Information Base Procedures for Generation of Synthetic Thermal Scenes

Final Report

M. Rose Kress

Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
Vicksburg, MS

Technical Report EL-92
DA Project AT40-SC-001

SWOE Report 92-1
February 1992

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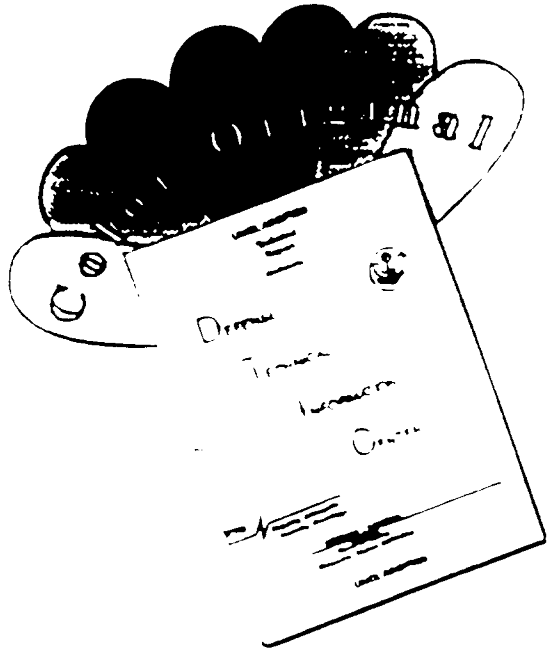

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FOREWORD

SWOE Report 92-1, February 1992, was prepared by Dr. M. Rose Kress of Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

This report is a contribution to the Smart Weapons Operability Enhancement (SWOE) Program. SWOE is a coordinated, Army, Navy, Marine Corps, Air Force and DARPA program initiated to enhance performance of future smart weapon systems through an integrated process of applying knowledge of the broadest possible range of battlefield conditions.

Performance of smart weapons can vary widely, depending on the environment in which the systems operate. Temporal and spatial dynamics significantly impact weapon performance. Testing of developmental weapon systems has been limited to a few selected combinations of targets and environment conditions, primarily because of the high costs of full-scale field tests and limited access to the areas or events for which performance data are required.

Performance predictions are needed for a broad range of background environmental conditions and targets. Meeting this need takes advantage of significant DoD investments by Army, Navy, Marine Corps and Air Force in 1) basic and applied environmental research, data collection, analysis, modeling and rendering capabilities, 2) extensive target measurement capabilities and geometry models, and 3) currently available computational capabilities. The SWOE program takes advantage of these DoD investments to produce an integrated process.

SWOE is developing, validating, and demonstrating the capability of this integrated process to handle complex target and background environment interactions for a world-wide range of battlefield conditions. SWOE is providing the DoD smart weapons and autonomous target recognition (ATR) communities with a validated capability to integrate measurement, information base, modeling and scene rendering techniques for complex environments. The result of a DoD-wide partnership, this effort works in concert with both advanced weapon system developers and major weapon system test and evaluation programs.

The SWOE program started in FY89 under Balanced Technology Initiative (BTI) sponsorship. Present sponsorship is by the U.S. Army Corps of Engineers (lead service), the individual services, and the Joint Test and Evaluation (JT&E) program of the Office of the Director of Defense Research and Engineering (DDR&E), Office of the Secretary of Defense (OSD).

The Program Director is Dr. L.E. Link, Technical Director of the U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL). The Program Manager is Dr. J.P. Welsh, CRREL. The Integration Manager is Mr. Richard Palmer, CRREL. The task areas and their managers are as follows: Modeling Task Area, LTC George G. Koenig, USAF, Geophysics Laboratory (GL), of the Air Force Phillips Laboratories; Information Bases Task Area, Mr. Harold W. West, PE, U.S. Army Engineer, Waterways Experiment Station (WES); Scene Rendering Task Area, Mr. Mike Hardaway, Corps of Engineers, Topographic Engineering Center (TEC); Validation Task Area, Dr. Jon Martin, Atmospheric Sciences Laboratory (ASL) of the Army Materiel Command.

PREFACE

The study reported herein was conducted during the period January 1990 to October 1991 by personnel of the Environmental Systems Division (ESD), Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). The study was authorized and monitored by Dr. Pat Welsh, Program Manager, Smart Weapons Operability Enhancement Program, US Army Engineer Cold Regions Research and Engineering Laboratory. The work was performed as part of the Balanced Technology Initiative, Multisensor Aided Targeting Program, for the US Army Communications Electronics Command (CECOM) Center for Night Vision and Electro-optics, Fort Belvoir, VA. Program Monitor was Mr. Dave Bohan, CECOM. Procedures were developed under the Corps of Engineers Scene Dynamics Research Program (Department of the Army Project AT40-SC-001). Technical Monitor for this study was Mr. Jerry R. Lundien of the Headquarters, US Army Corps of Engineers.

Dr. M. Rose Kress of the Environmental Analysis Group (EAG), EL, was principal investigator and was responsible for design and development of the digital information base and data analysis procedures. Ms. May Causey contributed to data analysis and prepared the graphics. Mr. Jerrell Ballard, Jr., EAG, and Mr. Kenneth Grossman, Atlantic Research Corporation Professional Services, assisted with computer programming and data format conversion. Dr. Kress prepared the report.

The work was conducted under the general supervision of Mr. Harold W. West, Chief, EAG; Dr. Victor Barber, Acting Chief, ESD; and Dr. John Harrison, Chief, EL.

Dr. Robert W. Whalin was Director of WES. COL Leonard G. Hassell, EN, was Commander and Deputy Director.

This report should be cited as follows:

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
knots (international)	0.5144444	meters per second

INFORMATION BASE PROCEDURES FOR GENERATION OF SYNTHETIC THERMAL SCENES

PART I: INTRODUCTION

Background

1. The Balanced Technology Initiative, Smart Weapons Operability Enhancement (SWOE), Multisensor Aided Targeting Program is a Tri-Service (US Army, Navy, and Air Force) initiative aimed at providing the capability to simulate complex terrain backgrounds for use by smart weapons designers, developers, and evaluators. Multisensor-based weapons designed to automatically locate and acquire targets must be able to isolate targets in relatively complex background scenes. The capability to evaluate the effects of various terrain, weather, and atmospheric conditions on smart weapons sensor performance is greatly enhanced by the ability to quantitatively characterize terrain features and numerically model dynamic background terrain signatures.

2. Accurate, quantitative representations of environmental background conditions will have application to smart weapons system evaluation, concept trade-off decisions, automatic/aided target recognition development and evaluation, and Department of Defense (DoD) weapons development test and evaluation processes. Digital three-dimensional (3-D) representations of terrain and weather conditions can be used for software and hardware in the loop testing by DoD weapons systems developers.

3. Procedures are being developed for generation of thermal scenes that depict realistic landscape perspective and are radiometrically correct. Radiometric fidelity of a synthetic thermal scene depends on the ability to model the physics of the 3-D environment accurately. The demands of realistic landscape perspective and radiometric fidelity require a quantitative characterization of the total scene environment in terms relevant to thermal signature numerical modeling and graphic 3-D scene generation and display.

4. The thermal scene generation procedure includes four integrated components:

a. Environmental information bases that characterize the static and dynamic aspects of the landscape to be simulated.

b. Physics-based numerical models (driven by the information base) that predict the background thermal signatures as a function of time of day.

c. Radiance models that predict the radiometric signatures of the landscape for a particular sensor type from a specified viewing perspective.

d. A computer graphics system for generating a two-dimensional image array of the synthetic thermal scene as viewed by a stand-off sensor (Link and West 1991).

Purpose and Scope

5. The purpose of this report is to document the methods developed for the environmental information base component of the overall SWOE thermal scene generation procedure. Scope is limited to documentation of the information base content and data processing/analysis procedures developed to satisfy the other component requirements: thermal signature modeling, thermal radiance field predictions, and generation of realistic graphic representations of 3-D thermal backgrounds. The numerical models themselves, the 3-D visualization tools, and database requirements for other wavebands or for target signature predictions will be described in subsequent reports.

Landscape Area

6. A site at Fort Hunter Liggett, California, was selected by the study sponsor for application of the environmental information base procedures for use in generating a 3-D thermal scene for a waveband of 8 to 14 μ. Figure 1 shows the location of the site. The landscape area considered for the information base is approximately 1.5 by 2 km with local relief of about 100 m. A satellite image acquired on 10 October 1989 by SPOT Image Corporation over the area is shown in Figure 2. These are commercially available satellite data collected at a nominal ground resolution of 10 m in the 400- to 900-nm waveband.

PART II: ENVIRONMENTAL INFORMATION BASE

Function

7. The function of the environmental information base in the scene generation procedure is to organize, store, analyze, retrieve, and display all data required for proper execution of each component in the procedure. Primarily this involves providing quantitative environmental data on all combinations of terrain and weather conditions present in the landscape area for which thermal signature predictions will be made. For example, an area with a sandy soil, covered by short grass vegetation on a 5-deg* north-facing slope would represent one unique environmental condition for which thermal signatures could be calculated. Complex landscapes always contain a multitude of these terrain factor combinations, referred to here as individual landscape features.

8. As used in this report, a landscape feature is a contiguous area on the ground having uniform conditions of soil, vegetation, ground slope, and slope aspect for which a thermal calculation is appropriate. Thermal signatures are highly dependent upon solar loading and weather conditions; therefore, signatures are calculated for different times of the day and Julian days of the year. The concept of landscape features is illustrated in Figure 3. By considering all relevant environmental factors simultaneously, the landscape can be subdivided into uniform areas referred to as features. The physical size of landscape features varies with the spatial complexity of the terrain. The terrain data are stored in the information base as grid cell arrays.

9. To achieve realistic perspective in the generated scene, the shape and spatial distribution of landscape features must be characterized in three dimensions. For numerical modeling purposes, each landscape feature must be quantified in terms relevant to thermal signature calculations by defining values for their physical, spectral, and thermal properties. The dynamic nature of certain terrain factors adds seasonal and diurnal complexity to the environmental characterization (e.g., vegetation density, soil moisture content).

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* A table of factors for converting non-SI units of measurement to SI units is presented on page 3.

Content and Structure

10. An integral part of the 3-D scene generation procedure, the information base contains all spatial and attribute data required to define the total landscape environment (land, water, atmosphere, sky, etc.). The content and structure of the information base are driven largely by the various requirements of the numerical models and the SWOE scene generation software.

11. The information base contains three kinds of data: digital terrain data (e.g., topography, soil types, vegetation types); physical, thermal, and spectral terrain attribute data (e.g., moisture content, emissivity, reflectance); and meteorological (weather and atmospheric) data (e.g., air temperature, visibility).

12. Digital terrain data are representations of portions of the earth's surface stored in computer-compatible formats. These data depict characteristics such as elevation, vegetation types, soil types, and other relevant environmental information. Digital terrain data used in the scene generation procedure are stored in raster format and managed by a geographic information system (GIS). The Geographical Resources Analysis Software System (GRASS) (US Army Engineer Construction Engineering Research Laboratory 1989) was used for this study.

13. The physics-based thermal signature prediction models used in the scene generation procedure require as inputs complete, quantitative descriptions of the physical, thermal, and spectral attributes of each landscape feature. These data are most efficiently stored and retrieved in tabular format in a relational database management system (RDBMS). The Informix RDBMS was used (Informix Software, Inc., Menlo Park, CA). The RDBMS associates each stored numerical value with the corresponding landscape feature depicted in the GIS.

14. Meteorological data are required throughout the scene generation process and have particular importance to the radiation field prediction models. Both surface weather and upper atmospheric profile data are required. These data are also stored in tabular format in the RDBMS. Meteorological data are assumed to apply to the entire landscape area modeled and therefore are associated with all landscape features within the area.

PART III: INFORMATION BASE DEVELOPMENT PROCEDURES

15. Five separate but integrated numerical computer models are used during the signature prediction and radiance field calculation components of the procedure (Hummel et al. 1991). In addition, specialized computer graphics software is employed to generate a 3-D visualization of the synthetic thermal landscape using the numerical model output. As the first step in development of the information base, a list of inputs required by each component in the procedure was compiled. This process resulted in a complete list of environmental data needed for the entire scene generation procedure. This list is given as Table 1. Identifying the information types (and values) required by each scene generation component was a critical factor in establishing digital data content and processing specifications.

16. Data format specifications required by the numerical models and those required by the computer graphics software were different, although both used many of the same data inputs. Several of the data analysis procedures discussed below were developed to provide an efficient method of converting numerical model output into reliable input data for the computer graphics environment.

Digital Terrain Data

17. Six digital terrain data files are required in the scene generation procedure: topographic elevation, ground surface slope, slope aspect, vegetation type, and surface and subsurface soil type. These data files are described below.

Topographic elevation

18. Digital topographic elevation data define the basic 3-D geometry of the landscape and are used directly during generation of the synthetic scene. The best available digital elevation data for the Fort Hunter Liggett area were in grid cell format with a 25-m grid cell spacing. A fractal algorithm was used to interpolate the gridded data to a cell resolution of 2 m.* This algorithm recursively subdivides the existing elevation grid cells until the specified cell resolution is reached. The newly generated grid cells are

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* Personal Communication, 1990, J. Conant, Aerodyne Research, Inc., Billerica, MA.

assigned distance weighted elevation values modified by a random perturbation factor. The resulting 2-m elevation grid is shown in Plate 1. A 3-D wire frame perspective using these data is shown as Figure 4.

Ground slope magnitude and slope aspect

19. Ground slope magnitude is defined as the inclination of the terrain surface from horizontal. Slope aspect is referenced clockwise from north. The slope and aspect of the landscape surface affect the amount of radiation intercepted by the surface and thus the resultant thermal signature. Slope and aspect also influence whether a particular landscape feature is visible from a specified observer/sensor viewpoint and thus are important during 3-D visualization of the simulated scene. Values for both are required in the scene generation procedure for each landscape feature.

20. Digital terrain data depicting slope and aspect values were produced from the 2-m resolution elevation data. A slope value in degrees (Struve 1977) and an aspect value expressed as degrees from north (US Army Construction Engineering Research Laboratory 1989) were calculated for each grid cell in the elevation data array.

21. Certain constraints in the SWOE scene generation procedure made it necessary to reduce the spatial variability in the slope and aspect digital terrain data by grouping values into a limited number of classes. The first constraint was the requirement by the graphics software for vector representations of the landscape features. Retaining the actual slope and aspect value for each grid cell resulted, when converted to a vector format, in a file exceeding the size limitation of the computer graphics software. The second constraint concerned the sensitivity of the thermal signature prediction models to the slope and aspect parameters.

22. To meet the file size requirements of the computer graphics component and also retain slope and aspect sensitivity in the numerical models, class ranges were established for these two factors. For each grid cell, the digital slope and aspect value was reassigned to the appropriate class. The class ranges are listed in Table 2. Class midpoints were used during numerical calculations of surface tempertures and radiances. Plates 2 and 3 illustrate the distribution of slope and aspect classed values, respectively, within the area.

Vegetation types

23. A key factor in the 3-D simulation of thermal background scenes is the proper representation of vegetation. Currently, thermal signature prediction models are available in the scene generation process for short grass, coniferous and deciduous forest canopy, and isolated trees. All vegetation within the landscape area must be assigned one of these three types.

24. A vegetation type map, consistent with the capabilities of the numerical models, was prepared for the Hunter Liggett area using the high-resolution (10-m) SPOT satellite imagery (Figure 2). The vegetation type map was derived using a standard density slice technique (Swain and Davis 1978). The continuous gray tone digital values of the single-band satellite image were converted to a series of brightness ranges, each corresponding to a vegetation type. Plate 4 illustrates the vegetation type distribution and includes a no-vegetation (bare ground) category.

25. The x,y locations of all trees in the landscape area were also determined using satellite data and computer digitizing techniques. Figure 5 shows the tree locations in the Hunter Liggett area.

Surface and subsurface soil types

26. Unified Soil Classification System (USCS) soil types were digitized from an existing 1:50,000-scale engineering soils map (Defense Mapping Agency 1980). Data on surface soil (Figure 6) and subsurface soil (Figure 7) characteristics were compiled.

Terrain Data Analysis Procedures

27. The digital terrain data were then used to identify and delineate landscape features. Landscape features are contiguous areas with uniform conditions of surface soil type, subsurface soil type, vegetation type, ground slope, and slope aspect.

28. Determination of landscape features was a two-step operation implemented in the GIS. First, a new digital terrain data file was constructed which combined the values of the five existing data files by simply assigning a unique value to each combination of existing values that actually occurred. This new data file reclassed each grid cell in terms of its particular combination of vegetation type, surface soil type, subsurface soil type, ground slope, and slope aspect. This step was executed in the GIS and resulted in a raster file that was registered to the other raster digital terrain files.

This processing operation resulted in 86 (of a possible 240) unique combinations of the five terrain factors.

29. The second step was to locate the boundaries of all contiguous areas of like landscape feature codes. This was accomplished by applying a raster-to-vector conversion technique to the landscape feature data file. The result was a polygon vector file in which each polygon had one of the 86 landscape feature codes. The conversion identified 1,337 individual landscape features (polygons), each assigned one of the 86 unique landscape feature codes. Plate 5 illustrates the landscape features in vector format. Table 3 lists the 86 unique combinations that occurred in the Hunter Liggett landscape area, their description, and the landscape feature code assigned to each combination.

Quantitative Terrain Data

30. In addition to the digital terrain data, a wide range of quantitative data defining the physical, thermal, and spectral attributes of each landscape feature is required. These parameters are listed in Table 1. Complete descriptions of these attributes, as well as estimates of their value for various vegetation and soil types, can be found in Balick, Link, and Scoggins (1981); Balick, Scoggins, and Link (1981); Smith et al. (1981); Turner (1986); Dornbusch (1990);* Hummel et al. (1991); Jones (1991); and Jordon (1991).**

31. The terrain attribute data required as input to the scene generation procedure are stored in tabular format in the RDBMS and cross-referenced to the digital terrain data stored in the GIS. As each component in the scene generation procedure is used, the required terrain attribute data are extracted from the RDBMS and made available for use in numerical model calculations.

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* W. K. Dornbusch, 1990 (Jan), "Engineering and Environmental Data Bases and Analysis for Smart Munitions Sensors; Task B: Environmental/Terrain Data Development for Smart Weapons Research," prepared by Science and Technology Corporation for US Army Engineer Waterways Experiment Station, Vicksburg, MS.

** Rachel Jordon, 1991, "A One-Dimensional Temperature Model for a Snow Cover," US Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Meteorological Data

32. Also required for the scene generation procedure are meteorological data that include surface weather, atmospheric conditions, and solar loading. Meteorological parameters used in the procedure are listed in Table 1. The ability to derive or estimate certain required meteorological data is included as part of the procedure, especially solar insolation.

33. Four weeks of meteorological data were acquired and stored in the RDBMS for the Fort Hunter Liggett study area. These data represent a typical week of weather conditions for the months of January, April, July, and October and were acquired and provided by the US Army Atmospheric Sciences Laboratory. One upper atmospheric profile, recorded by radiosonde, is listed in Table 4. Measured incoming solar data were not available for Fort Hunter Liggett for the dates used for this modeling effort and thus were calculated based on other meteorological data.

PART IV: SUMMARY AND RECOMMENDATIONS

34. This report describes the analysis procedures and content of a digital environmental information base developed for generation of computer-based synthetic thermal background scenes. A prototype information base was designed and developed for a 2- by 1.5-km site at Fort Hunter Liggett, California.

35. Considerable effort was devoted to locating or estimating appropriate values for many of the Hunter Liggett terrain and weather parameters needed in the scene generation procedure. Many of the required meteorological factors are not included in commonly available standard weather databases such as those maintained by the Air Force and the National Oceanic and Atmospheric Administration (NOAA). Published values for many of the thermal and spectral properties of landscape features are difficult to acquire. Methods of estimating values for these parameters should be developed and included as part of an improved scene generation procedure.

36. Additional research is needed to evaluate and adapt certain commonly available digital terrain and weather data from Government sources (such as the Defense Mapping Agency, the US Geological Survey, and NOAA) to the scene generation procedure.

37. Similar environmental information bases should be developed for locations in distinctly different ecological regions, especially desert, tropical, and arctic environments.

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Table 1

<u>Information Base Content for Synthetic</u>

<u>Thermal Scene Generation</u>

Elevation
Ground slope magnitude
Slope aspect
Vegetation type
- Grass
  - Percent ground cover
  - Height
  - State - measure of plant vigor
  - Longwave emissivity
  - Shortwave absorptivity
- Forest canopy
  - Stomatal resistance
  - Longwave emissivity
  - Shortwave absorptivity
  - Longwave transfer coefficient
  - View angle matrix

Surface and subsurface soil type
- Number of nodes in layer
- Quartz content of soil
- Roughness length
- Bulk transfer coefficient for eddy diffusivity
- Turbulent Prandtl number
- Turbulent Schmidt number
- Windless convection coefficient
- Shortwave absorptivity
- Intrinsic density of dry material
- Bulk density of dry material
- Heat capacity of dry mineral solids
- Dry soil thermal conductivity
- Soil coarseness code
- Plasticity index
- Albedo
- Hemispherical emissivity
- Thermal diffusivity
- Temperature of nodes
- Thickness of nodes
- Total bulk water density

Meteorological
- Latitude of recording station
- Longitude of recording station
- ZULU time difference
- Elevation of recording station
- Height above ground of recording station
- Averaged surface albedo of landscape area

(Continued)

Table 1 (Concluded)

Meterological (cont.)
Time interval of data
Year
Julian day
Local hour, time
Atmospheric pressure
Air temperature
Relative humidity
Wind speed
Wind direction
Visibility
Global incoming solar radiation
Direct incoming solar radiation
Diffuse incoming solar radiation
Downwelling thermal IR radiation
Low cloud cover, percent
Low cloud cover, type
Midlevel cloud cover, percent
Midlevel cloud cover, type
High cloud cover, percent
High cloud cover, type
Precipitation type
Precipitation rate
Precipitation grain size

Table 2

Class Ranges for Slope and Aspect

Slope (deg)

Class	Class Range, deg	Slope Value Used for Calculation
1	0-5	2.5
2	>5-10	7.5
3	>10-15	12.5
4	>15-20	17.5
5	>20	23.0

Aspect (deg from north)

Class	Class Range, deg	Aspect Value Used for Calculation
1	1-90	45
2	91-180	135
3	181-270	225
4	271-360	315

Table 3

Landscape Feature Codes and Descriptions Present in Hunter Liggett Area

Landscape Feature Code	Vegetation Type*	USCS Soil Type		Ground Slope Class**	Aspect Class**
		Surface	Subsurface		
01	DECI	SM	SM	1	1
02	DECI	SM	SM	1	2
03	DECI	SM	SM	1	3
04	DECI	SM	SM	1	4
05	DECI	SM	SM	2	1
06	DECI	SM	SM	2	2
07	DECI	SM	SM	2	3
08	DECI	SM	SM	2	4
09	DECI	SM	SM	3	1
11	DECI	SM	SM	3	3
12	DECI	SM	SM	3	4
13	DECI	SM	SM	4	1
15	DECI	SM	SM	4	3
16	DECI	SM	SM	4	4
17	DECI	SM	SM	5	1
18	DECI	SM	SM	5	2
19	DECI	SM	SM	5	3
20	DECI	SM	SM	5	4
21	DECI	CL	CL	1	1
22	DECI	CL	CL	1	2
23	DECI	CL	CL	1	3
24	DECI	CL	CL	1	4
25	DECI	CL	CL	2	1
27	DECI	CL	CL	2	4
29	GRASS	SM	SM	1	1
30	GRASS	SM	SM	1	2
31	GRASS	SM	SM	1	3
32	GRASS	SM	SM	1	4
33	GRASS	SM	SM	2	1
34	GRASS	SM	SM	2	2
35	GRASS	SM	SM	2	3
36	GRASS	SM	SM	2	4
37	GRASS	SM	SM	3	1
38	GRASS	SM	SM	3	2
39	GRASS	SM	SM	3	3
40	GRASS	SM	SM	3	4
41	GRASS	SM	SM	4	1
42	GRASS	SM	SM	4	2
43	GRASS	SM	SM	4	3

(Continued)

* Codes are defined as follows: DECI = deciduous canopy, SM = sand, and CL = clay.

** See Table 2 for class definitions.

Table 3 (Concluded)

Landscape Feature Code	Vegetation Type*	USCS Soil Type Surface	USCS Soil Type Subsurface	Ground Slope Class**	Aspect Class**
44	GRASS	SM	SM	4	4
45	GRASS	SM	SM	5	1
46	GRASS	SM	SM	5	2
47	GRASS	SM	SM	5	3
48	GRASS	SM	SM	5	4
49	GRASS	CL	CL	1	1
50	GRASS	CL	CL	1	2
51	GRASS	CL	CL	1	3
52	GRASS	CL	CL	1	4
53	GRASS	CL	CL	2	1
54	GRASS	CL	CL	2	2
55	GRASS	CL	CL	2	3
56	GRASS	CL	CL	2	4
57	GRASS	CL	CL	3	3
59	BARE	SM	SM	1	1
60	BARE	SM	SM	1	2
61	BARE	SM	SM	1	3
62	BARE	SM	SM	1	4
63	BARE	SM	SM	2	1
64	BARE	SM	SM	2	2
65	BARE	SM	SM	2	3
66	BARE	SM	SM	2	4
68	BARE	SM	SM	3	2
69	BARE	SM	SM	3	3
70	BARE	SM	SM	3	4
72	BARE	SM	SM	4	2
73	BARE	SM	SM	4	3
74	BARE	SM	SM	4	4
75	BARE	SM	SM	5	1
76	BARE	SM	SM	5	2
77	BARE	SM	SM	5	3
78	BARE	SM	SM	5	4
79	BARE	CL	CL	1	1
80	BARE	CL	CL	1	2
81	BARE	CL	CL	1	3
82	BARE	CL	CL	1	4
84	BARE	CL	CL	2	2
85	BARE	CL	CL	2	3
86	BARE	CL	CL	2	4

Table 4

Upper Atmospheric Profile of Hunter Liggett

20 Sep 1989

Height Above Ground, m	Atmospheric Pressure, mb	Temperature °C	Dew Point Depression °C	Wind Direction deg	Wind Speed knots
Surface	979	10.2	1.2	--	Calm
1,504	850	14.0	18	350	13
3,110	700	4.2	19	005	10
5,580	500	-9.1	26	300	25
7,748	400	-22.1	16	290	30
		Significant Levels			
	961	9.6	1.5		
	919	12.8	8.0		
	907	15.2	17		
	861	13.8	12		
	839	13.6	21		
	800	10.8	8		
	768	6.2	14		
	702	4.0	17		
	691	4.6	26		
	638	3.2	--		
	588	0.0	30		
	575	-0.9	33		
	433	-17.5	15		
	381	-24.7	18		

Wind

Elevation Above Surface, m	Wind Direction deg	Wind Speed knots
Surface	--	Calm
2,000	325	06
3,000	325	10
4,000	330	10
6,000	350	14
7,000	355	14
8,000	355	13
9,000	005	11
11,000	005	10
12,000	355	12
14,000	350	12
16,000	320	16
19,000	295	22
20,000	255	25
25,000	290	29
26,000	295	28

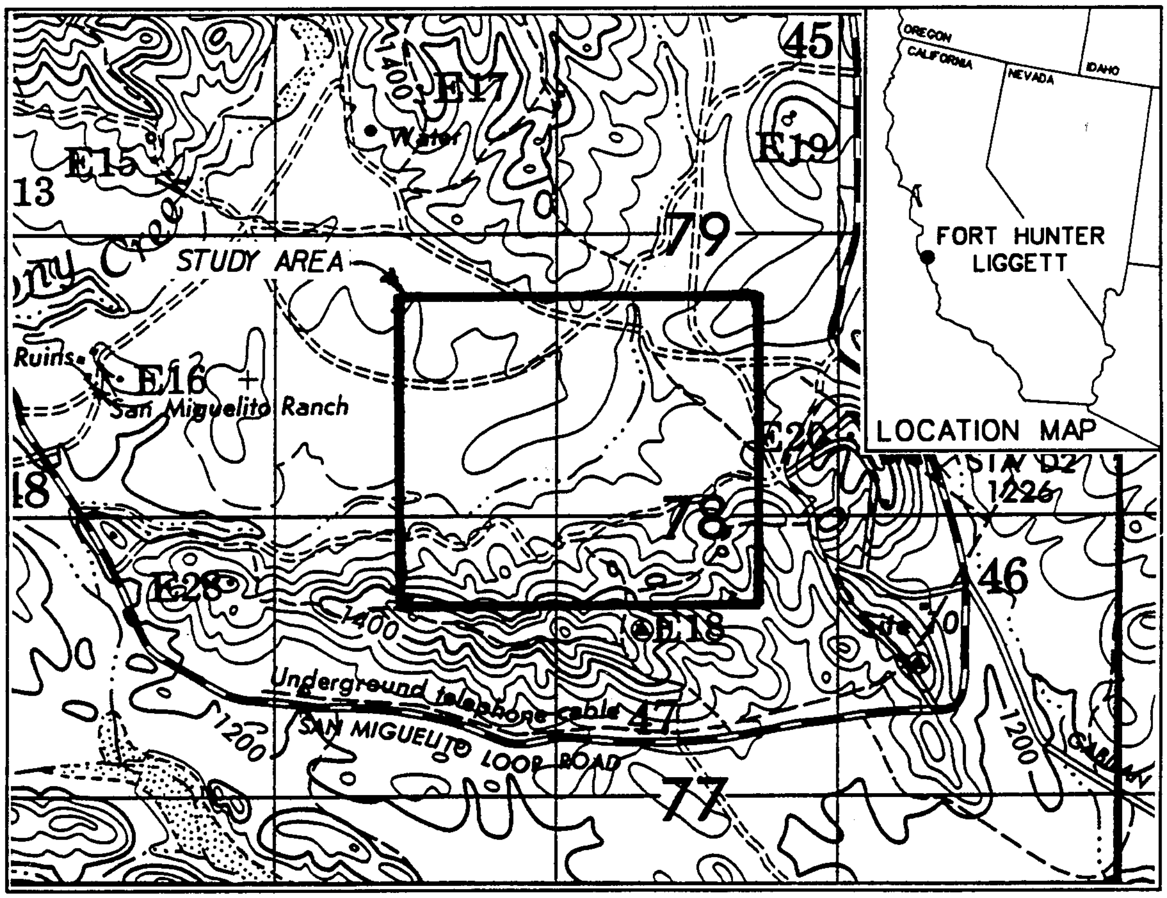


Figure 1. Location of Fort Hunter Liggett, California, study area

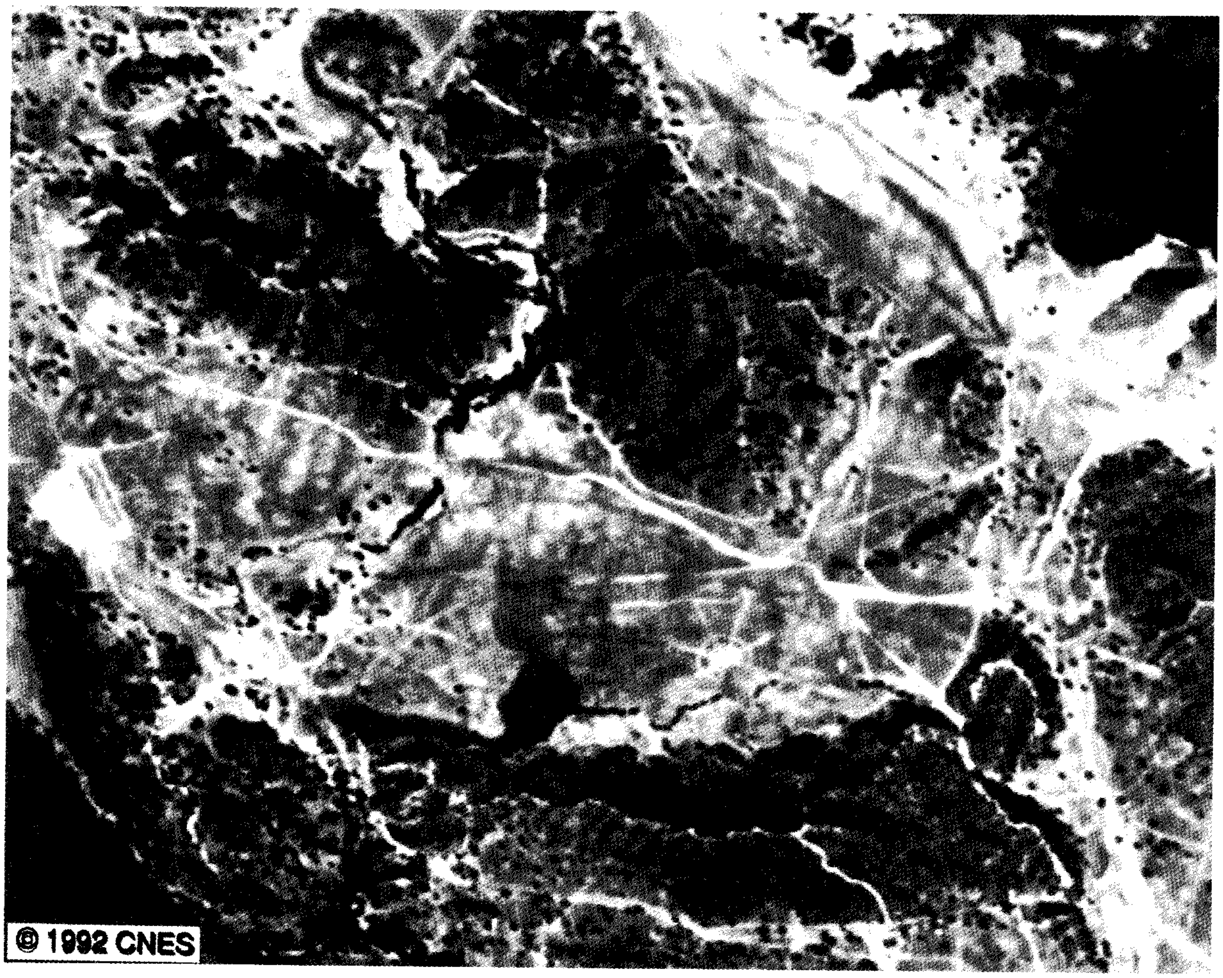


Figure 2. Satellite image of Fort Hunter Liggett area and surrounding terrain, collected 30 Aug 89 by SPOT Image Corporation

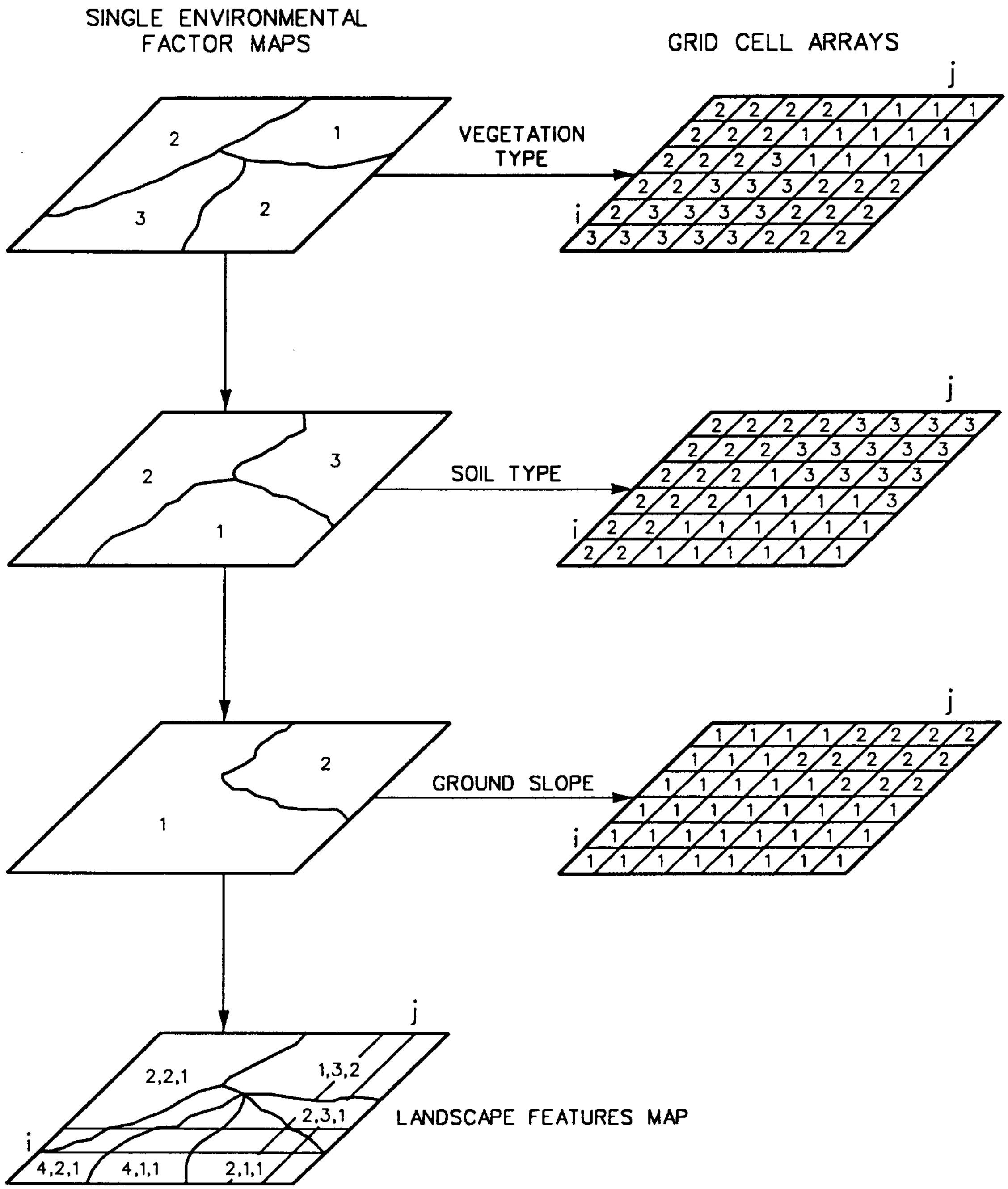


Figure 3. Landscape feature concept. By considering all relevant terrain characteristics simultaneously, contiguous uniform areas are identified. The terrain data are stored in the information base as grid cell arrays

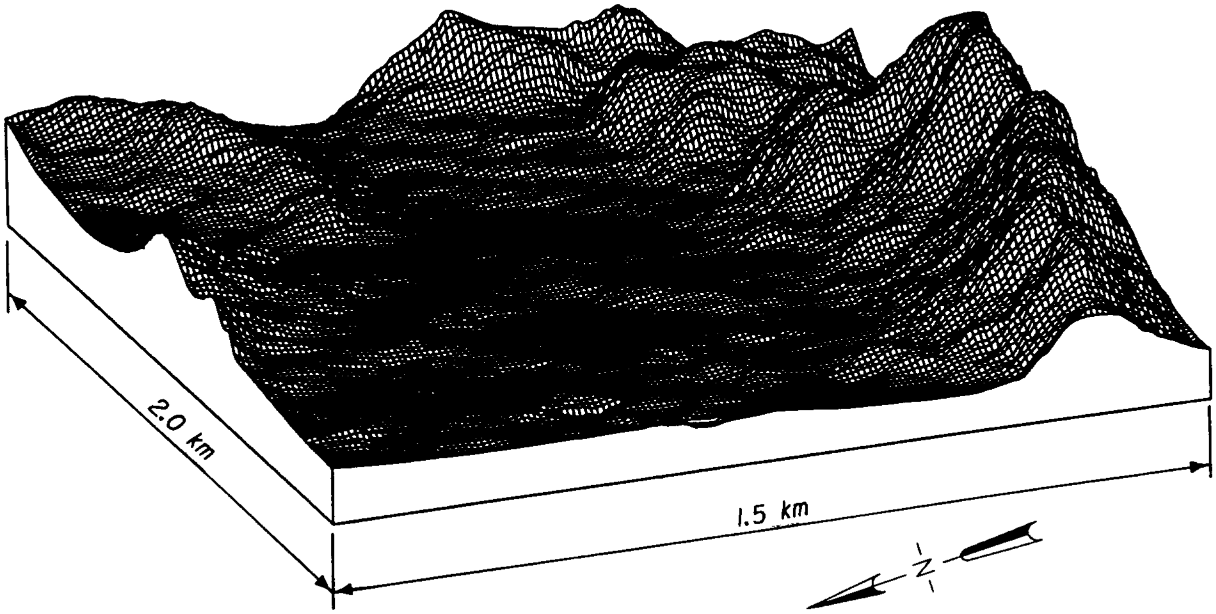


Figure 4. Three-dimensional view of Fort Hunter Liggett area topographic ground surface

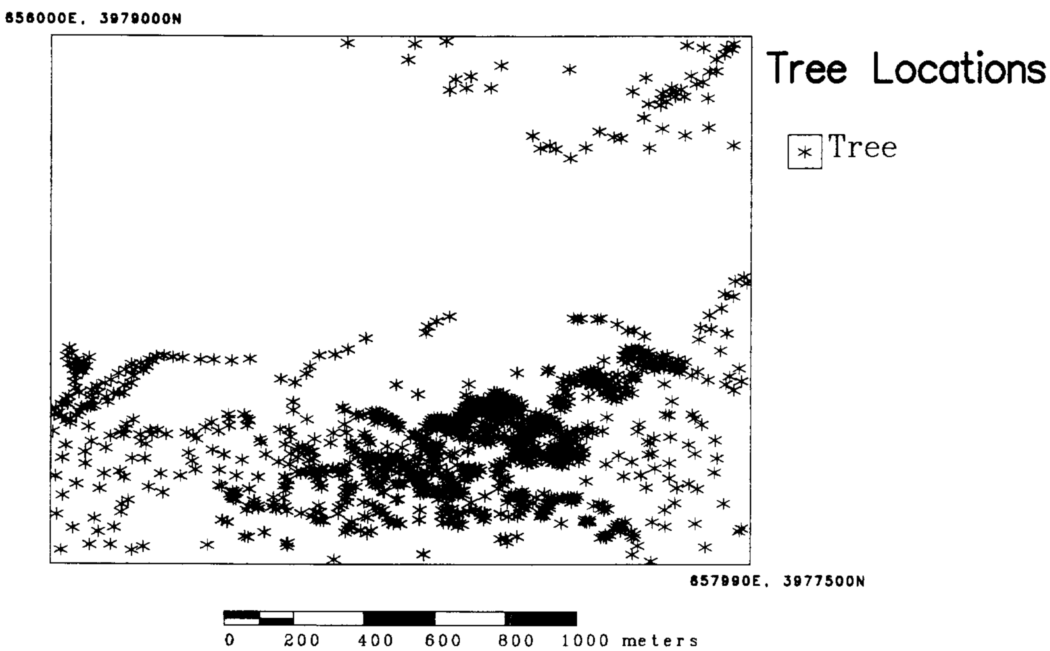


Figure 5. Location of trees in Fort Hunter Liggett area

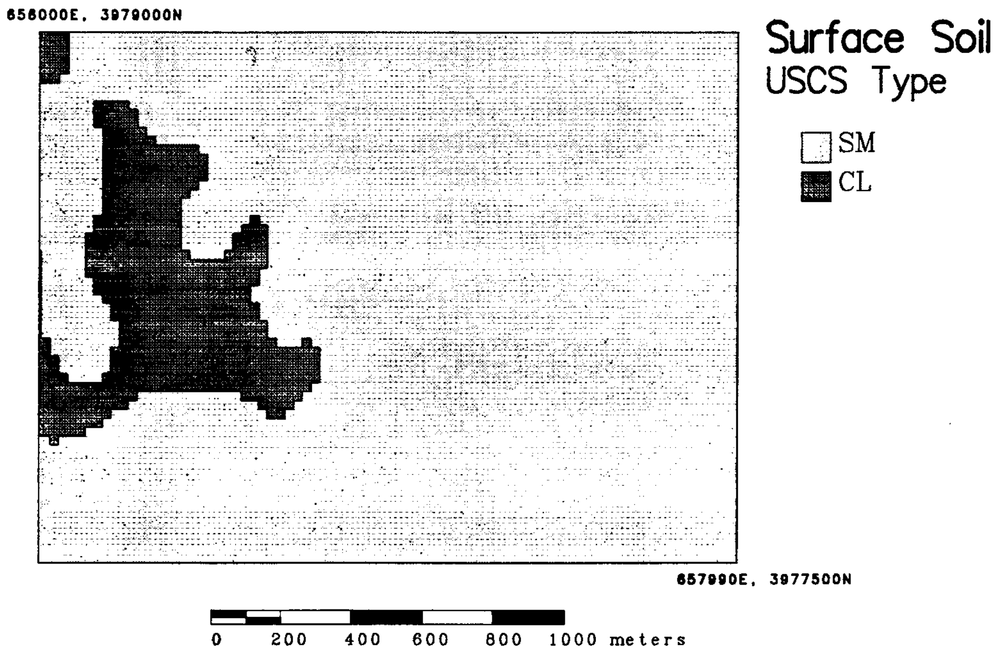


Figure 6. Surface soil types for
Fort Hunter Liggett area

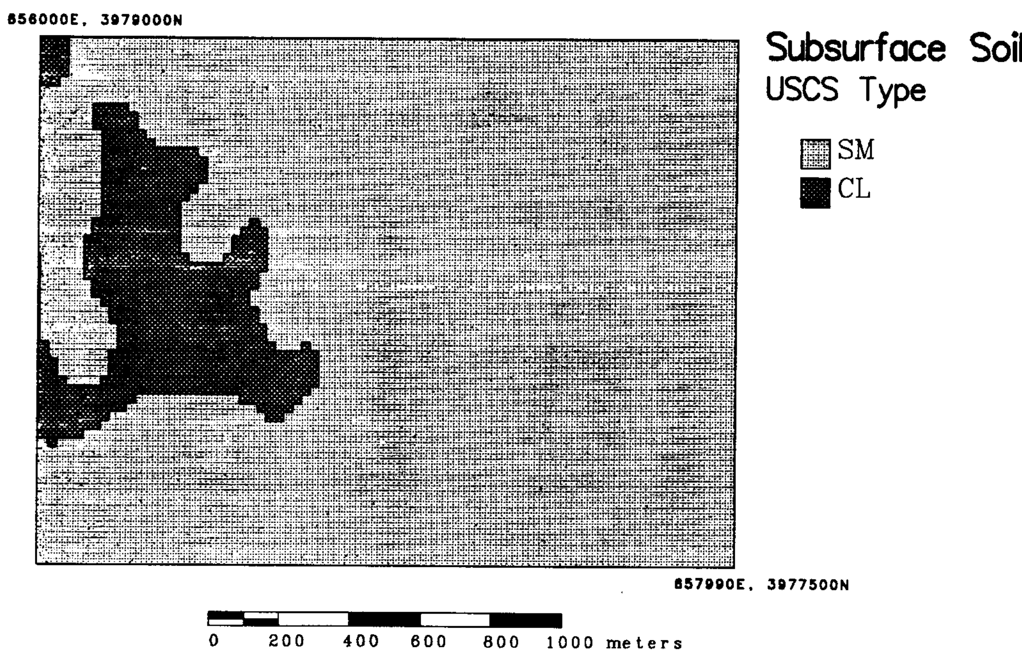
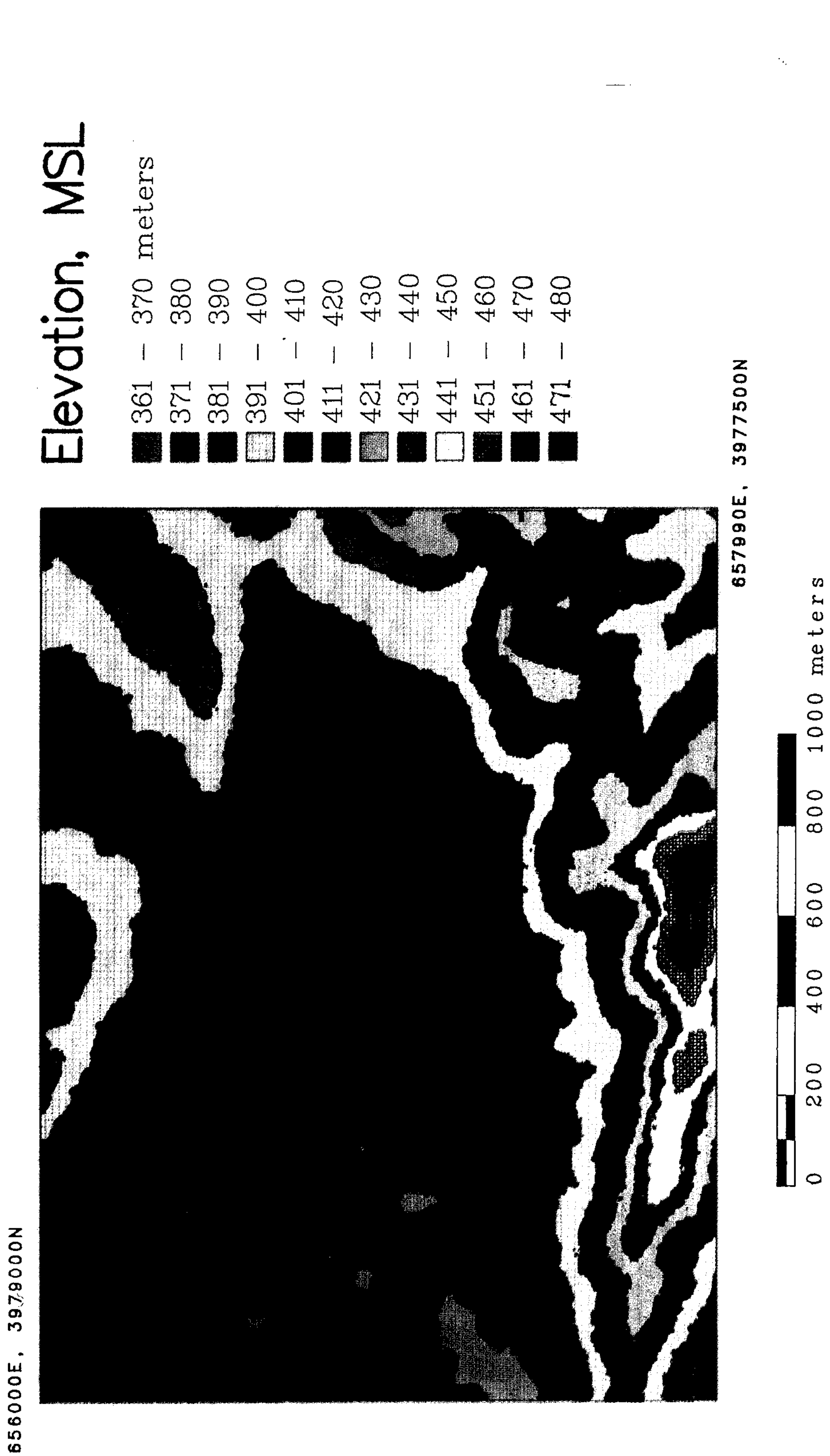
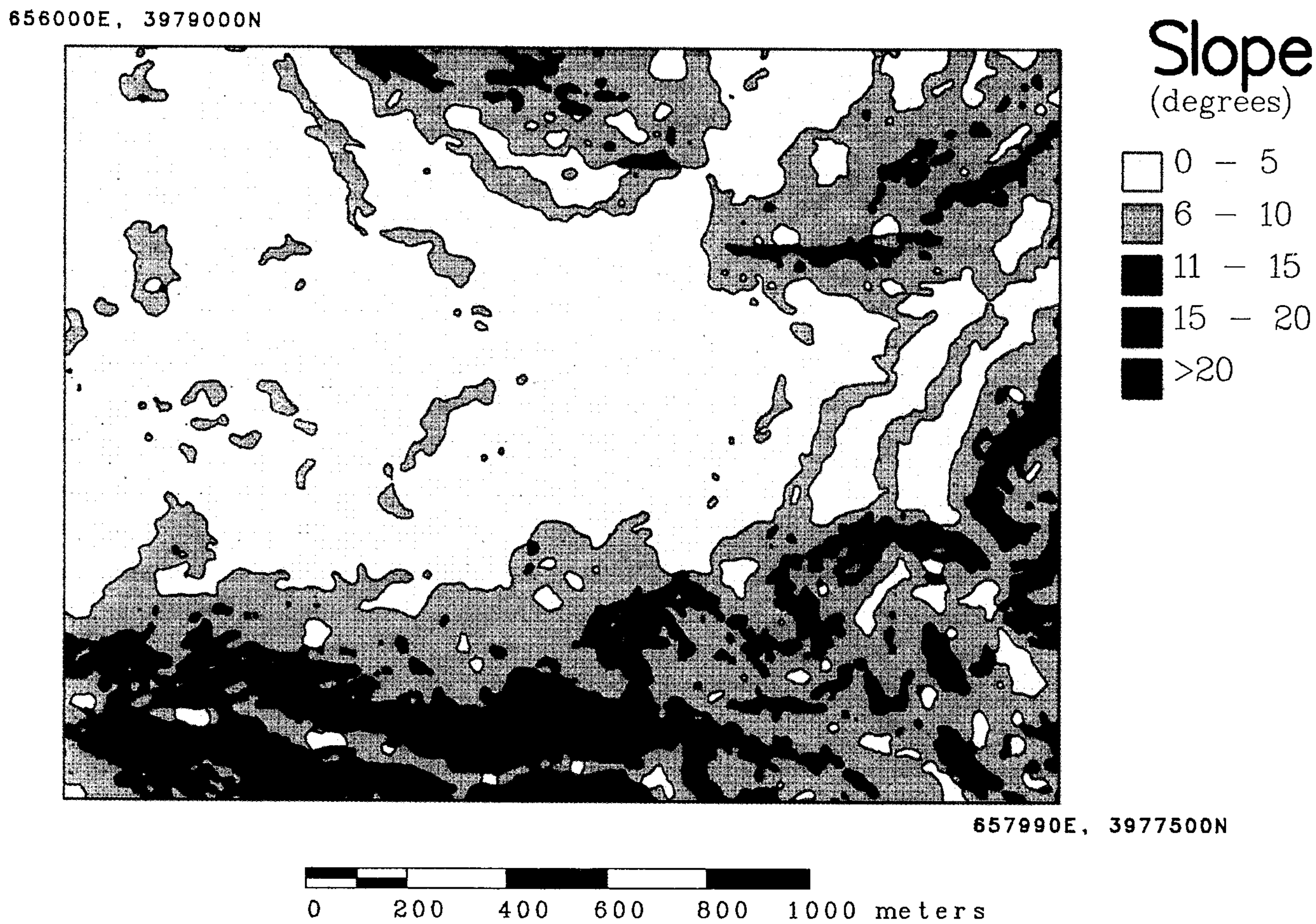


Figure 7. Subsurface soil types for
Fort Hunter Liggett area



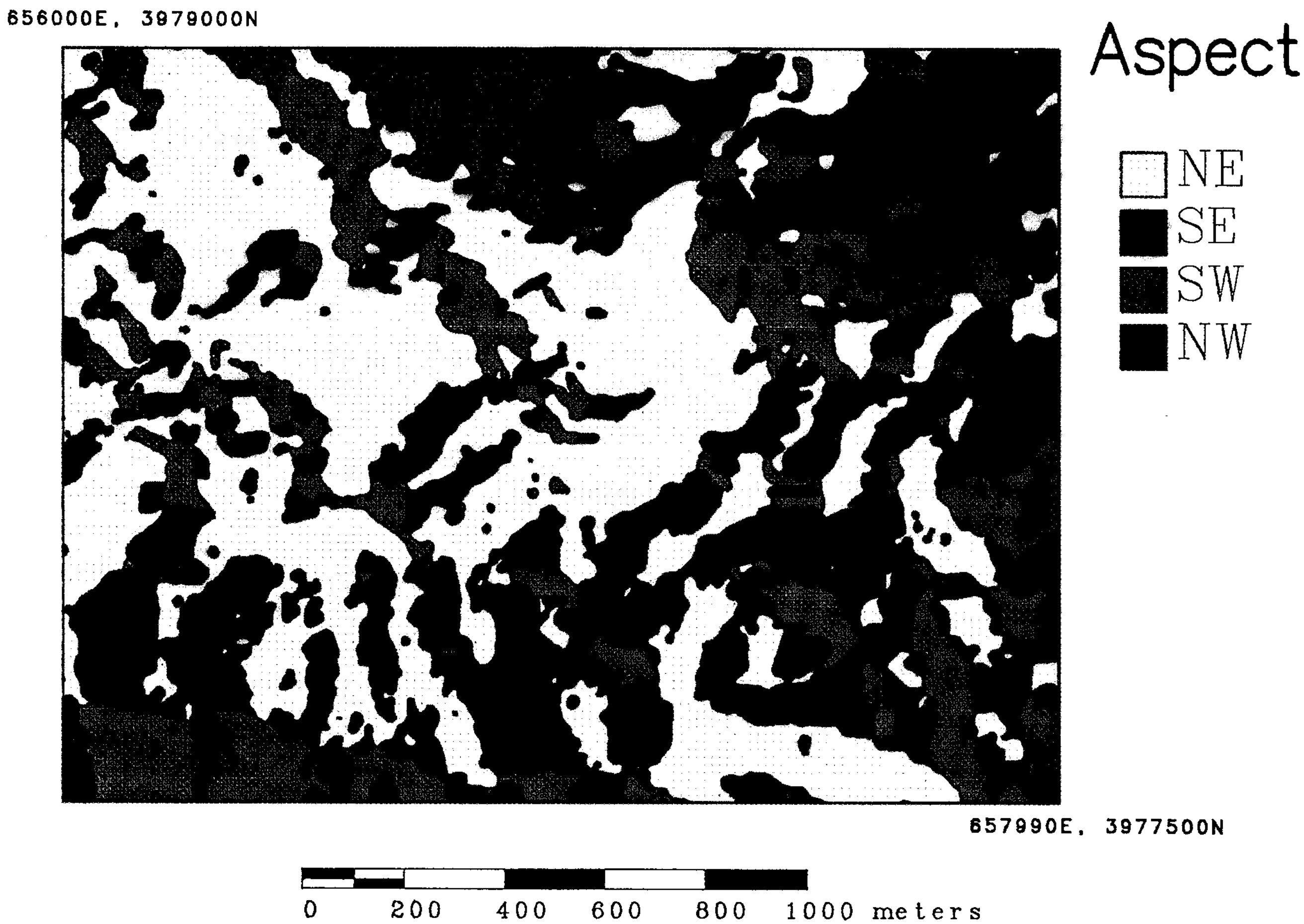
ELEVATION DATA FOR FORT HUNTER LIGGETT AREA

PLATE 1



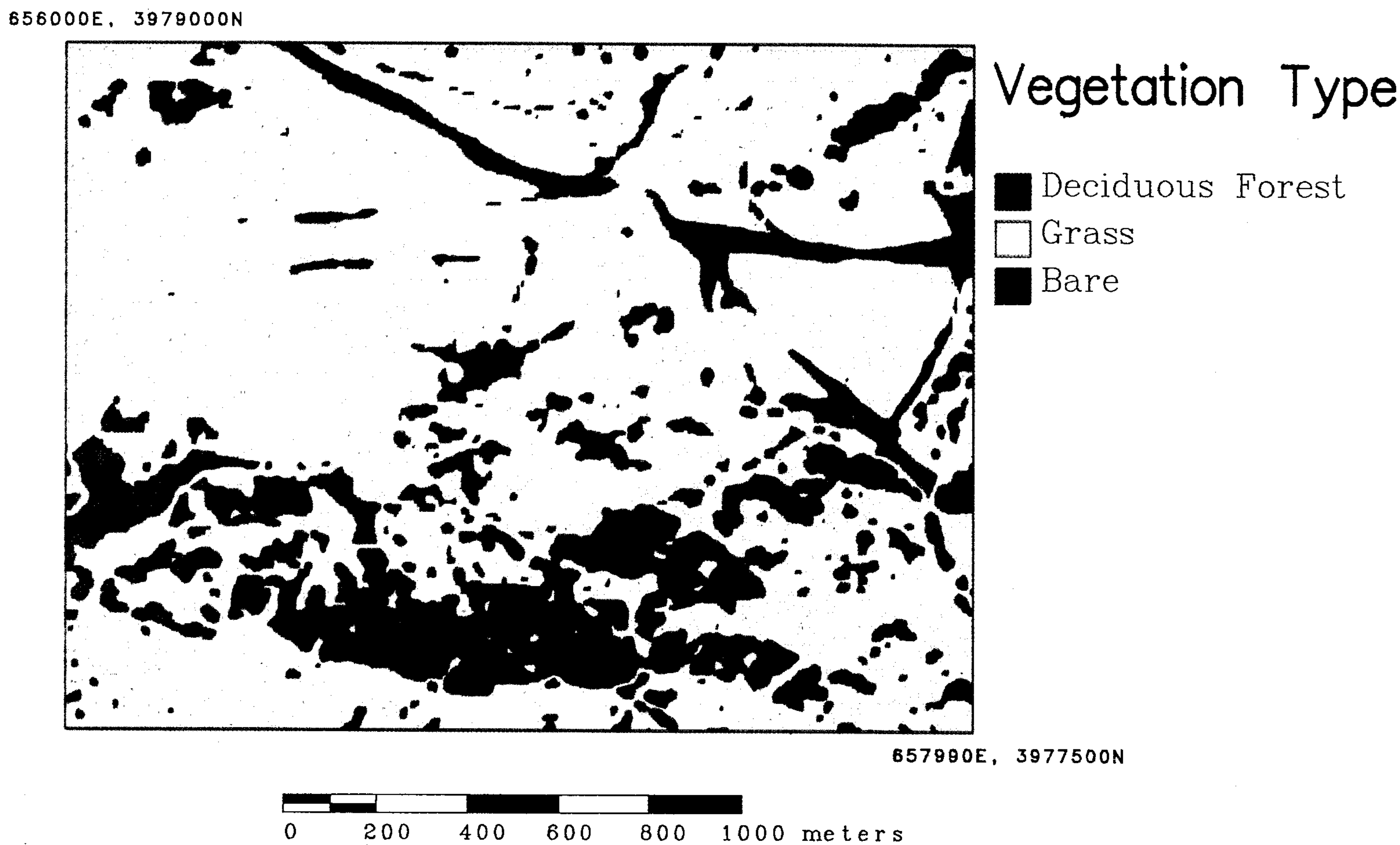
GROUND SLOPE MAGNITUDE FOR FORT HUNTER LIGGETT AREA

PLATE 2



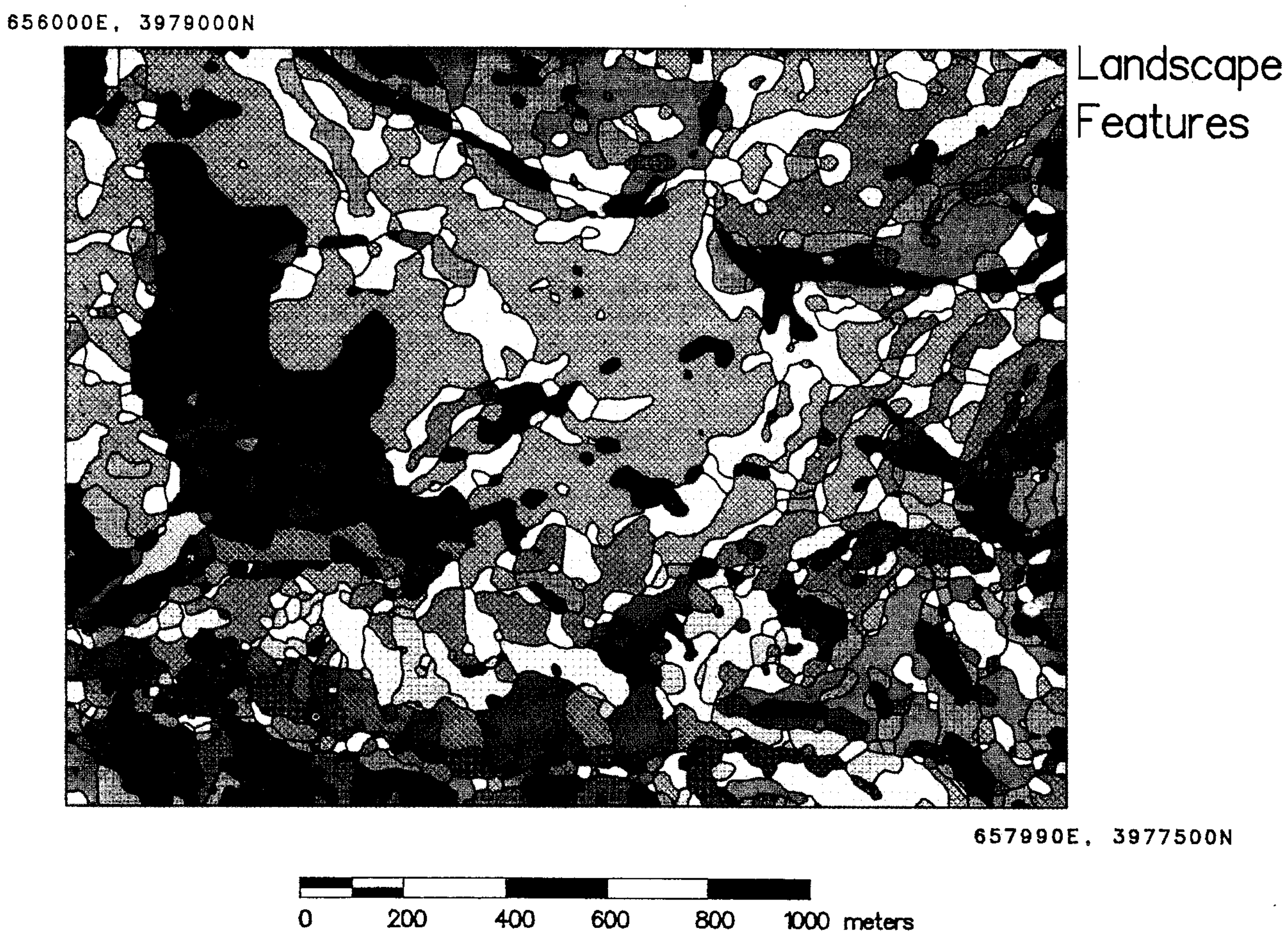
SLOPE ASPECT FOR FORT HUNTER LIGGETT AREA

PLATE 3



VEGETATION DATA FOR FORT HUNTER LIGGETT AREA

PLATE 4



LANDSCAPE FEATURES IDENTIFIED AT FORT HUNTER LIGGETT AREA

PLATE 5

REPORT DOCUMENTATION PAGE

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13. ABSTRACT (*Maximum 200 words*)

Procedures are being developed for computer generation of thermal images that depict realistic landscape perspective and are radiometrically correct. Digital three-dimensional (3-D) representations of thermal terrain conditions can be used for software and hardware in the loop testing by weapons system designers, developers, and evaluators. The procedure has four components: (a) environmental information bases that characterize the static and dynamic aspects of the landscape, (b) physics-based numerical thermal prediction models, (c) radiance prediction models, and (d) computer graphics system for generating a 3-D thermal landscape perspective. This report describes the information base content, structure, and analysis methods developed to store and access 3-D terrain, weather, physical, thermal, and spectral property data required to support all procedure components. Methods for characterizing and quantifying environmental information as a 3-D dynamic landscape; formatting, managing, and retrieving diverse environmental information for numerical modeling purposes;

(Continued)

14. SUBJECT TERMS

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Synthetic image
Thermal

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13. (Concluded).

and analyzing terrain data are discussed. The spatial elements of the landscape are configured in a geographic information system and define the 3-D aspects of the environment. Physical, spectral, and thermal properties of the spatial elements are configured in a relational database management system integrated with the geographic information system.