.020	81.063	
282	1478	1.007	1	0.007	0.011	95.949	0.020	81.122	
283	1284	1.007	2	0.004	0.011	95.960	0.020	81.141	
284	1077	1.007	1	0.007	0.011	95.971	0.020	81.161	
285	28	1.007	1	0.007	0.011	95.982	0.020	81.180	
286	7	1.007	1	0.007	0.011	95.993	0.020	81.200	
287	495	1.007	3	0.002	0.011	96.004	0.050	81.259	
288	1022	1.007	1	0.007	0.011	96.014	0.020	81.277	
289	67	1.007	2	0.003	0.011	96.025	0.339	81.317	
290	459	1.007	1	0.007	0.011	96.036	0.020	81.336	
291	756	1.007	2	0.003	0.011	96.046	0.339	81.355	

(6 of 14 sheets)

Table 13 (Continued)

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(Cont. 196-4)

(17 of 16 sheets)

Table B3 (Continued)

ITEM NO.	TERMINAL AREA SQ. MI.	TOTAL AREA SQ. MI.	NO. OF OCCUR.	MEAN AREA SQ. MI.	AREA SQ. MI.	OCCURRENCES SQ. MI.	ITEM NO.	TERMINAL AREA SQ. MI.	TOTAL AREA SQ. MI.	NO. OF OCCUR.	MEAN AREA SQ. MI.	AREA SQ. MI.	OCCURRENCES SQ. MI.
754	776	1.005	2	0.003	0.000	0.000	889	975	1.004	3	0.002	0.007	0.000
755	845	1.005	2	0.003	0.000	0.000	890	976	1.004	3	0.002	0.007	0.000
756	955	1.005	2	0.003	0.000	0.000	891	977	1.004	3	0.002	0.007	0.000
757	745	1.005	2	0.003	0.000	0.000	892	978	1.004	3	0.002	0.007	0.000
758	31	1.005	2	0.003	0.000	0.000	893	979	1.004	3	0.002	0.007	0.000
759	1906	1.005	2	0.003	0.000	0.000	894	980	1.004	3	0.002	0.007	0.000
760	92	1.005	2	0.003	0.000	0.000	895	981	1.004	3	0.002	0.007	0.000
761	875	1.005	2	0.003	0.000	0.000	896	982	1.004	3	0.002	0.007	0.000
762	1079	1.005	2	0.003	0.000	0.000	897	983	1.004	3	0.002	0.007	0.000
763	415	1.005	2	0.003	0.000	0.000	898	984	1.004	3	0.002	0.007	0.000
764	645	1.005	2	0.003	0.000	0.000	899	985	1.004	3	0.002	0.007	0.000
765	118	1.005	2	0.003	0.000	0.000	900	986	1.004	3	0.002	0.007	0.000
766	1066	1.005	2	0.003	0.000	0.000	901	987	1.004	3	0.002	0.007	0.000
767	134	1.005	2	0.003	0.000	0.000	902	988	1.004	3	0.002	0.007	0.000
768	130	1.005	2	0.003	0.000	0.000	903	989	1.004	3	0.002	0.007	0.000
769	933	1.005	2	0.003	0.000	0.000	904	990	1.004	3	0.002	0.007	0.000
770	160	1.005	2	0.003	0.000	0.000	905	991	1.004	3	0.002	0.007	0.000
771	163	1.005	2	0.003	0.000	0.000	906	992	1.004	3	0.002	0.007	0.000
772	163	1.005	2	0.003	0.000	0.000	907	993	1.004	3	0.002	0.007	0.000
773	163	1.005	2	0.003	0.000	0.000	908	994	1.004	3	0.002	0.007	0.000
774	477	1.005	2	0.003	0.000	0.000	909	995	1.004	3	0.002	0.007	0.000
775	784	1.005	2	0.003	0.000	0.000	910	996	1.004	3	0.002	0.007	0.000
776	438	1.005	2	0.003	0.000	0.000	911	997	1.004	3	0.002	0.007	0.000
777	689	1.005	2	0.003	0.000	0.000	912	998	1.004	3	0.002	0.007	0.000
778	532	1.005	2	0.003	0.000	0.000	913	999	1.004	3	0.002	0.007	0.000
779	167	1.005	2	0.003	0.000	0.000	914	1000	1.004	3	0.002	0.007	0.000
780	826	1.005	2	0.003	0.000	0.000	915	1001	1.004	3	0.002	0.007	0.000
781	1258	1.005	2	0.003	0.000	0.000	916	1002	1.004	3	0.002	0.007	0.000
782	826	1.005	2	0.003	0.000	0.000	917	1003	1.004	3	0.002	0.007	0.000
783	1247	1.005	2	0.003	0.000	0.000	918	1004	1.004	3	0.002	0.007	0.000
784	351	1.005	2	0.003	0.000	0.000	919	1005	1.004	3	0.002	0.007	0.000
785	1994	1.005	2	0.003	0.000	0.000	920	1006	1.004	3	0.002	0.007	0.000
786	173	1.005	2	0.003	0.000	0.000	921	1007	1.004	3	0.002	0.007	0.000
787	831	1.005	2	0.003	0.000	0.000	922	1008	1.004	3	0.002	0.007	0.000
788	482	1.005	2	0.003	0.000	0.000	923	1009	1.004	3	0.002	0.007	0.000
789	1154	1.005	2	0.003	0.000	0.000	924	1010	1.004	3	0.002	0.007	0.000
790	974	1.005	2	0.003	0.000	0.000	925	1011	1.004	3	0.002	0.007	0.000
791	562	1.005	2	0.003	0.000	0.000	926	1012	1.004	3	0.002	0.007	0.000
792	301	1.005	2	0.003	0.000	0.000	927	1013	1.004	3	0.002	0.007	0.000
793	1951	1.005	2	0.003	0.000	0.000	928	1014	1.004	3	0.002	0.007	0.000
794	508	1.005	2	0.003	0.000	0.000	929	1015	1.004	3	0.002	0.007	0.000
795	1424	1.005	2	0.003	0.000	0.000	930	1016	1.004	3	0.002	0.007	0.000
796	738	1.005	2	0.003	0.000	0.000	931	1017	1.004	3	0.002	0.007	0.000
797	608	1.005	2	0.003	0.000	0.000	932	1018	1.004	3	0.002	0.007	0.000
798	146	1.005	2	0.003	0.000	0.000	933	1019	1.004	3	0.002	0.007	0.000
799	216	1.005	2	0.003	0.000	0.000	934	1020	1.004	3	0.002	0.007	0.000
800	697	1.005	2	0.003	0.000	0.000	935	1021	1.004	3	0.002	0.007	0.000
801	5	1.005	2	0.003	0.000	0.000	936	1022	1.004	3	0.002	0.007	0.000
802	1405	1.005	2	0.003	0.000	0.000	937	1023	1.004	3	0.002	0.007	0.000
803	379	1.005	2	0.003	0.000	0.000	938	1024	1.004	3	0.002	0.007	0.000
804	1357	1.005	2	0.003	0.000	0.000	939	1025	1.004	3	0.002	0.007	0.000
805	957	1.005	2	0.003	0.000	0.000	940	1026	1.004	3	0.002	0.007	0.000
806	235	1.005	2	0.003	0.000	0.000	941	1027	1.004	3	0.002	0.007	0.000
807	163	1.005	2	0.003	0.000	0.000	942	1028	1.004	3	0.002	0.007	0.000

(Continued)

(8 of 14 sheets)

Table B3 (Continued)

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Table 33 (Continued)

ITEM NO.	TERMINAL UNIT	TOTAL AREA SQ. MI.	NO. OF ACCU.	MEAN AREA SQ. MI.	AREA SQ. MI.	ACCURACIES SQ. MI.
1078	1067	1.002	1	0.002	0.004	0.004
1079	1061	1.002	1	0.002	0.004	0.004
1080	957	1.002	1	0.002	0.004	0.004
1081	75	1.002	1	0.002	0.004	0.004
1082	152	1.002	1	0.002	0.004	0.004
1083	152	1.002	1	0.002	0.004	0.004
1084	115	1.002	2	0.001	0.004	0.004
1085	115	1.002	2	0.001	0.004	0.004
1086	123	1.002	1	0.002	0.004	0.004
1087	921	1.002	1	0.002	0.004	0.004
1088	284	1.002	1	0.002	0.004	0.004
1089	1404	1.002	1	0.002	0.004	0.004
1090	923	1.002	1	0.002	0.004	0.004
1091	662	1.002	1	0.002	0.004	0.004
1092	116	1.002	1	0.002	0.004	0.004
1093	46	1.002	1	0.002	0.004	0.004
1094	920	1.002	1	0.002	0.004	0.004
1095	401	1.002	1	0.002	0.004	0.004
1096	283	1.002	1	0.002	0.004	0.004
1097	443	1.002	1	0.002	0.004	0.004
1098	1233	1.002	1	0.002	0.004	0.004
1099	966	1.002	1	0.002	0.004	0.004
1100	74	1.002	1	0.002	0.004	0.004
1101	1441	1.002	1	0.002	0.004	0.004
1102	170	1.002	1	0.002	0.004	0.004
1103	984	1.002	1	0.002	0.004	0.004
1104	35	1.002	1	0.002	0.004	0.004
1105	443	1.002	1	0.002	0.004	0.004
1106	1328	1.002	1	0.002	0.004	0.004
1107	444	1.002	1	0.002	0.004	0.004
1108	836	1.002	1	0.002	0.004	0.004
1109	1049	1.002	1	0.002	0.004	0.004
1110	446	1.002	1	0.002	0.004	0.004
1111	963	1.002	1	0.002	0.004	0.004
1112	70	1.002	1	0.002	0.004	0.004
1113	52	1.002	1	0.002	0.004	0.004
1114	392	1.002	1	0.002	0.004	0.004
1115	538	1.002	1	0.002	0.004	0.004
1116	766	1.002	1	0.002	0.004	0.004
1117	622	1.002	2	0.001	0.004	0.004
1118	77	1.002	2	0.001	0.004	0.004
1119	59	1.002	1	0.002	0.004	0.004
1120	906	1.002	1	0.002	0.004	0.004
1121	335	1.002	1	0.002	0.004	0.004
1122	335	1.002	1	0.002	0.004	0.004
1123	1127	1.002	1	0.002	0.004	0.004
1124	774	1.002	1	0.002	0.004	0.004
1125	904	1.002	1	0.002	0.004	0.004
1126	18	1.002	1	0.002	0.004	0.004
1127	1051	1.002	1	0.002	0.004	0.004
1128	312	1.002	1	0.002	0.004	0.004
1129	1334	1.002	1	0.002	0.004	0.004
1130	362	1.002	1	0.002	0.004	0.004
1131	1135	1.002	1	0.002	0.004	0.004
1132	1135	1.002	1	0.002	0.004	0.004
1133	1135	1.002	1	0.002	0.004	0.004
1134	1135	1.002	1	0.002	0.004	0.004
1135	1135	1.002	1	0.002	0.004	0.004
1136	1135	1.002	1	0.002	0.004	0.004
1137	1135	1.002	1	0.002	0.004	0.004
1138	1135	1.002	1	0.002	0.004	0.004
1139	1135	1.002	1	0.002	0.004	0.004
1140	1135	1.002	1	0.002	0.004	0.004
1141	1135	1.002	1	0.002	0.004	0.004
1142	1135	1.002	1	0.002	0.004	0.004
1143	1135	1.002	1	0.002	0.004	0.004
1144	1135	1.002	1	0.002	0.004	0.004
1145	1135	1.002	1	0.002	0.004	0.004
1146	1135	1.002	1	0.002	0.004	0.004
1147	1135	1.002	1	0.002	0.004	0.004
1148	1135	1.002	1	0.002	0.004	0.004
1149	1135	1.002	1	0.002	0.004	0.004
1150	1135	1.002	1	0.002	0.004	0.004
1151	1135	1.002	1	0.002	0.004	0.004
1152	1135	1.002	1	0.002	0.004	0.004
1153	1135	1.002	1	0.002	0.004	0.004
1154	1135	1.002	1	0.002	0.004	0.004
1155	1135	1.002	1	0.002	0.004	0.004
1156	1135	1.002	1	0.002	0.004	0.004
1157	1135	1.002	1	0.002	0.004	0.004
1158	1135	1.002	1	0.002	0.004	0.004
1159	1135	1.002	1	0.002	0.004	0.004
1160	1135	1.002	1	0.002	0.004	0.004
1161	1135	1.002	1	0.002	0.004	0.004
1162	1135	1.002	1	0.002	0.004	0.004
1163	1135	1.002	1	0.002	0.004	0.004
1164	1135	1.002	1	0.002	0.004	0.004
1165	1135	1.002	1	0.002	0.004	0.004
1166	1135	1.002	1	0.002	0.004	0.004
1167	1135	1.002	1	0.002	0.004	0.004
1168	1135	1.002	1	0.002	0.004	0.004
1169	1135	1.002	1	0.002	0.004	0.004
1170	1135	1.002	1	0.002	0.004	0.004
1171	1135	1.002	1	0.002	0.004	0.004
1172	1135	1.002	1	0.002	0.004	0.004
1173	1135	1.002	1	0.002	0.004	0.004
1174	1135	1.002	1	0.002	0.004	0.004
1175	1135	1.002	1	0.002	0.004	0.004
1176	1135	1.002	1	0.002	0.004	0.004
1177	1135	1.002	1	0.002	0.004	0.004
1178	1135	1.002	1	0.002	0.004	0.004
1179	1135	1.002	1	0.002	0.004	0.004
1180	1135	1.002	1	0.002	0.004	0.004
1181	1135	1.002	1	0.002	0.004	0.004
1182	1135	1.002	1	0.002	0.004	0.004
1183	1135	1.002	1	0.002	0.004	0.004
1184	1135	1.002	1	0.002	0.004	0.004
1185	1135	1.002	1	0.002	0.004	0.004
1186	1135	1.002	1	0.002	0.004	0.004
1187	1135	1.002	1	0.002	0.004	0.004
1188	1135	1.002	1	0.002	0.004	0.004
1189	1135	1.002	1	0.002	0.004	0.004
1190	1135	1.002	1	0.002	0.004	0.004
1191	1135	1.002	1	0.002	0.004	0.004
1192	1135	1.002	1	0.002	0.004	0.004
1193	1135	1.002	1	0.002	0.004	0.004
1194	1135	1.002	1	0.002	0.004	0.004
1195	1135	1.002	1	0.002	0.004	0.004
1196	1135	1.002	1	0.002	0.004	0.004
1197	1135	1.002	1	0.002	0.004	0.004
1198	1135	1.002	1	0.002	0.004	0.004
1199	1135	1.002	1	0.002	0.004	0.004
1200	1135	1.002	1	0.002	0.004	0.004

(Continued)

(11 of 14 sheets)

Table B3 (Continued)

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(continued)

Table B3 (Continued)

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(Cont. from p. 1)

Whereas less than 0.001 are shown as 0.000,

Table B3 (Continued)

ITEM	TERMIN	TOTAL AREA	NO. OF	MEAN AREA	AREA	OCCURRENCES
NO.	NO.	SO. MI.	SO. MI.	SO. MI.	SO. MI.	SO. MI.
1404	115	0.000*	1	0.000	0.001	99.994
1405	267	0.000	1	0.000	0.001	99.997
1406	406	0.000	1	0.000	0.001	99.992
1407	422	0.000	1	0.000	0.001	99.998
1408	1407	0.000	1	0.000	0.001	99.999
1409	604	0.000	1	0.000	0.001	99.999
					0.001	100.000
					0.000	100.000

*Areas less than 0.001 are shown as 0.000.

Table B4

Summary of Linear Terrain Unit, Length, and Occurrence Data
for Fort Knox Study Area 1 (FK1)

ITEM NO.	TERRAIN UNIT	TOTAL LENGTH MILES	NO. OF OCCUR	MEAN LENGTH MILES	LENGTH		OCCURRENCE	
					<<<<<<>>>>>>	<<<<<<>>>>>>	<<<<<<>>>>>>	<<<<<<>>>>>>
					%	S %	%	S %
1	2	7.350	5	1.470	24.590	24.590	9.804	9.804
2	6	3.230	1	3.230	10.806	35.396	1.961	11.765
3	17	3.110	1	3.110	10.409	45.801	1.961	13.725
4	15	2.600	6	0.433	8.699	54.500	11.765	25.490
5	12	2.580	7	0.369	8.632	63.131	13.725	39.816
6	6	2.150	1	2.150	7.193	70.325	1.961	41.176
7	13	1.950	9	0.217	6.524	76.848	17.647	58.824
8	11	1.780	7	0.254	5.955	82.804	13.725	72.549
9	7	1.690	1	1.690	5.654	88.458	1.961	74.910
10	14	0.720	3	0.240	2.409	90.867	5.882	80.302
11	5	0.630	2	0.315	2.104	92.974	3.922	84.314
12	16	0.620	1	0.620	2.074	95.049	1.961	86.275
13	10	0.520	2	0.260	1.740	96.788	3.922	90.196
14	4	0.340	2	0.170	1.138	97.926	3.922	94.118
15	1	0.280	1	0.280	0.937	98.862	1.961	96.078
16	3	0.170	1	0.170	0.569	99.431	1.961	98.039
17	9	0.170	1	0.170	0.569	100.000	1.961	100.000

Table B5

Summary of Linear Terrain Unit, Length, and Occurrence Data
for Fort Knox Study Area 2 (FK2)

ITEM NO.	TERRAIN UNIT	TOTAL LENGTH MILES	NO. OF OCCUR	MEAN LENGTH MILES	LENGTH		OCCURRENCE	
					<<<<<< >>>>>>	<<<<<< >>>>>>	<<<<<< >>>>>>	<<<<<< >>>>>>
					%	%	%	%
1	3	4.690	2	2.345	18.277	18.277	2.667	2.667
2	8	3.380	7	0.483	13.172	31.450	9.333	12.000
3	7	2.190	32	0.068	8.535	39.984	42.667	54.667
4	26	1.850	1	1.850	7.210	47.194	1.333	56.000
5	2	1.230	1	1.230	4.793	51.908	1.333	57.333
6	24	1.170	3	0.390	4.560	56.547	4.000	61.333
7	13	0.980	7	0.140	3.819	60.366	9.333	70.667
8	5	0.970	2	0.485	3.780	64.147	2.667	73.333
9	23	0.920	1	0.920	3.585	67.732	1.333	74.667
10	1	0.920	1	0.920	3.585	71.317	1.333	76.000
11	21	0.920	1	0.920	3.585	74.903	1.333	77.333
12	9	0.830	2	0.415	3.235	78.137	2.667	80.000
13	22	0.800	1	0.800	3.118	81.255	1.333	81.333
14	16	0.750	2	0.375	2.923	84.178	2.667	84.000
15	10	0.540	1	0.540	2.104	86.282	1.333	85.333
16	18	0.480	1	0.480	1.871	88.193	1.333	86.667
17	19	0.460	1	0.460	1.793	89.945	1.333	88.000
18	25	0.460	1	0.460	1.793	91.738	1.333	89.333
19	21	0.460	1	0.460	1.793	93.531	1.333	90.667
20	15	0.450	1	0.450	1.754	95.284	1.333	92.000
21	4	0.380	1	0.380	1.481	96.765	1.333	93.333
22	17	0.310	1	0.310	1.208	97.973	1.333	94.667
23	14	0.200	1	0.200	0.779	98.753	1.333	96.000
24	6	0.140	1	0.140	0.546	99.299	1.333	97.333
25	11	0.090	1	0.090	0.351	99.649	1.333	98.667
26	12	0.090	1	0.090	0.351	100.000	1.333	100.000

Table 26

(1 of 6 sheets)

(Cont'd)

Accumulative total

Table 66 (Continued)									
ITEM NO.	TERMINAL MILE	TOTAL LENGTH OF MILES	NO. OF OCCUR	MEAN LENGTH OF MILES	LENGTH OF MILES	LENGTH OF MILES	LENGTH OF MILES	LENGTH OF MILES	LENGTH OF MILES
324	484	1.320	1	0.320	0.074	0.074	0.074	0.074	0.074
325	99	1.320	1	0.320	0.074	0.074	0.074	0.074	0.074
326	489	1.320	1	0.320	0.074	0.074	0.074	0.074	0.074
327	334	1.320	2	0.160	0.074	0.074	0.074	0.074	0.074
328	199	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
329	502	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
330	482	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
331	88	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
332	922	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
333	934	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
334	420	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
335	421	1.310	1	0.310	0.072	0.072	0.072	0.072	0.072
336	171	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
337	502	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
338	501	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
339	40	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
340	314	1.300	2	0.150	0.070	0.070	0.070	0.070	0.070
341	506	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
342	110	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
343	31	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
344	93	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
345	348	1.300	2	0.150	0.070	0.070	0.070	0.070	0.070
346	315	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
347	401	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
348	402	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
349	110	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
350	474	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
351	474	1.300	2	0.150	0.070	0.070	0.070	0.070	0.070
352	453	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
353	494	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
354	299	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
355	126	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
356	51	1.300	2	0.150	0.070	0.070	0.070	0.070	0.070
357	237	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
358	541	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
359	152	1.300	2	0.150	0.070	0.070	0.070	0.070	0.070
360	417	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
361	404	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
362	404	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
363	456	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
364	456	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
365	409	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
366	141	1.300	2	0.150	0.070	0.070	0.070	0.070	0.070
367	424	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
368	424	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
369	44	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
370	496	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
371	503	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
372	421	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
373	506	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
374	406	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070
375	429	1.300	1	0.300	0.070	0.070	0.070	0.070	0.070

(4 of 6 sheets)

(Continued)

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Table B7
Summary of Areal Occupancy and Frequency of Occurrence of Areal Terrain Factor Classes
Used to Describe Soil, Slope, Surface Roughness, and Visibility

Soil Type				Soil Strength				Slope				Surface Roughness				Visibility			
Class No.	Percent Area	Percent Occurrence		Class No.	Percent Area	Percent Occurrence		Class No.	Percent Area	Percent Occurrence		Class No.	Percent Area	Percent Occurrence		Class No.	Percent Area	Percent Occurrence	
West Germany Tract (WGT)																			
1	100.00	100.0		4	58.3	67.4		3	29.3	26.7		2	77.1	73.5		2	73.3	80.3	
				6	37.8	27.8		4	27.2	32.6		3	18.5	17.8		4	25.7	17.8	
				7	2.7	3.1		2	25.4	18.4		4	4.4	8.8		7	0.5	0.7	
				5	1.2	1.7		5	2.0	16.8						6	0.4	1.0	
								6	3.3	3.8						5	0.1	0.1	
								1	2.6	1.3									
								7	0.2	0.4									
Fort Knox (FK1)																			
1	100.00	100.0		6	41.8	40.2		2	38.8	38.6		3	45.4	43.3		2	61.2	53.9	
				7	18.8	19.3		1	30.1	25.5		2	31.3	34.0		3	25.3	29.6	
				5	13.7	16.5		3	16.3	24.9		1	14.0	12.8		5	6.3	8.4	
				8	11.8	13.4		4	4.7	8.4		4	7.4	7.5		4	4.8	4.4	
				9	11.8	10.3		6	2.1	2.5		5	1.0	2.5		7	2.0	3.4	
				10	2.1	0.3										6	0.4	0.3	
Fort Knox (FK2)																			
1	100.00	100.0		5	41.0	38.4		3	51.4	38.8		3	60.4	61.2		2	72.5	62.1	
				7	20.0	20.1		2	41.6	49.1		2	21.4	21.4		3	19.8	25.4	
				4	16.7	22.8		4	5.0	9.4		5	9.4	7.1		4	5.7	8.9	
				6	9.0	9.8		1	1.6	1.8		4	8.8	10.3		5	1.3	2.2	
				8	5.6	2.7		5	0.4	0.9						8	0.7	1.3	
				3	5.6	4.5													
				2	1.9	1.8													

Table B8
Summary of Areal Occupancy and Frequency of Occurrence of Areal Terrain Factor Classes Used to Describe Obstacles

Obstacle Approach Angle			Obstacle Vert Magnitude			Obstacle Base Width			Obstacle Length			Obstacle Spacing			Obstacle Separating Type		
Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence
West Germany Transect (WGT)																	
9	52.6	43.2	2	54.7	47.5	4	53.4	44.1	6	41.7	48.7	8	54.6	46.9	1	74.3	76.1
7	26.6	19.3	3	27.7	22.1	1	26.5	18.9	5	27.3	21.7	1	39.4	40.7	2	25.7	23.5
5	8.7	19.2	1	16.6	28.7	5	16.3	30.3	7	25.7	23.9	2	5.5	11.7			
14	5.7	7.0	4	0.5	0.7	3	3.8	6.6	1	5.3	5.7	3	0.4	0.6			
3	5.2	9.7	7	0.3	0.6	2	0.1	0.1				5	0.1	0.1			
11	0.7	1.1	5	0.2	0.3												
1	0.3	0.4															
13	0.1	0.2															
Fort Knox (FK1)																	
13	50.0	46.7	1	71.6	73.2	5	43.4	42.4	1	32.6	32.4	2	44.0	42.4	1	100.0	100.0
1	32.6	32.4	2	12.6	13.7	1	34.8	35.8	6	28.2	23.4	1	38.8	37.4			
8	6.9	8.1	6	7.4	5.9	4	12.3	10.3	5	22.4	25.2	4	5.4	4.1			
14	4.6	5.6	3	6.8	5.9	3	5.8	6.2	2	12.0	12.1	3	4.0	3.4			
10	3.8	5.3	4	1.7	1.2	2	3.6	5.3	3	2.5	4.1	6	3.3	5.0			
11	1.4	1.9							4	2.4	2.8	5	2.9	6.2			
												7	1.6	1.2			
Fort Knox (FK2)																	
13	43.6	40.6	2	41.6	38.8	5	38.1	33.9	6	70.3	70.5	2	42.5	41.5	1	93.0	90.2
12	21.0	22.8	1	19.0	17.9	1	28.7	35.3	2	9.8	6.7	3	28.7	29.0	2	7.0	9.8
1	10.4	12.5	4	17.7	24.1	3	20.6	14.3	1	9.8	11.6	1	20.0	22.8			
14	10.0	12.5	6	8.6	6.2	4	12.5	16.1	5	9.2	9.4	5	8.6	6.2			
8	6.7	3.1	3	7.4	9.4	2	0.1	0.4	4	0.6	0.9	4	0.2	0.4			
10	4.2	6.7	7	4.5	2.7				3	0.2	0.4						
11	4.0	1.8	5	1.2	0.9				7	0.1	0.4						

Summary of Areal Occupancy and Frequency of Occurrence of Areal Terrain Factor Classes
Used to Describe Vegetation

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Summary of Linear Occupancy and Frequency of Occurrence of Linear Terrain Factor C

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• Trails.

Table B9

Linear Occupancy and Frequency of Occurrence of Areal Terrain Factor Classes
Used to Describe Vegetation

Spacing Class No.	Stem Diameter Class 4			Stem Diameter Class 5			Stem Diameter Class 6			Stem Diameter Class 7			Stem Diameter Class 8		
	Percent Area	Percent Occurrence	Spacing Class No.	Percent Area	Percent Occurrence	Spacing Class No.	Percent Area	Percent Occurrence	Spacing Class No.	Percent Area	Percent Occurrence	Spacing Class No.	Percent Area	Percent Occurrence	
	West Germany Transect (WGT)														
	68.3	68.9	2	73.8	81.0	2	74.0	81.4	2	74.6	82.7	2	74.7	82.8	
	25.6	17.8	6	25.4	17.3	6	25.3	17.1	5	24.8	16.2	5	24.8	16.1	
	5.0	10.4	1	0.4	0.8	1	0.4	0.8	1	0.4	0.8	1	0.4	0.8	
	0.4	1.2	3	0.2	0.3	3	0.2	0.4	4	0.1	0.3	4	0.1	0.2	
	0.4	0.8	4	0.1	0.4	4	0.1	0.3	3	0.0	0.1	3	0.1	0.2	
	0.1	0.5	5	0.1	0.2	5	0.0	0.1							
	0.1	0.3													
	Fort Knox (FK1)														
	34.0	30.8	5	28.7	25.2	1	33.0	35.2	1	37.6	42.4	1	49.3	54.8	
	28.7	30.8	1	24.8	23.4	5	22.5	15.6	5	25.0	17.1	5	18.6	10.6	
	22.1	19.3	6	22.6	23.1	4	18.6	20.6	2	11.8	12.5	4	13.2	14.6	
	13.5	16.2	4	16.1	16.5	6	12.1	14.0	4	11.6	14.6	3	12.7	11.2	
	1.1	1.6	3	7.0	10.0	2	10.1	8.7	3	6.8	6.5	6	5.3	6.9	
	0.6	1.2	2	0.6	1.2	3	3.6	5.9	6	5.3	6.9	2	0.9	1.9	
			7	0.3	0.6										
	Fort Knox (FK2)														
	45.8	52.2	1	46.6	53.6	1	53.2	59.4	1	53.4	59.8	1	53.8	59.8	
	26.4	19.6	5	30.3	25.0	5	24.9	21.0	5	25.0	21.4	4	25.1	17.4	
	16.3	17.9	6	8.9	8.0	7	8.0	5.4	7	8.0	5.4	6	12.1	10.3	
	8.0	5.4	8	7.0	4.0	4	7.4	5.8	4	7.3	5.4	5	7.2	9.4	
	2.2	2.2	4	5.2	6.7	6	4.3	5.4	6	4.1	4.9	3	2.3	3.1	
	1.4	2.7	3	1.0	1.3	3	2.3	3.1	3	2.3	3.1				
			7	0.9	1.3										

Table B10

Linear Occupancy and Frequency of Occurrence of Linear Terrain Factor Classes

Differential Bank Height or Slope Magnitude		Right Approach Angle			Low Bank Height or Vertical Magnitude			Base Width or Top Width			Water Depth			Water Velocity		
Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence	Class No.	Percent Area	Percent Occurrence
West Germany Transect (WGT)																
64.8	64.9	3	18.6	16.8	1	45.6	47.1	3	34.6	37.2	1	80.3	87.0	1	80.3	87.0
11.8	12.0	7	14.0	15.0	2	33.2	33.1	4	32.0	33.4	3	11.5	7.9	3	15.2	9.6
8.0	7.6	1	10.4	12.2	3	11.4	10.8	5	26.1	29.9	4	5.6	3.0	4	4.2	3.2
6.6	6.4	11	9.2	9.4	4	7.6	6.4	6	4.2	3.6	5	2.3	1.9	2	0.3	0.2
6.2	6.0	9	7.7	10.8	7	1.1	1.1	21	1.8	1.7	2	0.3	0.2			
0.7	0.9	5	7.6	8.3	6	1.0	0.7	9	0.6	0.5						
0.6	0.5	12	6.3	4.5	8	0.1	0.1	8	0.5	0.6						
0.6	0.7	13	5.5	6.0	5	0.1	0.2	13	0.1	0.1						
0.6	0.9	10	4.6	2.8												
		8	3.1	2.8												
		14	2.7	2.2												
		16	2.5	2.4												
		15	2.3	2.7												
		20	1.8	1.1												
		18	1.6	1.2												
		21	0.8	0.7												
		17	0.8	0.7												
		19	0.6	0.3												
		6	0.1	0.2												
Fort Knox (FK1)																
47.3	29.4	12	27.0	15.7	1	43.4	45.1	3	43.4	78.4	1	38.6	17.6	1	38.6	17.6
29.7	49.0	8	24.7	39.2	2	18.1	19.6	5	34.3	15.7	3	36.9	62.7	3	36.9	62.7
10.8	2.0	6	19.1	7.8	8	18.0	3.9	6	21.8	5.9	6	18.0	3.9	4	18.0	3.9
6.5	17.6	10	18.2	33.3	3	10.7	13.7				2	6.5	15.7	2	6.5	15.7
5.6	2.0	14	11.0	3.9	4	9.8	17.6									
Fort Knox (FK2)																
51.8	80.0	8	20.3	18.7	1	46.2	17.3	4	35.7	21.3	3	51.6	32.0	1	28.1	6.7
33.2	12.0	11	19.8	4.0	2	41.7	65.3	3	27.6	65.3	1	30.2	8.0	4	27.3	13.3
5.5	4.0	12	15.4	48.0	3	10.3	16.0	5	24.0	5.3	2	18.2	60.0	3	26.4	20.0
3.5	1.3	6	15.3	10.7	4	1.8	1.3	6	9.2	5.3				2	18.2	60.0
1.8	1.3	4	8.5	4.0				7	1.8	1.3						
1.2	1.3	10	6.9	6.7				9	1.8	1.3						
		14	5.5	5.3												
		9	4.8	1.3												
		7	3.6	1.3												

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B

Table B11
Vehicle Characteristics

Vehicle Characteristics				
No.	Identification	Dimensions	M114A1E1	M151A2
1	Vehicle type (KVEH = 0 for tracked and 1 for wheeled)	--	0	1
2	Gross vehicle weight	kips	15.7	3.2
3	Track type (NFL = 0 for nonflexible and 1 for flexible)	in.	1	NA
4	Grouser height for tracks; number of tires for wheeled tire ply rating	--	1	4
5	Tire ply rating	--	NA	6
6	Gross rated horsepower	bhp	160	71
7	Number of people in vehicle on normal mission	--	NA	NA
8	Winch capacity (use 0 for no winch)	kips	NA	NA
9	Number of tracks or tires	--	2	4
10	Number of axles	--	NA	2
11	Vehicle width	in.	91.8	64
12	Vehicle length	in.	195.8	165
13	Track width or nominal tire width	in.	16.5	7
14	Wheel rim diameter	in.	NA	23
15	Recommended tire pressure (highway)	psi	NA	20
16	Recommended tire pressure (cross-country)	psi	NA	4
17	Area of one track shoe (tracked) or number of wheels (wheeled)	in. ²	66	4
18	Number of bogies (tracked) or chain indicator wheeled (0 = no chains, 1 = chains)	--	8	0
19	Maximum vertical step the vehicle can climb	in.	NA	NA
20	Vehicle ground clearance at the center of greatest wheel span	in.	NA	12
21	Minimum vehicle ground clearance	in.	14.25	9
22	Rear end clearance (vertical clearance of vehicle trailing edge)	in.	23.5	18
23	Vehicle departure angle	deg	36	37
24	Vertical clearance of vehicle's leading edge	in.	40.5	18
25	Vehicle approach angle	deg	68	66
26	Length of track on ground or wheel diameter	in.	95	30
27	Height of vehicle pushbar	in.	40.5	18
28	Distance between first and last wheel center lines	in.	NA	85
29	Horizontal distance from the center of gravity to the front wheel center lines	in.	NA	45
30	Vertical distance from the center of gravity to the road wheel center lines	in.	NA	10
31	Maximum span between adjacent wheel center lines	in.	NA	85
32	Angle between a line parallel to the ground surface and the line connecting the center of gravity and the center of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle.	deg	14	NA
33	Distance from the center of gravity to the center of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle.	in.	69	NA
34	Vertical distance from the ground to the center of the rear wheel	in.	19	14

(Continued)

1 of 2 sheets

Table B11 (Concluded)

Vehicle Characteristics				
No.	Identification	Dimensions	M114A1R1	M121A2
35	Track thickness plus the radius of the rear wheel (road wheel or idler). The wheel is the one used to determine approach angle. (wheeled = NW)	in.	9	NA
36	Rolling radius of tire or sprocket pitch radius	in.	7.0	14
37	Height of rigid point used to determine approach angle	in.	40.5	18
38	Maximum braking force the vehicle develops	--	0.8	0.8
39	Loaded wheel radius	in.	NA	14
40	Total ground contact area	in. ²	3134	NA
41	Distance vehicle spans before significant motion begins	in.	43.5	15
42	Maximum force the pushbar can withstand	kips	31.3	3.2
43	Maximum axle load/gross vehicle weight	--	NA	0.5
44	Vehicle rated horsepower per ton	hp/ton	20.7	44
45	Transmission type (0 = automatic; 1 = manual)	--	0	1
46	Prop. drive gear ratio	--	4.17	4.06
47	Final drive gear efficiency	--	0.93	0.9
48	Number of gears in transmission	--	4	4
49	Gear ratios for transmission	--	NA	NA
50	Transmission efficiency	--	0.95	0.9
51	Gear ratio from engine to torque converter	--	NA	NA
52	Denotes presence of a torque converter lockup (No = 0; Yes = 1)	--	NA	NA
53	Input torque at which the torque converter curves were measured	--	NA	NA
54	Number of point pairs in array TWE1 (see item 55)	--	NA	NA
55	Array containing torque converter input speed versus converter torque ratio curve	--	NA	NA
56	Number of point pairs in array TTM (see item 57)	--	NA	NA
57	Array containing torque converter torque multiplying coefficient versus converter speed ratio curve	--	NA	NA
58	Number of point pairs in array TTE (see item 59)	--	NA	NA
59	Array containing net engine torque versus engine speed curve	--	+	+
60	Number of point pairs in array VOOB (see item 61)	--	NA	NA
61	Array containing vehicle velocity versus obstacle height at 2.5-g vertical acceleration	--	**	**
62	Number of points in array VRIDE (see item 63)	--	8	6
63	Array containing ride dynamics versus speed curve	--	+	+
64	Vehicle swimming speed	mph	3.4	NA
65	Vehicle fording speed	mph	2.0	2
66	Auxiliary water propulsion factor (0.5 = No, 0.8 = Yes)	--	0.5	0.5
67	Ingress sump angle of the vehicle	deg	17	NA
68	Fording depth or draft height	in.	53	21
69	Recommended tire pressure (sand)	psi	NA	15

**Measured tractive force-speed curve substituted for this relation. See Table B12.

**See Table B13.

†See Table B14.

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Table B12

Tractive Force-Speed Relations for Vehicle Characteristic 59 Table B11

M151A2		M114A1E1	
Tractive Force, lb	Speed mph	Tractive Force, lb	Speed mph
2195	0	9650	0
2185	4.9	9650	3
2050	7.5	9350	4
1815	10.0	8350	5
1205	10.1	6500	6
1180	12.0	5850	7
1085	15.5	5000	8
870	19.8	4050	10
660	19.9	3120	12
650	25.0	2600	16
615	30.0	2050	20
560	33.0	1700	24
420	33.1	1550	28
385	40.0	1300	32
355	45.0	1000	36
340	50.0		
310	56.0		
275	65.0		

NOTE: Data furnished by TACOM.

Table B13
Obstacle Height-Speed Relations for Vehicle Characteristic 61 in Table B11

M151A2		M114A1E1	
<u>Obstacle Height</u> <u>in.</u>	<u>Speed</u> <u>mph</u>	<u>Obstacle Height</u> <u>in.</u>	<u>Speed</u> <u>mph</u>
40.0	0.0	15.0	0.0
40.0	1.2	15.0	4.90
30.0	1.4	12.0	5.25
20.0	1.8	9.5	6.00
15.0	2.2	6.8	7.50
10.0	3.0	5.0	9.00
5.3	5.0	2.5	12.00
3.4	7.5	1.0	15.00
2.5	10.0	0.5	17.10
1.8	15.0	0.0	18.00
1.2	20.0	0.0	40.00
1.0	40.0		

Data from WES field tests.

Table B14

Ride-Speed Relations for Vehicle Characteristic No. 63 in Table B11

M151A2		M114A1E1	
RMS	Speed	RMS	Speed
<u>in.</u>	<u>mph</u>	<u>in.</u>	<u>mph</u>
0.20	60.0	0.20	30.1
0.57	60.0	0.77	30.0
0.75	45.0	1.00	23.5
1.00	34.0	1.25	20.5
1.50	22.0	1.50	18.5
2.00	16.0	2.00	16.6
2.50	12.5	2.75	15.5
3.00	11.0	8.00	7.5
5.75	2.0		
8.00	2.0		

Data from WES field tests.

Table B15

Performance Prediction for M1A1 in Port Main Battle Area 1 (PMA)

VEHICLE: M1A1; AREA 2 FORT NIGHT

VEHICLE UNIT	X AREA	IN UNIT ACCUM	PREDICTED IN UNIT ACCUM	CONTROLLING FORCE		VEHICLE UNIT	Y AREA	IN UNIT ACCUM	PREDICTED IN UNIT ACCUM	CONTROLLING FORCE	
				UP	DOWN					UP	DOWN
1	0.1	0.4	23.4	0	0	51	0.1	0.4	23.4	0	0
2	0.2	0.8	23.0	10	10	52	0.2	0.8	23.0	10	10
3	0.3	1.2	22.6	20	20	53	0.3	1.2	22.6	20	20
4	0.4	1.6	22.2	30	30	54	0.4	1.6	22.2	30	30
5	0.5	2.0	21.8	40	40	55	0.5	2.0	21.8	40	40
6	0.6	2.4	21.4	50	50	56	0.6	2.4	21.4	50	50
7	0.7	2.8	21.0	60	60	57	0.7	2.8	21.0	60	60
8	0.8	3.2	20.6	70	70	58	0.8	3.2	20.6	70	70
9	0.9	3.6	20.2	80	80	59	0.9	3.6	20.2	80	80
10	1.0	4.0	19.8	90	90	60	1.0	4.0	19.8	90	90
11	1.1	4.4	19.4	0	0	61	1.1	4.4	19.4	0	0
12	1.2	4.8	19.0	10	10	62	1.2	4.8	19.0	10	10
13	1.3	5.2	18.6	20	20	63	1.3	5.2	18.6	20	20
14	1.4	5.6	18.2	30	30	64	1.4	5.6	18.2	30	30
15	1.5	6.0	17.8	40	40	65	1.5	6.0	17.8	40	40
16	1.6	6.4	17.4	50	50	66	1.6	6.4	17.4	50	50
17	1.7	6.8	17.0	60	60	67	1.7	6.8	17.0	60	60
18	1.8	7.2	16.6	70	70	68	1.8	7.2	16.6	70	70
19	1.9	7.6	16.2	80	80	69	1.9	7.6	16.2	80	80
20	2.0	8.0	15.8	90	90	70	2.0	8.0	15.8	90	90
21	2.1	8.4	15.4	0	0	71	2.1	8.4	15.4	0	0
22	2.2	8.8	15.0	10	10	72	2.2	8.8	15.0	10	10
23	2.3	9.2	14.6	20	20	73	2.3	9.2	14.6	20	20
24	2.4	9.6	14.2	30	30	74	2.4	9.6	14.2	30	30
25	2.5	10.0	13.8	40	40	75	2.5	10.0	13.8	40	40
26	2.6	10.4	13.4	50	50	76	2.6	10.4	13.4	50	50
27	2.7	10.8	13.0	60	60	77	2.7	10.8	13.0	60	60
28	2.8	11.2	12.6	70	70	78	2.8	11.2	12.6	70	70
29	2.9	11.6	12.2	80	80	79	2.9	11.6	12.2	80	80
30	3.0	12.0	11.8	90	90	80	3.0	12.0	11.8	90	90
31	3.1	12.4	11.4	0	0	81	3.1	12.4	11.4	0	0
32	3.2	12.8	11.0	10	10	82	3.2	12.8	11.0	10	10
33	3.3	13.2	10.6	20	20	83	3.3	13.2	10.6	20	20
34	3.4	13.6	10.2	30	30	84	3.4	13.6	10.2	30	30
35	3.5	14.0	9.8	40	40	85	3.5	14.0	9.8	40	40
36	3.6	14.4	9.4	50	50	86	3.6	14.4	9.4	50	50
37	3.7	14.8	9.0	60	60	87	3.7	14.8	9.0	60	60
38	3.8	15.2	8.6	70	70	88	3.8	15.2	8.6	70	70
39	3.9	15.6	8.2	80	80	89	3.9	15.6	8.2	80	80
40	4.0	16.0	7.8	90	90	90	4.0	16.0	7.8	90	90
41	4.1	16.4	7.4	0	0	91	4.1	16.4	7.4	0	0
42	4.2	16.8	7.0	10	10	92	4.2	16.8	7.0	10	10
43	4.3	17.2	6.6	20	20	93	4.3	17.2	6.6	20	20
44	4.4	17.6	6.2	30	30	94	4.4	17.6	6.2	30	30
45	4.5	18.0	5.8	40	40	95	4.5	18.0	5.8	40	40
46	4.6	18.4	5.4	50	50	96	4.6	18.4	5.4	50	50
47	4.7	18.8	5.0	60	60	97	4.7	18.8	5.0	60	60
48	4.8	19.2	4.6	70	70	98	4.8	19.2	4.6	70	70
49	4.9	19.6	4.2	80	80	99	4.9	19.6	4.2	80	80
50	5.0	20.0	3.8	90	90	100	5.0	20.0	3.8	90	90

(Continued)

(1 of 2 sheets)

VEHICLE: M1143151 AREA 2 FORTY NMOX

(2 of 2 sheets)

* For convenience, 0.1 mph was arbitrarily assigned for "no go" condition.

Summary of Terrain Unit Frequency - Speed Data for the M14A1E1 in Areal Terrain

<u>West German Traverses (WGT)</u>			<u>Port Knox (PKL)</u>		<u>Port Knox (PKL)</u>	
Terrain Unit	Speed mph		Terrain Unit	Speed mph	Terrain Unit	Speed mph
Frequency			Frequency		Frequency	
Z			Z		Z	
0.1	23.5		0.5	30.1	0.5	23.4
7.2	23.5		9.9	21.1	9.8	17.7
10.0	22.2		20.3	17.7	20.2	16.0
20.0	20.4		30.2	16.6	30.0	14.8
30.0	17.2		40.0	15.7	40.4	13.7
40.0	15.4		50.4	14.2	50.8	12.5
50.0	13.6		60.3	12.3	60.1	10.9
60.0	12.1		70.2	11.2	70.4	4.9
70.0	10.8		80.0	10.3	80.3	3.0
80.0	8.9		90.0	8.8		
90.0	6.4					
96.3	0.8		99.3	4.5	87.0	0.1
96.3	0.1		100.0	0.1	100.0	0.1

Table B17

Summary of Diagnostics for M114A1E1
in Areal Terrain

<u>Controlling</u> <u>Factor No.</u>	<u>Percent of Total Area</u>				
	<u>0-20</u>	<u>0-40</u>	<u>0-60</u>	<u>0-80</u>	<u>0-100</u>
<u>West Germany Transect (WGT)</u>					
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.1
3	0.0	0.0	0.0	0.0	0.2
4	0.0	0.0	0.0	0.0	0.4
5	14.7	27.4	32.0	34.0	34.0
6	0.0	3.1	5.0	5.9	5.9
7	0.0	0.2	0.3	0.8	0.9
8	0.7	0.7	8.3	15.9	18.2
9	4.5	8.5	13.9	18.0	19.4
10	0.1	0.2	0.4	5.3	21.0
<u>Fort Knox (FK1)</u>					
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.8
5	5.3	11.6	12.5	13.9	14.0
6	5.0	5.4	5.4	8.9	11.0
7	1.0	1.4	2.7	3.2	5.7
8	1.1	4.0	13.8	15.9	24.0
9	7.2	11.7	15.5	25.2	28.9
10	0.4	6.0	10.1	12.9	15.6
<u>Fort Knox (FK2)</u>					
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.6	12.6
4	0.0	0.0	0.0	0.0	7.9
5	7.9	12.9	14.0	14.0	14.0
6	0.6	0.9	1.0	1.0	1.0
7	0.8	0.8	0.8	1.5	1.5
8	4.3	6.4	9.7	11.3	11.3
9	3.8	1.5	6.4	6.6	6.6
10	2.6	13.5	28.1	44.9	44.9

Table B18

Summary of Diagnostics for M151A2
in Areal Terrain

Controlling Factor No.	Percent of Total Area				
	0-20	0-40	0-60	0-80	0-100
<u>West German Transect (WGT)</u>					
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.2
3	0.0	0.0	0.0	0.0	0.4
4	0.0	0.0	0.0	0.0	1.2
5	13.3	14.6	14.6	14.6	14.6
6	2.0	2.0	2.0	2.0	2.0
7	0.7	1.1	1.2	1.2	1.2
8	0.2	17.1	25.4	25.4	25.4
9	3.5	3.9	4.2	4.2	4.8
10	0.3	1.3	12.6	32.6	50.2
<u>Fort Knox (FK1)</u>					
1	0.0	0.0	0.0	0.0	2.1
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0
5	1.0	5.1	5.2	5.4	6.9
6	4.7	4.8	6.4	8.6	8.7
7	5.7	8.0	8.0	8.5	10.4
8	6.5	9.5	12.9	18.3	22.8
9	1.3	3.4	3.5	5.7	12.0
10	0.7	9.3	24.0	33.5	37.0
<u>Fort Knox (FK2)</u>					
1	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	4.8	20.0
4	0.0	0.0	0.0	3.1	7.7
5	3.2	9.8	9.8	9.8	9.8
6	0.4	0.4	0.4	0.4	0.4
7	1.8	1.8	1.8	1.8	1.8
8	9.6	15.2	20.4	24.1	24.1
9	1.5	1.5	1.5	1.7	1.7
10	3.5	11.4	26.2	34.4	34.4

Table B19
Summary of Vehicle Performance in Linear Terrain Units

Vehicle	Type of Linear Features						
	Wet Concave*		Dry Concave**		Convex +		All Linear Features
	Length Per- mile	cent Go	Length Per- mile	cent Go	Length Per- mile	cent Go	Length Per- mile
West Germany Transect (WGT)							
M151A2	85.18	15	17.78	24	318.61	68	336.39 66 421.57 56
M114A1E1	85.18	41	17.78	48	318.61	79	336.39 77 421.57 70
Fort Knox (FK1)							
M151A2	16.41	31	13.48	62	0.0	NA	13.48 62 29.89 45
M114A1E1	16.41	60	13.48	77	0.0	NA	13.48 77 29.89 68
Fort Knox (FK2)							
M151A2	13.24	69	5.20	22	7.22	100	12.42 68 25.66 68
M114A1E1	13.24	77	5.20	58	7.22	100	12.42 82 25.66 80

* Wet concave - negative features such as rivers, streams, and ditches which contain water.

** Dry concave - negative features which contain no water.

+ Convex - Positive features such as road embankments and levees.

Summary of Vehicle Performance Diagnostics in Linear Terrains

Reasons for No Go															
in Linear Terrains															
Vehicle	Water			Bank Angle			Surface			Traction			Vehicle		
	Greater than			and Height			Strength			Available			Geometry -		
	Maximum			Combination			Less than			Less than			Linear Feature		
	Allowable			One Pass			Minimum			Surface			Geometry		
	Length	Percent		Length	Percent		Length	Percent		Length	Percent		Length	Percent	
Mile	No Go		Mile	No Go		Mile	No Go		Mile	No Go		Mile	No Go		
West Germany Transect (WGT)															
M151A2	20.40	11	0.0	0	16.69	9	0	0	131.67	71	16.69	9	185.45		
M114A1E1	0.0	0	15.26	12	20.35	16	0	0	91.57	72	0.0	0	127.18		
Fort Knox (FK1)															
M151A2	5.38	32	0.00	0	2.58	16	0	0	8.61	62	0.0	0	16.58		
M114A1E1	0.0	0	5.38	56	2.58	27	0	0	1.67	17	0.0	0	9.63		
Fort Knox (FK2)															
M151A1	0.0	0	0.0	0	0.77	9	0	0	7.44	91	0.0	0	8.21		
M114A1E1	0.0	0	0.0	0	0.77	15	0	0	4.45	85	0.0	0	5.22		