US Army Corps
of Engineers

AD-A200 653

DIGITAL TERRAIN DATA IN SUPPORT OF LAND COMBAT MODELS

ENGINEER STUDIES CENTER

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USAESC-R-88-16

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Prepared by

US Army Corps of Engineers
Engineer Studies Center

September 1988

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

ADA200653

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY: N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): USAESC-R-88-16	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: US Army Engineer Studies Center; 6b. OFFICE SYMBOL (If applicable): CEESC	7a. NAME OF MONITORING ORGANIZATION: US Army Engineer School
6c. ADDRESS (City, State, and ZIP Code): Casey Building 2594, Telegraph and Leaf Roads, Fort Belvoir, VA 22060-5583	7b. ADDRESS (City, State, and ZIP Code): Ft Leonard Wood, MO 65473-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: US Army Corps of Engineers; 8b. OFFICE SYMBOL (If applicable): USACE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): 20 Massachusetts Ave., NW, Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 0; PROJECT NO. 0; TASK NO. 0; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
(U) Digital Terrain Data in Support of Land Combat Models

12. PERSONAL AUTHOR(S)
REYNOLDS, Stephen C.; TAYLOR, Richard L.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8712 TO 8809	8809	70

16. SUPPLEMENTARY NOTATION
DA Agency Accession No: DA314821

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Engineers, Wargame Simulation, Model Development, Data Base, Digital Terrain, Mapping, Geographic Information

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Chief of Engineers has designated the Engineer Studies Center (ESC) as the Center of Engineer Modeling for the US Army Corps of Engineers (USACE) and the USACE point of contact for the Army Model Improvement Program (AMIP). Part of the research supporting the EMIP Plan addressed the availability of the digital terrain data (DTD) needed by models to adequately represent the influence of terrain on the outcome of the battle.

This report identifies requirements for DTD in models at each level in the hierarchy of Army models. Three specific models (CASTFOREM, VIC, and FORCEM) were examined to determine how they use terrain data and to assess the availability of the DTD required by the models. However, the DTD issues facing the Army extend far beyond the modeling community. ESC hopes that this analysis will contribute to finding a solution to the Army's pressing needs for DTD, not only to support modeling, but more importantly to support the new generations of weapons and command and control systems that require DTD to function.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: DALE F. MEANS, COL, Corps of Engineers, CDR/DIR, ESC	22b. TELEPHONE (Include Area Code): (202) 355-2374; 22c. OFFICE SYMBOL: CEESC

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

USAESC-R-88-16

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Total	55

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ACKNOWLEDGMENTS

The Engineer Studies Center, US Army Corps of Engineers, prepared this report. COL Dale F. Means was the Commander/Director; Mr. Dean E. Considine was the Technical Director. The Engineer Model Improvement Plan team is directed by Mr. Larry W. Wright (Senior Project Manager). The principal author of this monograph was Mr. Stephen C. Reynolds.

This monograph was prepared for publication by Mrs. Collie J. Johnson. Mr. Chris Y. K. Lew, Mr. John E. Hobbs, and Ms. Linda W. Smith provided the graphics.

ESC would like to thank the many people from the following Army organizations who contributed their time: the Office of the Chief of Engineers; the Office of the Assistant Chief of Engineers; the TRADOC Analysis Command both at Fort Leavenworth and at White Sands; the Engineer School; the Concepts Analysis Agency; the Army Materiel Systems Analysis Activity; the Army Model Improvement Program Management Office; the Belvoir Research and Development Engineer Center; the Engineer Topographic Laboratories; Construction Engineering and Research Laboratory; and, the Waterways Experiment Station.

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EXECUTIVE SUMMARY

The Chief of Engineers has designated the Engineer Studies Center (ESC) as the Center of Engineer Modeling for the US Army Corps of Engineers (USACE) and the USACE point of contact for the Army Model Improvement Program (AMIP). As such, ESC has evaluated the current status of combat engineer modeling, identified a number of deficiencies in combat engineer modeling, and prepared the Engineer Model Improvement Program (EMIP) Plan which is designed to correct those deficiencies.

Part of the research supporting the EMIP Plan addressed the availability of the digital terrain data (DTD) needed by models to adequately represent the influence of terrain on the outcome of the battle. The results of that research are presented as Annex E in the EMIP plan. However, the DTD issues facing the Army extend far beyond the modeling community. The results of ESC's DTD research are published here as a separate monograph to provide wider circulation for its findings. ESC hopes that this analysis will contribute to finding a solution to the Army's pressing needs for DTD, not only to support modeling, but more importantly to support the new generations of weapons and command & control systems that require DTD to function.

The Army is faced with a near-term (1988-1992) shortfall in the availability of new digital terrain data. Both The Engineer Topographic Laboratories (ETL) and the Office of the Deputy Chief of Staff for Intelligence (ODCSINT) have represented the Army in discussions with the Defense Mapping Agency (DMA) concerning the Army's near-term requirements for digital terrain data sets. DMA has stated their commitment to develop a product specification for interim terrain data (ITD) and deliver a prototype data set to the Army by the end of 1988. ITD, to be acceptable by the Army, must be easily usable, cost effective, and adaptable to existing and near-term fieldable Army tactical and non-tactical systems/programs with respect to their operating systems and specific applications. ITD must also be co-producible by the Army and private industry. Finally, ITD should be economically translatable to the future DMA tactical terrain data (TTD) system.

The DTD needs of tactical systems should drive the production of ITD in the near-term and TTD in the long-term. However, the needs of the modeling community and the needs of the tactical systems should be closely related since the areas analyzed for possible deployment of the new tactical systems are the areas where studies will be done using models. ESC is not in a position to establish the Army's priority for new DTD production (those priorities must be set by the Deputy Chief of Staff for Intelligence, in cooperation with the Deputy Chief of Staff for Operations). From the perspective of model requirements alone, ESC suggests priority be given to digitizing existing hard copy tactical terrain analysis data base (TTADB) source material, since it has the terrain feature information and data density most appropriate to the widest segment of model needs. ESC also recommends that the production of new DTD be scheduled based on the relative priority of modeling efforts in each geographic area.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACE ....Assistant Chief of Engineers
AG.....................air-to-ground
ALBE..................air land battle environment
AMIP.................. Army Model Improvement Program
AMM...................Army Mobility Model
AMS...................Analytical Mapping System
AO.....................area of operation
AOP...................avenues of approach
ARC/INFO.............Arc and Information (a commercial GIS)
ARTBASS..............Army Training Battle Simulation System
AT.....................artillery

BFLD..................battlefield data
BP.....................battle position

CAA...................Concepts Analysis Agency
CAD...................Concepts and Analysis Division (ETL)
CASTFOREM............Combined Arms and Support Task Force Evaluation Model
CCM...................cross-country movement
CERL..................Construction Engineering Research Laboratory
CONUS.................Continental United States
CSS...................combat service support
C^3I..................command, control, communications, and intelligence

DA.....................Department of the Army
DFAD..................Digital Feature Analysis Data
DMA...................Defense Mapping Agency
DOD...................Department of Defense
DTD...................Digital Terrain (Topographic) Data
DTED..................Digital Terrain Elevation Data
DTSS..................Digital Topographic Support System

EHSC..................Engineering and Housing Support Center
EMIP..................Engineer Model Improvement Program
ESC...................Engineer Studies Center
ETL...................Engineer Topographic Laboratories

FIREFINDER...........Counter Battery Fire Finding System
FORCEM...............Force Evaluation Model
FP.....................firing point
FRG...................Federal Republic of Germany

GIS...................geographic information system
GM....................ground movement
GNC...................Global Navigation Chart
GRASS.................Geographical Resources Analysis Support System
GSL...................Geographic Sciences Laboratory

IPB...................intelligence preparation of the battlefield

ITD....................Interim Terrain Data

JPL....................Jet Propulsion Laboratory
LO.....................logistics
LOC....................lines of communication
LOS....................line of sight
MC&G...................mapping, charting, and geodesy
MCP....................movement control point
MOSS...................Multiple Overlay and Statistical System

NATO...................North Atlantic Treaty Organization
NBC....................nuclear, biological, chemical

ODCSINT................Office of the Deputy Chief of Staff for Intelligence
ONC....................Operational Navigational Chart

POL....................petroleum, oils and lubricants
PTADB..................Planning Terrain Analysis Data Base

R&D....................research and development
ROK....................Republic of Korea
RP.....................Release Point

SP.....................Start Point
STD....................special terrain data

TAC....................Terrain Analysis Center
TAWS...................Terrain Analysis Work Station
TERCOM.................terrain contour matching
TPC....................Tactical Pilotage Chart
TRAC-WSMR..............TRADOC Analysis Command, White Sands Missile Range
TRADOC.................Training and Doctrine Command
TTADB..................Tactical Terrain Analysis Data Base
TTD....................tactical terrain data

US.....................United States
USACE..................United States Army Corps of Engineers
USAES..................United States Army Engineer School
UTM....................universal transverse mercator

VIC....................Vector-in-Commander
VIP....................Vector-in-Commander Preprocessor
VOD....................vertical obstruction data

WES....................Waterways Experiment Station

DIGITAL TERRAIN DATA
IN SUPPORT OF LAND COMBAT MODELS

I. INTRODUCTION

1. Purpose. This report identifies requirements for digital terrain data (DTD) in combat simulations at each level in the hierarchy of Army models. This report was done in support of the Engineer Model Improvement Program (EMIP) Plan, and it appears as Annex E in the final report of that plan.[1] It is published here as a separate monograph to provide wider circulation for its findings since the DTD issues facing the Army extend far beyond the modeling community. Three specific models (Combined Arms and Support Task Force Evaluation Model [CASTFOREM], Vector-in-Commander [VIC], and Force Evaluation Model [FORCEM]) were examined to determine how they use terrain data and to assess the availability of DTD at the different levels of resolution required by these models.

2. Scope. This analysis evaluates:

a. The status of DTD production in the Army and at the Defense Mapping Agency (DMA) -- in terms of database content and geographic coverage.

b. The DTD requirements of high-, medium-, and low-resolution Army models (as represented by CASTFOREM, VIC, and FORCEM) -- also in terms of database content and geographic coverage.

3. Background. Advances in data collection and processing technology are changing the way the mapping, charting, and geodetic (MC&G) community collects and represents terrain information. Labor-intensive manual mapping procedures are giving way to a variety of automated and semi-automated mapping methods that electronically digitize topographic features and terrain information. These automated capabilities will greatly enhance the ability to store, manipulate, update, and display topographic products. The transformation is occurring at all levels of the Department of Defense (DOD), from the mapping experts at DMA to Army topographic field units. As a result, MC&G organizations, methods, and equipment are now being prepared to operate in the digital environment of the future. These changes will affect the way combat simulation models accept and interpret information about the physical battlefield environment.

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[1] *Engineer Model Improvement Program (EMIP) Plan* (ESC, September 1988).

a. **DMA responsibilities.** DMA produces, revises, and distributes standard MC&G products throughout the Department of Defense (DOD) community. To keep pace with the demand for digital products, DMA is changing its mapping methods and equipment. DMA's Systems Center is coordinating the design and development of the Mark 90 modernization program, which is a new, computer-oriented, highly automated production system. The Mark 90 system is designed to produce 28 or more standard products.[2] A new tactical terrain data (TTD) set that is currently under development will be added to the list of Mark 90 products in the near future. The complete set of Mark 90 standard products will meet a significant portion of the DOD community's digital terrain requirements. However, DMA will not begin TTD production until the Mark 90 system reaches its initial operational capability in 1992 or later. In the interim (1988-1992), the Army's requirements for DTD must be met with current standard products or interim terrain data (ITD) produced to meet the most urgent needs. Among the standard digital terrain products DMA can now produce are:

(1) Digital terrain elevation data (DTED)

(2) Digital feature analysis data (DFAD)

(3) Counter-Artillery, Counter-Battery Locating System (FIREFINDER)

(4) Vertical Obstruction Data (VOD)

(5) Terrain Contour Matching (TERCOM)

b. **Army responsibilities.** The Army is also changing to take advantage of the capabilities of the new digital topographic world. The Engineer Topographic Laboratories (ETL) are developing the digital topographic support system (DTSS) that will enable US Army topographic field units to operate in a digital production mode. Two reports prepared by the ETL outline Army digital terrain requirements for weapon systems, tactical support systems, training systems, and modeling.[3] Initially, DMA indicated that requirements not met by the current standard digital products (DTED, DFAD) would not be satisfied until the Mark 90 system became operational and started

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[2] *Tactical Terrain Data Prototype* (DMA, 9 October 1987).

[3] Herrmann, Richard A., et al., *Army Digital Topographic Data Requirements*, Report ETL-GSL-4 (ETL, August 84) and Regis J. Orsinger, et al., *Army Tactical Digital Terrain Data Requirements*, Report ETL-SR-1 (ETL, July 1987).

producing TTD. Thus, the Army is faced with a near-term (1988-1992) shortfall in the availability of new digital terrain data. The Army topographic community is concerned that TTD production by Mark 90 in 1992 may be optimistic -- and when the Mark 90 system comes on line, it will take time to develop the data bases and build the area coverage needed to satisfy all mid-term (1993-2002) Army DTD requirements.[4] However, ETL's Concepts and Analysis Division (CAD) is committed to ensuring that the Army's near-term requirements for a tactical-level digital terrain analysis product are fulfilled by an acceptable means. To this end, both ETL and the Office of the Deputy Chief of Staff for Intelligence (ODCSINT) have represented the Army in discussions with the DMA to provide an ITD product to adequately and expediently service the Army's near-term (1988-1993+) tactical and analysis community requirements for digital terrain data sets (before TTD is available in volume). DMA's recent decision to support the DTSS with a volume of ITD required for operational deployment has been underscored by their commitment to develop a product specification for ITD by 31 August 1988 and deliver a prototype data set to the Army by the end of 1988. ITD, to be acceptable by the Army must be easily usable, cost effective, and adaptable to either existing or near-term fieldable Army tactical and non-tactical systems/programs with respect to their operating systems and specific applications. ITD must also be co-producible by the Army and private industry. Finally, ITD should be economically translatable to the future DMA TTD.

4. Limits. This analysis focuses on the MC&G community's ability to meet the DTD needs of existing models -- it does not attempt to specify standard DTD formats, structures, or transformations. DTD standards should be determined by a thorough analysis and evaluation of the digital terrain requirements of weapon systems and tactical support systems. Models should take advantage of the available DTD products, but they should not preempt the requirements of systems in the field. This analysis did consider the results of a 1984 ETL study which consolidated the Army's DTD requirements (to include

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[4]Personal conversation between Mr. Richard L. Taylor of ESC, and LTC John Olesak, Office of the Deputy Chief of Staff for Intelligence (ODCSINT), November 20, 1987 and the ETL Command Briefing presented to ESC personnel by COL Alan Laubscher, November 30, 1987.

the Army modeling community).[5] These specifications form the basis of DMA's TTD specifications, as well as the Army's special terrain data (STD) specifications. The STD specifications are designed to meet Army high-resolution DTD requirements not met by TTD. Together, TTD and STD will serve as the Army's standard DTD sets for the future.

5. Approach. This analysis began with a review of Department of the Army (DA) Pamphlet 25-30 to identify technical manuals, field manuals, regulations or other publications relating to the Army's use of DTD. Next, interviews were conducted with the key personnel who produce and use DTD, as well as those who prepare reports relating to DTD. Among those interviewed were representatives of various DOD and Army staff elements, including: DMA, ODCSINT, and the Assistant Chief of Engineers (ACE). Information pertinent to the state of DTD production was also obtained from ETL, the Waterways Experiment Station (WES), the US Army TRADOC Analysis Command at White Sands Missile Range (TRAC-WSMR), and the US Army Concepts Analysis Agency (CAA).

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[5] *Army Digital Topographic Data Requirements, Volume IV: US Army Specifications for DTD Requirements*, Report ETL-GSL-4 (ETL, August 1984).

II. STATUS OF DTD DATA AND PRODUCTION

6. DTD Production. The uses of DTD, the technology needed to generate DTD, and the organizations tasked to produce DTD have all evolved rapidly over the past 10 years. The production of standard military DTD is the mission of DMA. ETL has the responsibility of coordinating Army requirements with DMA. ETL also has responsibility for managing research, development, and production of Army DTD requirements that are not met by DMA. The US Army Corps of Engineers Research and Development (USACE R&D) community, Army field units, and private contractors are also involved in producing DTD to meet special requirements. Because the different DTD products developed by these organizations have evolved over time to meet specific requirements, they are not always compatible. The different DTD vary in content (elevation, vegetation, lines of communication, etc.), format (raster or vector), resolution (raster grid size or vector data density), data structure (data base layout), accuracy (location error), geographic coverage (Europe, Central America, etc.), and means of data base generation (fully automated or manually entered). Figure 1 gives a summary of the features of some key DTD data sets. The long range goal of the MC&G community is to standardize DTD requirements. However, until the DMA Mark 90 program becomes operational, the modeling community must make the best use of all existing sources of DTD. Therefore, this analysis does not distinguish between original sources of digital terrain production and sources that acquire digitized elevation data from another DTD source and add additional terrain feature data. It was assumed that DTD, no matter where or how produced, is available to support model users.

7. DMA. Two offices at DMA are primarily responsible for producing DTD: the Hydrographic/Topographic Center and the Aerospace Center. Two significant standard DTD products prepared in these centers are considered essential to Army modelers: digital terrain elevation data (DTED), and digital feature analysis data (DFAD). DTD for the FIREFINDER system is also produced at DMA and, where coverage is available, it should be considered for model use. Since the location of DTD coverage for FIREFINDER could reveal potential deployment locations of FIREFINDER systems, this information is classified and is not included in this report. DMA has also produced limited

A SUMMARY OF MAJOR DTD DATA SET FEATURES

DATA SET	STATUS	FEATURE DENSITY	TERRAIN FEATURES
DTED (level 1)	operational	3 arc-sec (100 m)	elevation
DTED (level 2)	limited coverage	1 arc-sec (30 m)	elevation
DFAD (level 1, edition 1)	operational	1:250,000 map equivalent	vegetation, surface material
DFAD (level 1, edition 2)	limited coverage	1:250,000 map equivalent	vegetation, surface material, LOCs
DFAD (level 1-C)	limited coverage (cartographic sources)	1:250,000 map equivalent	vegetation, surface material, LOCs
DFAD (level 2, edition 1)	limited coverage	1:50,000 map equivalent	vegetation, surface material
DFAD (level 2, edition 2)	limited coverage	1:50,000 map equivalent	vegetation, surface material, LOCs
ARTBASS	operational (non-standard product)	12.5-25 m	elevation, vegetation, CCM, rivers, roads, railroads, and bridges
Mobility Database (WES)	operational (non-standard product)	25-100 m	elevation, tree height, CCM, roads, vehicle speeds
ALBE	limited coverage (tech base demonstration)	100m	elevation, vegetation, slope, surface material, obstacle height, canopy closure, roads rivers, railroads, bridges, tunnels, dams, airfields, and meteorology
TTD	developmental	1:50,000 map equivalent	elevation, vegetation, slope, surface material, obstacles, urban areas, rivers, roads, railroads, bridges, and tunnels

Figure 1

sets of non-standard DTD. The initial sets of DTD for the Army Training Battle Simulation System (ARTBASS) were produced by DMA (ETL is now coordinating the production of additional DTD for ARTBASS through contract). DMA also produced the non-standard DTD set called ITD. In one form or another, these products supply most of the DMA-produced DTD used by Army combat simulation models. See Annex A for displays of the geographic coverage of these products.[6] DMA also produces two hard copy terrain data sets that are primary sources of terrain feature data for encoding in DTD products -- tactical terrain analysis data base (TTADB) is a set of feature overlays at 1:50,000 scale, and planning terrain analysis data base (PTADB) is a set of overlays at 1:250,000 scale.

8. USACE R&D Centers. Three USACE R&D laboratories are producing or updating DTD for Army use. ETL has the lead for DTD, but WES and the Construction Engineering Research Laboratory (CERL) both produce DTD products under reimbursable agreements to meet certain Army requirements.

a. ETL. Four non-standard DTD sources designed to meet unique Army requirements are managed by ETL: two are the responsibility of the Geographic Sciences Laboratory (GSL) and two are the responsibility of the Terrain Analysis Center (TAC).

(1) GSL oversees the terrain analysis work station (TAWS) project, the DTSS, and the air land battle environment (ALBE) test beds. These GSL systems are based on the Analytical Mapping System (AMS)/Multiple Overlay and Statistical System (MOSS) geographic information system (GIS). A GIS is a system for encoding, processing, manipulating, and generating spatial data -- in this case, terrain information. Each system can produce DTD but only does so for its own use. Both systems have been using hard copy TTADBs as source materials.

(2) TAC is now installing a GIS with the intent of processing worldwide water resources data in digital format. This will give TAC's GIS the ability to expand to include multi-theme DTD. TAC is also the Army's center for transforming DMA-produced DTED from tape to computer disk and video cassette for use on Microfix(T) systems. TAC produces hard copy ARTBASS data for Army users and manages contracts for the production of DTD for ARTBASS.

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[6] *Engineer Model Improvement Program (EMIP) Plan* (ESC, September 1988).

b. **WES**. The Mobility Systems Division of WES's Geotechnical Laboratory began developing digital mobility-terrain data bases in 1970 to support the evaluation and validation of the Army Mobility Model (AMM). Continued development of mobility-terrain data bases, funded mainly by Training and Doctrine Command (TRADOC), has focused on providing realistic mobility input to the CARMONETTE and CASTFOREM wargaming models. The Modeling and Terrain Unit of the Mobility Systems Division produces DTD using a commercially developed GIS called Arc and Information (ARC/INFO). ARC/INFO is a GIS system that can process and generate DTD from imagery, map sheets, and terrain overlays. WES uses many different terrain source materials, including TTADB.

c. **CERL**. Although CERL has not produced any DTD in support of Army combat simulation requirements, its Geographical Resources Analysis Support System (GRASS) can produce and process DTD data. This system is a GIS which supports CONUS installation planning and maintenance done by the USACE Engineering and Housing Support Center (EHSC). GRASS DTD has been produced for Fort Hood, and Fort Carson, and is now being generated for the Hoenfels Training area in West Germany.

d. **Summary**. Generically, the Army DTD is characterized by ARTBASS, TAWS, ALBE, and the WES data bases. While there are significant differences in these data sets in terms of their state of development and coverage, they each define terrain features as well as basic terrain elevation data. These feature data sets add information on vegetation, surface materials, surface drainage, transportation, and obstacles to more fully describe the terrain than can be done with elevation data alone. (Annex C lists the documents which give the specifications for these data sets.)[7] These systems can accept digital terrain elevation data from other sources such as DTED or they can generate their own digital terrain elevation data through manual means. Additional terrain feature information for these DTD sets is manually input from hard copy sources such as the TTADB, standard 1:50,000 scale topographic line maps, and other collateral sources.

9. Army Engineer Field Units. Engineer Topographic units are developing the capability to produce and maintain DTD:

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[7] *Engineer Model Improvement Program (EMIP) Plan* (ESC, September 1988).

a. **29th Engineer Battalion (Topographic).** The 29th is the Pacific theater topographic support battalion. The battalion is now installing the first phase of its digital modernization plan -- a Microvax II system which will serve as the foundation for DTD production and processing. Later phases will install various elements of the ALBE test bed system. By the end of 1988, the 29th will begin converting hard copy TTADBs to digital form.

b. **649th Engineer Battalion (Topographic).** The 649th is the European theater topographic support battalion. The battalion's limited DTD processing is now done by terrain teams using Microfix (T) systems. The 649th plans to eventually expand its DTD production capability to better support US Army Europe (USAREUR) terrain product needs.

c. **Other Topographic Units.** Similar conditions exist at the 30th Engineer Battalion (Topographic), which supports Third US Army missions, and the 1203d Engineer Battalion (Topographic), which is a National Guard unit.

d. The growing capability of field units to produce DTD must be coordinated by ETL to make sure the data sets produced are formatted properly and are available to users throughout the Army and, thus, avoid needless duplication of effort.

10. Contractors. Private firms have been a source of DTD in the past, and are expected to meet a portion of the Army's outstanding DTD requirements in the future. The BDM Corporation, the Jet Propulsion Laboratory (JPL), and various architectural and engineering firms have been suppliers of DTD in the past. Their DTD products are typically designed to support a specific model, analysis, or GIS data base. Once developed, the data can be applied to other uses as well. Since contractor-produced DTD is typically in non-standard format, other uses normally require reformatting.

III. DTD REQUIREMENTS FOR ARMY MODELS

11. DTD for The Hierarchy of Army Models. Every model has different requirements for terrain data based on its internal design, the types and sizes of forces it represents, the kinds of studies that use it, and the different geographic locations it must portray. The Army Model Improvement Program (AMIP) classifies models into a hierarchy based on their level of resolution. High resolution models require the greatest terrain detail but because they play smaller units (battalion and below), they operate on limited blocks of terrain. Medium resolution models need blocks of terrain large enough to maneuver division- and corps-size units and they sacrifice some terrain detail to get the area coverage they need. Low resolution models cover an entire theater of operation and, therefore, must be able to represent the geographic characteristics of theater lines of communication and strategically important terrain features like major avenues of approach. However, at the theater level it is not necessary to explicitly represent terrain in enough detail to support the play of tactical operations. ESC looked at the three AMIP automated simulations for the three levels in the hierarchy of Army models to better define the terrain requirements at each level of resolution. The three models (CASTFOREM, VIC, AND FORCEM) are discussed in detail in the EMIP Plan. **Figure 2** gives a summary of the terrain requirements of each model, and their use of DTD is summarized in the following paragraphs.

12. CASTFOREM Model Description. This evaluation of CASTFOREM's DTD requirements is based on a review of CASTFOREM documentation and interviews with the persons who maintain the CASTFOREM model.[8] CASTFOREM has a modular structure. Events in the model trigger action in eight process modules: command and control, communications, engineer, movement, engagement, surveillance, system/environment, and combat service support (CSS). These

[8]CASTFOREM Executive Summary (TRAC-WSMR, Simulation Support Division III, 20 September 1986); *CASTFOREM Scenario Writer's Guide* (TRAC-WSMR, Simulation Support Division III, 29 June 1987); *CASTFOREM Cookbook.3* (TRAC-WSMR, Simulation Support Division III, 6 August 1985); and personal interview between Mr. Richard Taylor, ESC and Messrs. Freeberg, Mackey, Champion, and Denney of TRAC-WSMR on 16 November 1987.

A SUMMARY OF CASTFOREM, VIC, & FORCEM TERRAIN PARAMETERS

	CASTFOREM	VIC	FORCEM
STANDARD GRID CELL RESOLUTION	100 m	4 km	10 km
TYPICAL AREA OF OPERATION	12 x 20 km	150 x 150 km	irregular (theater dependent)
TERRAIN ATTRIBUTES MODELED*	elevation vegetation built-up areas canopy closure	elevation vegetation built-up areas	elevation
	cross-country mobility (CCM)	trafficability	movement capability in & out of cells
	roads rivers obstacles	roads rivers obstacles	LOC networks

*Since each model has its own categories and classifications, this is only a rough outline of the features covered by the models.

Figure 2

modules are supported by various data types and data files. The data types and data files are used as reference points for the DTD requirements discussion.

a. **DTD Representation.** CASTFOREM represents terrain as square cells. The size of these cells is uniform within a terrain data set; however, the size of the cell can be changed to use different terrain data sets for different studies. Cells with 25-, 50-, and 100-meter sides have been used in the past. 100-meter grid cells are most often used because of the long run times involved with higher resolution grid cells, and the limited availability of higher resolution DTD to supply the model. There are nine terrain attributes for each cell that define roads, surface features, vegetation or built-up area heights, canopy closure, hydrography (rivers), cross-country movement (CCM) dry, CCM wet, elevation, and obstacles within that cell. One value is assigned for each of the terrain attributes within a cell. This means that the vegetation is of one uniform type, the elevation is of one height, and the CCM is of one value for the entire terrain cell. So far, all the terrain sets used by CASTFOREM have gotten input for these terrain attributes from the ARTBASS data base. Besides setting the grid cell size, the user sets the size of the area of operation (AO). AOs as small as 6 x 11 kilometers, and as large as 20 x 20 kilometers have been used, with the norm around 12 x 20 kilometers. This is roughly equivalent to the area of an M745 series 1:50,000 scale topographic line map of Germany.

b. **Off-line DTD requirements.** Before a CASTFOREM combat simulation can begin, the user is required to prepare the battlefield. One step in this preparation is to establish the physical layout of the battlefield using DTD. This is called off-line, pre-processed terrain data. This pre-processing of DTD is over and above the actual DTD requirements of the model itself. For example, a manual intelligence preparation of the battlefield (IPB) process is performed based on knowledge of the battlefield similar to that required of a battlefield commander preparing for actual battle. This is done before the actual combat simulation run is performed, and uses terrain information in either digital or analog form as a basis for decisions. Based on this terrain knowledge, the user specifies the value of the input variables used in the simulation model as discussed below.

(1) Maneuver Control Points (MCP). An MCP is nothing more than a battlefield coordinate (X, Y, and Z) that has been given a unique numeric name. Movement of both ground and air vehicles is accomplished over movement networks which are composed of linked MCPs. These MCPs usually correspond to, or are based upon established road or transportation networks provided by DTD or manual map analysis.

(2) Avenues of Approach (AOP). An AOP consists of MCPs that will represent a route of maneuver. The decision to establish AOPs is based on terrain intelligence that is provided prior to the simulation run, especially line of sight (LOS) analysis. The LOS is performed off-line prior to the simulation, and requires use of data provided from the ARTBASS DTD set or a manual process to produce comparable LOS information. Routes for avenues of approach are selected to minimize an attacking unit's exposure to direct fire systems as much as possible.

(3) Battle Positions (BP) and Firing Points (FP). A CASTFOREM BP consists of one or more firing positions; for moving units it also includes a start point (SP) and a release point (RP). When choosing static positions such as FPs within BPs, an off-line, line-of-sight analysis must be used to ensure that the unit using the position can actually see the areas of interest, as well as find out what it cannot observe. This off-line analysis is done prior to the combat simulation run using DTD supplied by the ARTBASS data base.

c. **On-line DTD requirements**. The major data types within CASTFOREM that use DTD are highlighted in the following paragraphs. The various data types and data files are referred to by the abbreviations and labels used in CASTFOREM.

(1) Battlefield data (BFLD-DATA). The purpose of this data type is to provide some of the initial physical battlefield parameters of the model. Several DTD requirements are found in this data type. DTD requirements are found in data files BF 10, BF 21/22, and BF 23.

(a) Data file BF 10 is used to designate the moisture condition (wet or dry) and the time of the year (summer or winter). This data must be specified by the user prior to the simulation run.

(b) Data file BF 21/22 is used to designate one of 16 surface features (i.e., agriculture, brushland, coniferous forest, orchard, grassland, open water, built-up areas, etc.), their height, and their foliation during summer and winter seasons. The user selects the season, but the feature data is extracted from the ARTBASS DTD.

(c) Data file BF 23 pertains to obstacles and the obstacles' minimum heights. Five categories of obstacles are represented: road and railroad cuts and fills, natural linear features, walls and fences, other man-made linear obstacles, and military obstacles. This input data is extracted from the ARTBASS DTD.

(2) Terrain Data (TERRAIN-DATA). The purpose of the terrain data type is to provide digitized terrain data to CASTFOREM modules. The terrain data files are provided via nine pre-processed binary files which are prepared using data from the ARTBASS data base. Battlefield data descriptions (BFLD-DATA discussed above) must have been input prior to reading the terrain files, and the descriptors on the header of each terrain binary file must match the descriptors for the battlefield data. Each binary terrain file consists of many data elements. The data elements related to DTD requirements call for nine terrain codes for each cell: road type, surface features, vegetation or built-up area height, canopy closure, hydrography (rivers), CCM (dry), CCM (wet), elevation (m), and obstacles. These data elements have been supplied in the past by ARTBASS DTD.

(3) Object library (OBJECT-LIB). The purpose of the object data type is to insert objects that are used by the engineer and CSS modules. Objects such as craters and various types of minefields can be placed by the user into the combat simulation run using this data type. Two terrain requirements, soil strength and trafficability, are used when defining these object types. Currently, these data elements are not being used and are set to zero.

(4) Type of Units (TYPE-UNITS). The purpose of this data type is to define the generic units on the battlefield. The unit's size, vulnerability, sensors, personnel, fuel capacity, etc., are described in this data. Of the variables that must be defined for each unit, two are DTD-related: the TU30 card (cross-country speed data) and the TU32 card (road speed data). The TU30 card sets the cross-country speed for each unit based on its current grid cell location. The cross-country movement (CCM) speeds are obtained from ARTBASS DTD. The TU32 card sets the road speed appropriate for the unit's

current grid cell location. Currently, road speed data are manually input based on a map analysis of the road network in the area being modeled.

(5) Line of Sight (LOS). Intervisibility, or LOS is computed for two purposes: placement of BPs and FPs (see the discussion of off-line DTD requirements), and LOS detection between an observer and target. LOS detection algorithms are embedded in the computer code and are used on a continuous basis throughout the battle simulation. LOS is computed utilizing digitized terrain, taking into consideration ground elevations and vegetation heights for each grid cell, and other factors such as height of weapon or sensor, and obscuration data. CASTFOREM calculates LOS as uniform anywhere within a terrain cell. This means if LOS is possible from any point within the cell, then all points within that cell will be considered to have LOS.

d. **Availability of DTD for CASTFOREM**. CASTFOREM is currently using only ARTBASS and WES data sets. DTD coverage suitable for CASTFOREM to use is available for portions of the Federal Republic of Germany (FRG), Korea, Egypt, Jordan, and Costa Rica (see Annex A).[9] Additional coverage will become available as new ARTBASS data sets are produced under contract over the next three years. The adequacy of the available DTD to support CASTFOREM terrain requirements is discussed in paragraph 15.

13. VIC Model Description. This evaluation is based on information obtained from the VIC model documentation and interviews with persons familiar with the VIC model.[10] VIC is a two-sided deterministic simulation of combat in a combined-arms environment. It represents land and air forces at the US Army corps level with a commensurate enemy force in a mid-intensity battle. The model is event-stepped for maneuver elements and time-stepped for calculation of support effects. It may be run in either an interruptible mode, or in a systematic batch mode. It has a series of pre-processors for constructing input data files and a comprehensive post-processor. VIC is

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[9] *Engineer Model Improvement Program (EMIP) Plan* (ESC, September 1988).

[10] *Vector in Commander (VIC) Combat Simulation*, Executive Summary, Model User's Guide, Post-processor User's Guide, and VIC Interactive Pre-processor (VIP) User's Guide, draft (TRAC-WSMR-TD, June 1987). *Vector in Commander (VIC) Combat Simulation*, Data Input and Methodology Manual, draft (TRAC-WSMR-TD, June 1987), and personal interview between Mr. Richard Taylor, ESC, and Messrs. Gamble, Porter, Lankford of TRAC-WSMR on 16 November 1987.

executed through a series of modules which each represent a major function on the battlefield (see Figure 3).

a. **DTD Representation.** Terrain is input to VIC in square grid cells. The data required for each cell represents four major terrain factors: vegetation, relief, area obstacles, and linear obstacles. These factors act in combination with maneuver unit factors to predict trafficability, line of sight, and visibility. The user of the model may specify the size of the grid cell; 4 kilometers by 4 kilometers is normally used. Special programs are provided in a pre-processor that will process digitized terrain at typical DTD resolutions (e.g., 25m, 50m, 100m) and synthesize it into the desired model cell resolution, in this case 4 kilometers by 4 kilometers. For example, previous runs of VIC have used a DTD set prepared by a contractor, which covered an area in West Germany that contained high-resolution data. In addition to setting the grid cell size, the user sets the size of the AO. Several sizes have been used in the past. A 150 km by 600 km area is a typical corps AO size used in VIC. This is about equivalent to six DMA 1:250,000 scale topographic line maps. The origin for the X and Y axes is determined by the user; the model will then read the location data in either X and Y coordinates or military universal transverse mercator (UTM) coordinates. Like CASTFOREM, VIC requires users to identify and define various terrain elements prior to running the simulation. Pre-processed DTD features are used for selecting avenues of approach, tactical areas, main supply routes, and barrier locations.

b. **Off-line DTD requirements.** Preparing a VIC combat simulation requires the use of off-line, pre-processed terrain data similar to CASTFOREM. This pre-processed DTD <u>is over and above the actual DTD requirements</u> of the model itself. A user must prepare the battlefield based upon a conceptual scenario. This is done before the actual combat simulation is performed. This DTD pre-processing takes place in the VIC Interactive Preprocessor (VIP). VIP constructs data input files and uses terrain information in digital form as a basis for graphical display. Based upon this terrain knowledge, the user selects required variables which are used in the simulation model and are addressed as a part of the VIP menu structure below.

(1) DTD is used by VIP to form the terrain displays that aid in preparing input to VIC. No one particular digital data base has been used

VIC MODULES

NUMBER	TITLE	ABBREVIATION
1	SYSTEM SPECIFICATIONS	SS
2	GLOBAL GROUND	GG
3	GROUND MOVEMENT	GM
4	ARTILLERY	AT
5	GLOBAL AIR	GA
6	AIR MAINTENANCE	AM
7	AIR-TO-GROUND ATTACK	AG
8	AIR INTELLIGENCE	AI
9	GROUND INTELLIGENCE	GI
10	FUSION INTELLIGENCE	FI
11	AIR DEFENSE	AD
12	DEFENSE SUPPRESSION	DS
13	ELECTRONIC WARFARE	EW
14	CHEMICAL	CH
15	open for expansion	
16	GRAPHICS DATA MODULE	GX
17	WEATHER DATA	WT
18	TERRAIN AND BARRIERS	TB
19	DECISION TABLES	DT
20	HELICOPTERS	HC
21	LOGISTICS	LO
22	COMMUNICATIONS	CO
23	RETURN TO DUTY	RD
24	POST-PROCESSOR	PT
25	MINEFIELDS	MF
26	AIR-TO-AIR	AA
27	FRONT LINE DETAILED ATTRITION	FL
28	SMOKE	SM
29	ENGINEERS	EN

Figure 3

exclusively; instead the best data available is used to cover the area of operations. As an example, the DTD provided by a contractor included a lines of communication (LOC) network data base, a surface feature data base, and a terrain elevation data base. The LOC network data base consisted of 14 vector formatted data features: autobahns, main roads, secondary roads, lightly surfaced roads, railroad lines, ferries, fords, heavy bridges, dams, road tunnels, rail tunnels, and three classes of rivers. The surface feature data base consists of: open areas, forest, urban, undefined areas, marsh, standing water, and heath. The terrain elevation data base was created from DMA DTED level I (rather than from the contractor DTD). This information was formatted to supply the required vegetation, relief, area obstacle, and linear obstacle data requirements of VIC.

(2) The VIP menu (Figure 4) is used to build various parts of a scenario and create VIC input files. Several of these use DTD as a basis for decisions.

(a) Path point, route plan, network, and logistics menus allow the user to select and plan general AOPs, and transportation networks for combat and CSS units to follow. These menus use DTD, particularly transportation and elevation data, as a decision aid. Five classes of transportation data (autobahns, main roads, secondary roads, fair weather road, railways) and digital elevation data have been used in the past.

(b) Barrier and line obstacle menus allow the user to create and deploy area obstacles (sometimes referred to as barrier obstacles) and line obstacles (sometimes referred to as linear obstacles). The user defines obstacles based on the terrain displayed in VIP. The ability to overlay area obstacles on the terrain was developed to allow the portrayal of features such as urban areas and nuclear, biological, and chemical (NBC) contaminated areas. However, VIC now allows each terrain grid square to have its own trafficability code, and area obstacles are no longer treated as an overlay to the terrain. Instead they are represented by the trafficability and visibility codes given to individual terrain grid squares. Line obstacles are still input as line segments that are overlayed on the terrain independent of the underlying grid square system. This allows for accurate positioning of natural and man-made linear obstacles, such as embankments and antitank ditches, without being restricted to the grid pattern.

VIP MAIN MENU STRUCTURE

```
 |--  KEYWORD
 |
 |--  HELP
 |
 |--  UNIT ID GEN
 |
 |
 |                                             | -- TACTICAL MENU
 |--  UNIT MENU   --  PATH PT MENU --          |
 |                                             | -- RT PLAN MENU
 |--  SUBORDINATE MENU                                 |
 |                                                     |
 |--  COMMUNICATIONS MENU                              |
 |                                                     |
 |--  RT PLAN MENU - - - - - - - - - - - - - - - - - - -
 |
 |--  MINEFIELD MENU
 |
 |--  BARRIER MENU
 |
 |--  LINE OB MENU
 |
 |--  NETWORK MENU -- | -- LOGISTICS MENU
 |
 |
 |
 |--  GRAPHICS
 |
 |--  PARAMETERS
 |
 |--  CHANGE PLANE
 |
 |--  PLAYBACK
 |                      | -- GRAPHIC
 |                      |
 |                      | -- TERRAIN
 |                      |
 |--  UTILITY MENU --    | --  MENU
                        |
                        | --  DEFINE
                        |
                        | --  SLIDE
```

Figure 4

(3) In addition to using DTD in VIP (to support the development of VIC input files), DTD must also be processed to provide the terrain grid square data used by VIC in the actual execution of the model.

c. **On-line DTD requirements.** VIC is executed through a series of modules (Figure 3), each of which represents a major function on the battlefield. These modules consist of data requirements, which are further subdivided into data segments. Each segment represents a block of data which is required by VIC. The modules and data segments are referred to by the abbreviations and labels used in VIC.

(1) Terrain and Barriers (TB). There are four segments in the TB module that require the direct use of DTD. These segments load and list all data associated with terrain and barriers.

(a) TB-ONE contains basic information on the extent and classification of vegetation. There is no inherent limitation to the number of vegetation classes VIC can play, but currently four classes are portrayed: dense forest, light vegetation, grassland, and urban areas. This segment provides vegetation data that is used in several modules.

(b) TB-TWO performs four major functions and uses DTD elevation data as its basic source. First, it classifies relief into major categories: plains, hills, and mountains using a VIC terrain classification algorithm (see glossary for further explanation). Second, it performs visibility mapping which combines the vegetation type (taken from TB-ONE) and the relief type into three visibility levels: good, fair, or poor. Third, it performs trafficability mapping which also combines relief and vegetation into three trafficability levels of good, fair, and poor. Finally, this segment performs LOS and exposure distance mapping. The LOS parameter is used to compute the fractional LOS in that type of terrain. The mean exposure length is used to determine the average time a target remains visible.

(c) TB-THREE allows the user to place area obstacles on the current terrain mapping. There is no inherent limitation to the number of area obstacle classes VIC can play, but seven types of area barriers are identified in the documentation: rivers, passable features, impassable features, urban areas, chemical-, biological-, and nuclear-contaminated areas. This segment is not being used at this time. Instead area obstacles are represented through the trafficability codes assigned to each grid square.

(d) TB-FOUR allows linear obstacles to be placed on the battlefield. There is no inherent limitation to the number of linear obstacle classes VIC can play, but currently four major types have been designated: rivers, canals, tank ditches, and embankments.

(2) Ground Movement (GM). Segment GM-THREE computes six distinct data variables that are based upon information supplied in the TB module. The four major variables affecting the movement of ground combat units are: a combined trafficability table, an opposed speed table, combined weather/barrier visibility table, and a combined environmental/obscurant visibility table.

(a) The combined trafficability table is a 3 by 3 table which is used to combine the trafficability due to the weather (good, fair, and poor) with the trafficability due to terrain (good, fair, poor) to produce an overall trafficability (good, fair, and poor). This overall trafficability is then used as input to the opposed speed table.

(b) The opposed speed table is a 2 by 3 by 11 table which is used to determine the speed of a moving unit when in contact with an opposing force. Opposed movement is indexed by mobility (1-mounted, 2-dismounted), trafficability (good, fair, and poor from the combined trafficability table above), and kill ratios computed from opposing forces in contact.

(c) The combined weather/barrier visibility table is a 3 by 3 table used to combine the visibilities due to weather (good, fair, and poor) and terrain (good, fair, and poor) into an overall environmental visibility of good, fair, and poor.

(d) The combined environmental/obscurant visibility table is a 3 by 3 table used to combine the environmental visibility with the visibility level due to smoke, dust, and debris to form an overall visibility.

(3) Global ground (GG). Segment GG-ONE contains two data variables that are DTD-related but are user input.

(a) The maximum day speed is used to compute unit travel speeds. It is expressed in kilometers/hour which provides the speed for unopposed movement during daylight hours; it is also used as input to opposed speed calculations. Currently, this variable is user-specified. VIC does not use CCM speed or on road speeds derived from DTD to calculate this variable.

(b) **Maximum night speed.** The discussion in the previous section on maximum day speed applies for night speed also.

(4) Logistics (LO). Segment LO-THREE contains three data variables that are affected by transportation data contained in DTD. All are used to determine the effectiveness of the road network for logistics operations. All codes are currently input by the user. The transportation element in the DTD set is currently not used as an input source.

(a) The road surface code requires information on the road surface that can be obtained from the DTD. Four classes are described: concrete, bituminous, gravel, and dirt.

(b) The road width code allows the choice of two values for road width: roadways greater than 24 feet wide and roadways less than 24 feet wide.

(c) The road terrain code requires that four types of terrain be characterized: flat, rolling hills, hills with curves, and mountainous with the type of terrain affecting the road speed.

(5) Artillery (AT). AT-THREE allows the evaluation of the effects of terrain on lethal areas of artillery-round impact. This is done through the Minimum Lethal Area Factor Data input variable. This factor states that certain munitions will not be fired into a terrain type that has an associated terrain factor less than this parameter. Perfect terrain (plains with grassland) has a factor of 1.0.

(6) Air-to-ground (AG). AG-THREE allows the evaluation of the effects of terrain on the probability of detecting a target. Terrain can obscure or partially obscure geographic areas. This is done through the Probability of Target Detection Data input variable. This parameter is a function of visibility (good, fair, and poor) and a target priority.

d. **Availability of DTD for VIC.** Currently, DTD that can satisfy VIC requirements is available in two regions of the world: FRG and Korea. VIC is using the best available data for the areas it is now simulating. The adequacy of the available DTD coverage to support future VIC terrain requirements is discussed in paragraph 16.

14. <u>FORCEM Model Description</u>. This evaluation is based on a review of the FORCEM model documentation and interviews with persons familiar with the

model.[11] FORCEM is a deterministic, average value model which is fully automated. There are no player interactions while the model is running. It is a completely two-sided model that operates on a time-step basis, representing the campaign in 12-hour time slices. Headquarters at corps, Army, and theater levels are represented. For each time step, the model cycles through a process to develop the combat situation for both sides; it makes decisions regarding actions to be taken by subordinate elements; it develops the combat and combat-support activities resulting from the decisions of both sides; it performs post-cycle status updates; and it produces output data for that time period.

a. **DTD Representation.** FORCEM represents terrain as square cells. The size of these cells is uniform within a terrain data set; however, the size of the cell can vary. Formerly 30 by 30 km cells were used, but 10 by 10 km cells are now being used. Each terrain cell is assigned the dominant terrain codes for each of eight directions into and out of the cell. Nine terrain types can be represented: oceans/lakes, low mountains, high mountains, rivers, cities, forests, roads, AOPs, and open terrain. Thus, each direction through a cell is digitized and coded according to the predominant natural or man-made feature in that cell. This procedure results in a detailed movement capability map that represents the difficulty of movement in each of the eight directions through the square. All runs of FORCEM have utilized terrain data that was manually encoded from map sheets at the 1:1,000,000 or 1:2,000,000 scale. DTD currently exists for the European, Korean, and Southwest Asia theaters. Superimposed on the terrain grid are logistics networks. Three types of logistics networks are represented: road, railway, and waterways. Major items of equipment and personnel flow along these networks. Materiel and personnel, as well as units arrive in the theater of operations through ports (both sea and air).

b. **Off-line DTD requirements.** Preparing a FORCEM combat simulation requires the use of off-line, pre-processed terrain data similar to that of

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[11]*FORCEM Evaluation Model Briefing Slides* (CAA, March 1985); *Command and Control in the Force Evaluation Model* (CAA, 14 January 1986); *FORCEM Combat Service Support* Module (CAA, 20 February 1986); *The FORCEM Fire Support Module* (CAA, May 1986) and personal interview between Messrs. Taylor, Reynolds, and Halayko of ESC, and Mr. Wallace Chandler, CAA on 23 November 1987.

CASTFOREM and VIC. A user must prepare the battlefield based upon an operational plan. This is done before the actual combat simulation is performed. The battlefield representation, using terrain information in digital form, is a basis for decisions in the model. DTD is encoded by hand at CAA from tactical pilotage charts (TPC), operational navigational charts (ONC), and global navigation charts (GNC), which are published at DMA. These CAA digital terrain files are then used as terrain input files to the model. As mentioned previously, the terrain in FORCEM now is represented using 10 by 10 km grid cells. The terrain features can be categorized into two functional areas: movement enhancements, and movement impediments. The movement impediments are features such as hills, mountains, forests, urban areas, rivers, lakes, and canals. Movement enhancement features such as roads and railways are also represented. Other features such as ports (airports and seaports) are also input prior to simulation by the user from map information.

c. **On-line DTD requirements.** Terrain and its representation in FORCEM is centered around a single theme: movement -- of units, personnel, equipment, and logistics. This movement centers around two categories of terrain features: LOCs and major surface features. This discussion centers on these features and how they are used in the model.

(1) Lines of communication (LOCs).

(a) Roads, railways, and waterways are the conduit for convoys, barges, and trains. These LOCs are encoded via the logistics networks. Units, supplies, and equipment moving along these networks are subject to interdiction and attrition. However, the networks themselves are not subject to damages. FORCEM does not distinguish certain features along the LOC infrastructure. For example, bridges and tunnels are not represented, nor are road classes (e.g., autobahn or two-lane roads). Petroleum, oils, and lubricants (POL) pipelines have been classified as a LOC feature in the past. However, FORCEM currently does not represent POL pipelines as a logistics network feature. POL pipelines (PPL) are assumed regardless of the lack of in-country facilities.

(b) From a functional standpoint, aerial ports of entry (airports) and seaports are identical. Seaports and airports are not extracted from a digital LOC file, but selected and input by the user prior to simulation. Materiel and personnel enter the theater through seaports and airfields. Ports are FORCEM "units" and have defined capacities and capabilities that can be subject to damage. Damage to ports is represented as a function of the casualties to port personnel. Port facilities such as piers, quays, cranes, and covered storage are not explicitly represented, so facility damage is not directly measurable.

(2) Major surface features. There are eight major surface terrain features that can be represented in FORCEM: low mountains, high mountains, lakes/rivers, urban areas, forests, high-speed roads, AOPs, and open terrain. A lack of other vegetation classes makes it difficult to accurately represent the mobility impacts of other types of terrain such as marshes and swamps.

d. **Availability of DTD for FORCEM.** Adequate DTD is currently available from DMA to satisfy FORCEM's low resolution terrain requirements. The adequacy of the available DTD to support future FORCEM terrain requirements is discussed in paragraph 17.

IV. CONCLUSIONS

15. CASTFOREM. DTD is used off-line to make IPB decisions prior to running CASTFOREM, especially to plan LOS, MCPs, AOPs, and BPs. DTD is used on-line to provide various model parameters for the computation of LOS and trafficability. ARTBASS DTD is currently used to satisfy the majority of CASTFOREM's DTD requirements (100-meter cell resolution).

a. CASTFOREM could make better use of existing DTD sources by replacing some data that is now manually input with data that is automatically processed from available DTD sources (some specific examples are given in Section V., RECOMMENDATIONS).

b. The need for DTD to support CASTFOREM is dependent on the studies that will use the model. However, ESC's assessment of how CASTFOREM is used leads us to the conclusion that existing DTD coverage, along with the additional areas being produced in ARTBASS format through ETL and WES, will be adequate to meet most CASTFOREM requirements. To use CASTFOREM to test battalion and smaller unit doctrine, tactics, force structure, and equipment, it is not necessary to run the simulation over every piece of terrain in the world where US battalions could fight. Except for special studies that need to play a specific geographic location or a unique type of terrain for which no DTD exists, the available DTD provides an adequate sample of different terrain types to represent the kinds of terrain situations US forces are likely to face.

16. VIC. VIC demonstrates an effective use of relatively high-resolution DTD as an off-line decision aid. The off-line DTD is used as input to a preprocessor that develops the low-resolution input required by the model itself (e.g., 100m spacings between elevation points are used as a base for terrain classifications of plains, hills, and mountains in low-resolution, 4 km cells).

a. VIC could make better use of existing DTD sources by replacing some data that is now manually input with data extracted from available DTD sources (some specific examples are given in Section V., RECOMMENDATIONS).

b. The need for DTD to support VIC is dependent on the specific studies that will use the model. If VIC is used only to study broad doctrine and force structure questions, then a small array of terrain data sets that cover the general types of terrain US corps are likely to have to fight on, is adequate to meet VIC's needs. However, middle level resolution models like VIC can and are used to analyze specific contingency planning issues. To be responsive to the need for analysis of corps operations in a particular area, DTD must be available for that specific area. The current delays in producing DTD mean that terrain coverage requirements must be planned well in advance for the data to be available when it is needed. The requirements for DTD to support VIC are not sufficient justification to generate an urgent need for new DTD production. But, the terrain areas that are of interest to the modeling community are the same areas where DTD is needed to support the fielding of new Army weapons and battlefield command, control, communications, and intelligence (C^3I) systems. VIC users must be aware of the coverage and formats of the DTD being produced for these new systems so they can make use of it in VIC when it becomes available.

17. FORCEM. DTD, currently used by FORCEM, is generated manually at extremely low resolutions by in-house personnel at CAA for both off-line decision making and a few on-line simulation decisions.

a. This in-house manual DTD generation could be eliminated by developing the ability to use existing DTD files to support FORCEM (this initiative is discussed in Section V., RECOMMENDATIONS).

b. Until CAA develops a preprocessor that can use digitized terrain input, there are no requirements for the production of new DTD coverage for FORCEM. Once a preprocessor is developed, the available DTED and DFAD coverage will satisfy FORCEM terrain requirements. However, the limitations of DFAD representation of LOC networks means CAA will still have to do some manual coding of LOC information until DMA produces the new standard DTD products.

V. RECOMMENDATIONS

18. Make Increased Use of DTD. Each of the models examined is manually entering terrain data that could be obtained from existing DTD sources.

a. CASTFOREM makes good use of DTD; efforts should continue to automate the extraction of additional terrain feature data from existing DTD files. For Example, TRAC-WSMR should:

(1) Use ARTBASS modified unified soil classification data to determine soil strength for OBJECT-LIB requirements.

(2) Use ARTBASS CCM data to supply trafficability data for OBJECT-LIB requirement.

(3) Use WES-Mobility AMM data to provide on-road speed data to the TU32 road speed card via the road code attribute for each cell. Currently, ARTBASS DTD only provides road classifications, not the speed for a distinct road type.

b. VIC and its preprocessor VIP make good use of DTD; efforts should continue to automate the extraction of additional terrain feature data from existing DTD files. For Example, TRAC-WSMR should:

(1) Use WES-Mobility AMM DTD to derive maximum day and night speeds (both CCM and road speeds) in the GG module.

(2) Use WES-Mobility AMM DTD to supply road surface codes, road width codes, and road terrain codes for the LO module.

c. FORCEM uses manually generated terrain input; efforts should be undertaken to automate the extraction of terrain data from existing DTD files. To reduce this manual effort CAA should:

(1) Develop an off-line DTD preprocessor (similar to VIP) to prepare terrain input for FORCEM.

(2) Use DMA's DFAD and DTED data as sources of DTD to satisfy current FORCEM requirements and to open the way for new standard DTD (including better LOC information) to be used in the future.

19. Make Model DTD Compatible With Tactical DTD. The generation of new DTD should be driven primarily by the requirements of new tactical weapons and C^3I systems, not by model requirements. However, the areas where DTD is needed for the new tactical systems are also the areas where model analysis will be needed. Therefore, when DTD is produced in the new standard formats

for tactical systems, it is important for the models to be able to read and extract the data they need.

a. CASTFOREM; The existing ARTBASS terrain data sets, plus the new data being produced by WES, will offer sufficient variety to support most CASTFOREM study requirements. However, there will certainly be special study requirements that need specific terrain locations not covered by the DTD produced in ARTBASS format. To be able to quickly respond to special study requirements, changes should be made to allow CASTFOREM to use new DTD formats. Extraction programs to convert other sources of DTD to ARTBASS format would give CASTFOREM access to new areas of coverage as they become available. While TRAC-WSMR could develop such extraction programs, ESC recommends ETL perform this task (in-house or through contract) since it should support not only CASTFOREM, but the ARTBASS system as well.

b. VIC: Because VIC has the greatest potential for use on studies of different geographic areas, it has the greatest need for additional terrain coverage. TRAC-WSMR should give priority to adapting VIP extraction programs to be able to read new DTD formats so that new coverage is available for use as soon as it is produced.

c. FORCEM: The key to supporting FORCEM with DTD is for CAA to develop a preprocessor to extract DTED and DFAD data and convert it to a form usable by FORCEM (see paragraph 18c). The existing DTED and DFAD resolution and coverage is adequate for current FORCEM needs, except for LOC network descriptions. The proposed new standard DTD products will have this LOC data. And, the design of the FORCEM preprocessor should allow for the use of new DTD sources as they become available.

20. Integrate DTD Requirements. ETL included the needs of the Army analysis community in their 1984 study, *Army Digital Topographic Data Requirements*. These requirements were validated by ODCSINT and were formally presented to DMA in October 1984. As discussed in paragraph 3 at the beginning of this report, the Army must establish its most critical DTD needs (those that cannot wait for the new DMA system) and develop a cost effective method of producing this urgently needed data.

a. In the past, Army modelers have funded DTD production by engaging contractors and government agencies such as WES, to meet model requirements not met through standard DMA terrain products. Such a case-by-case approach may meet the immediate needs of a particular model as used on a particular study. However, this shortsighted approach can lead to a proliferation of data base formats, unnecessary duplication of coverage, and needlessly expensive production costs. To avoid forcing modelers to resort to such measures, ETL must establish standards and specifications for the Army's interim terrain product needs, and then require that all new production efforts follow these standards. Fortunately, ETL is organized to do just that. ETL's Terrain Analysis Center (TAC) has the mission of terrain data production to meet Army requirements not met by DMA, and ETL's Concepts and Analysis Division (CAD) has been tasked to define the standards and specifications for interim DTD products. Unfortunately, ETL does not presently have either the priority or the resources to support such a program.

b. The study programs of the agencies using CASTFOREM, VIC, and FORCEM will determine the specific DTD coverage required to support these models. It is beyond the scope of this analysis to define those study programs. But, ESC believes VIC will have the greatest need for additional DTD production -- the available ARTBASS DTD and DTD being produced by WES will give CASTFOREM a variety of terrain types on which to investigate battalion-level combat; and CAA has terrain coverage for the theaters it normally uses for FORCEM. As discussed in paragraph 16b, the geographic areas requiring DTD for new tactical weapons and C^3I systems will also be of interest for use in VIC-supported studies. To support both the fielding of the new Army systems that require DTD and the use of VIC to support the analysis of corps-level operations, it will be necessary to develop DTD for all areas covered by US corps operation and contingency plans. To get a first approximation of the level of effort involved in producing this amount of new DTD, ESC asked ETL to develop a rough estimate of the time and cost required to produce an interim set of DTD from available source materials. ETL estimates the production of interim terrain data from existing hard copy TTADB coverage would require about 30 staff years, and would cost about $2 million (see Figure 5).[12]

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[12]An Investigation of Resource Needs for Production of Digital TTADBs/PTADBs in Support of Army Requirements for ITD, working paper (ETL, March 1988); and personal interviews between Mr. Reynolds of ESC and Mr. Richard Herrmann of ETL on 9 and 10 March 1988.

DTD RESOURCE REQUIREMENTS BY REGION

GEOGRAPHIC REGION	STAFF YEARS	DOLLARS (in millions)
EUROPE	14.5	1.0
WESTERN PACIFIC	8.3	0.5
AFRICA/MIDDLE EAST	2.0	0.1
CENTRAL AMERICA/ CARIBBEAN AND OTHER	5.0	0.3
TOTAL	29.8	1.9

Figure 5

c. ESC is not in a position to establish the Army's priority for new DTD production (those priorities must be set by the Deputy Chief of Staff for Intelligence, in cooperation with the Deputy Chief of Staff for Operations). Also, ESC believes that the needs of new tactical systems should be the primary consideration in setting the priorities for new DTD production. However, from the perspective of model requirements alone, ESC suggests priority be given to digitizing the TTADB source material, since it has the terrain feature information and data density most appropriate to VIC. ESC also recommends that the production of new DTD be scheduled in the following order based on the relative priority of modeling efforts in each geographic area (see Figure 6):

(1) Europe -- Since studies are most often designed to test US doctrine, tactics, and equipment against the most demanding mid-intensity threat, the most often required scenario involves modeling a NATO versus Warsaw Pact conflict in Europe. It is also likely that further arms reduction negotiations will generate urgent new requirements to analyze US combat

DTD DEVELOPMENT SCHEDULE

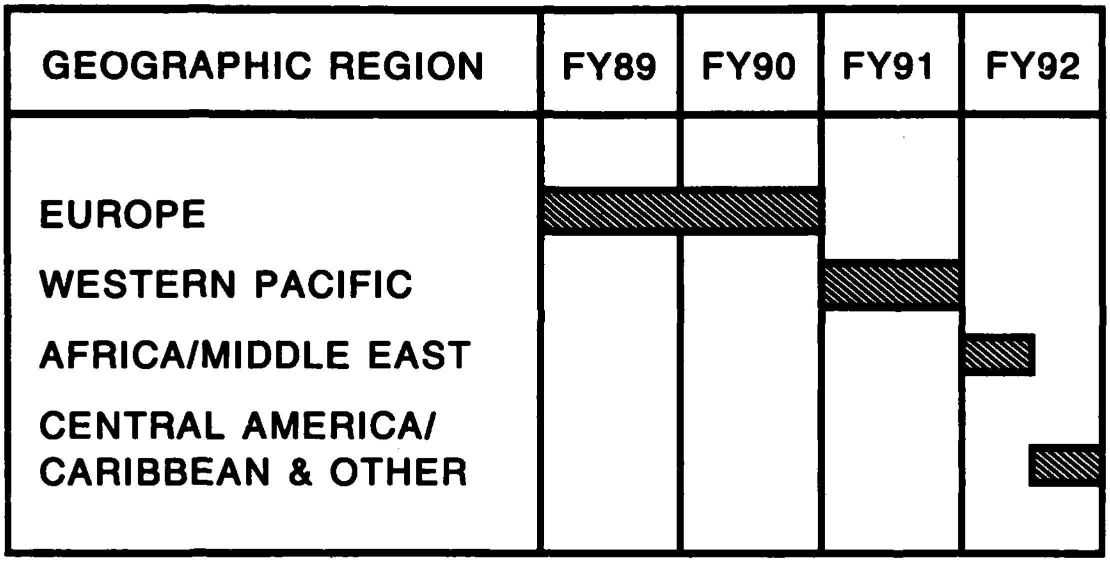

Figure 6

capabilities in Europe. If FORCEM begins to use VIC as a source of corps-level battle outcomes (as recommended in the EMIP Plan), DTD will be needed for all NATO corps sectors, not just the US corps sectors. Using ETL's estimates of 120 manhours and a cost range of $3,000 to $4,200 per map sheet, the available TTADB coverage of 233 map sheets in this area could be digitized by committing about 14-1/2 manyears (27,960 manhours) and something under $1 million ($699,000 to $978,600).

(2) Western Pacific -- With US forces forward deployed and operating under a combined command with the Republic of Korea (ROK), this is the next area where DTD is most needed to support combat models. The Deputy Undersecretary for Operations Research has approved the release of VIC to the ROK/US Combined Forces Command, and they will need DTD to run the model. Annex A shows that high resolution DTD coverage of Korea is limited.[13] The most urgent requirement is for additional DTD coverage of the Demilitarized

[13] *Engineer Model Improvement Program (EMIP) Plan* (ESC, September 1988).

Zone (DMZ), but coverage must eventually be extended to include the entire Korean peninsula. Using ETL's estimates of 120 manhours and cost range of $3,000 to $4,200 per map sheet, the available TTADB coverage of 134 map sheets in this area could be digitized by committing something over eight manyears (16,080 manhours) and about $.5 million ($402,000 to $562,800).

(3) Africa/Middle East -- Constantly changing conditions in the Central Command's area of responsibility make it important for the modeling community to be able to support contingency planning in this volatile area. Annex A shows that only a few countries in this area have any high-resolution DTD coverage, and that coverage is limited to a few locations in each country.[14] Using ETL's estimates of 120 manhours and cost range of $3,000 to $4,200 per map sheet, the available TTADB coverage of 32 map sheets in this area could be digitized with two manyears of effort (3,840 manhours) and about $100 thousand ($96,000 to $134,400).

(4) Central America/Caribbean -- As with the Central Command, volatile conditions throughout most of Southern Command's area of responsibility make it important for the modeling community to be able to support Southern Command study needs. Using ETL's estimates of 120 manhours and cost range of $3,000 to $4,200 per map sheet, the available TTADB coverage of 80 map sheets in this area could be digitized with five manyears of effort (9,600 manhours) and between one-quarter and one-third of $1 million ($240,000 to $336,000).

(5) Other -- There are certainly other areas throughout the world where contingency missions might occur (e.g. islands in the Pacific). But, the requirement for modeling analysis (particularly VIC-level analysis) is presently not high in these areas.

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[14] *Engineer Model Improvement Program (EMIP) Plan* (ESC, September 1988).

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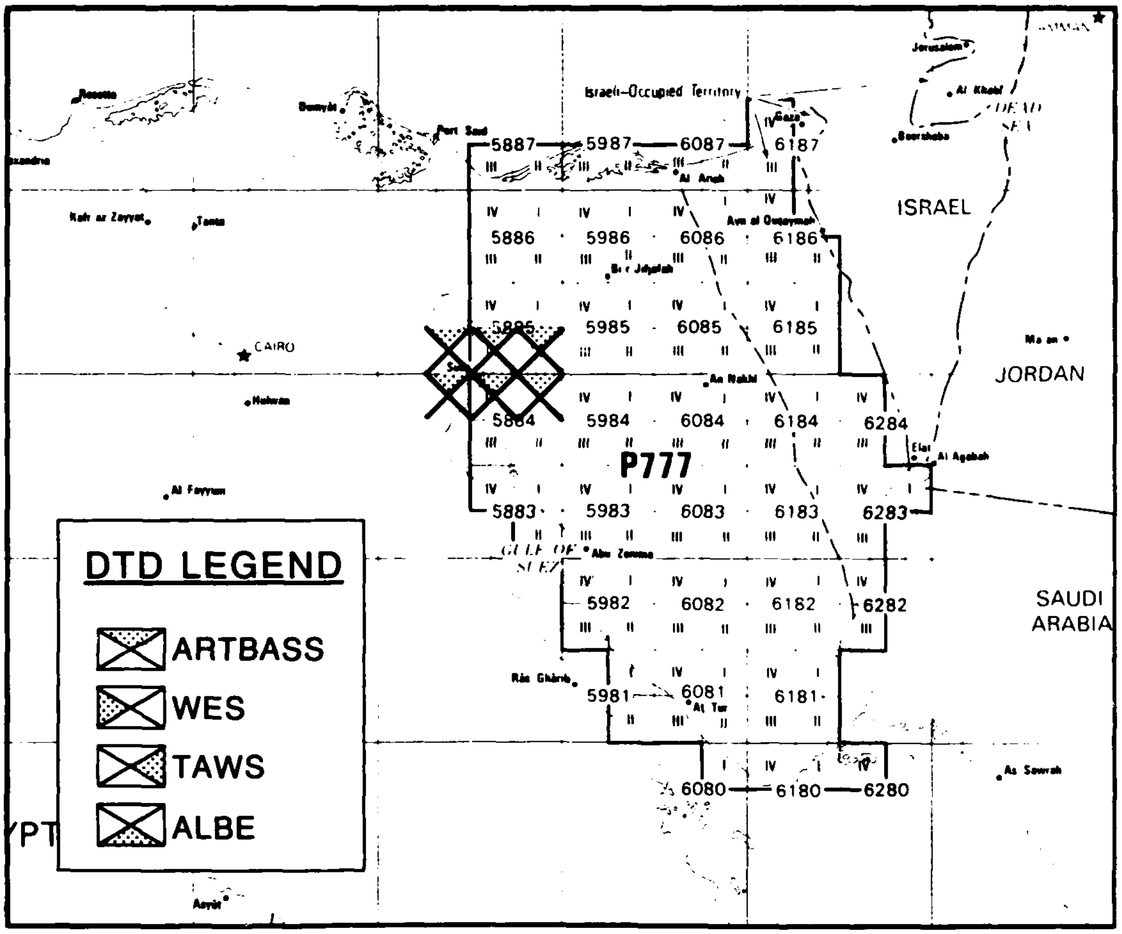
ANNEX A

DTD COVERAGE WORLDWIDE

Army DTD Production in Egypt



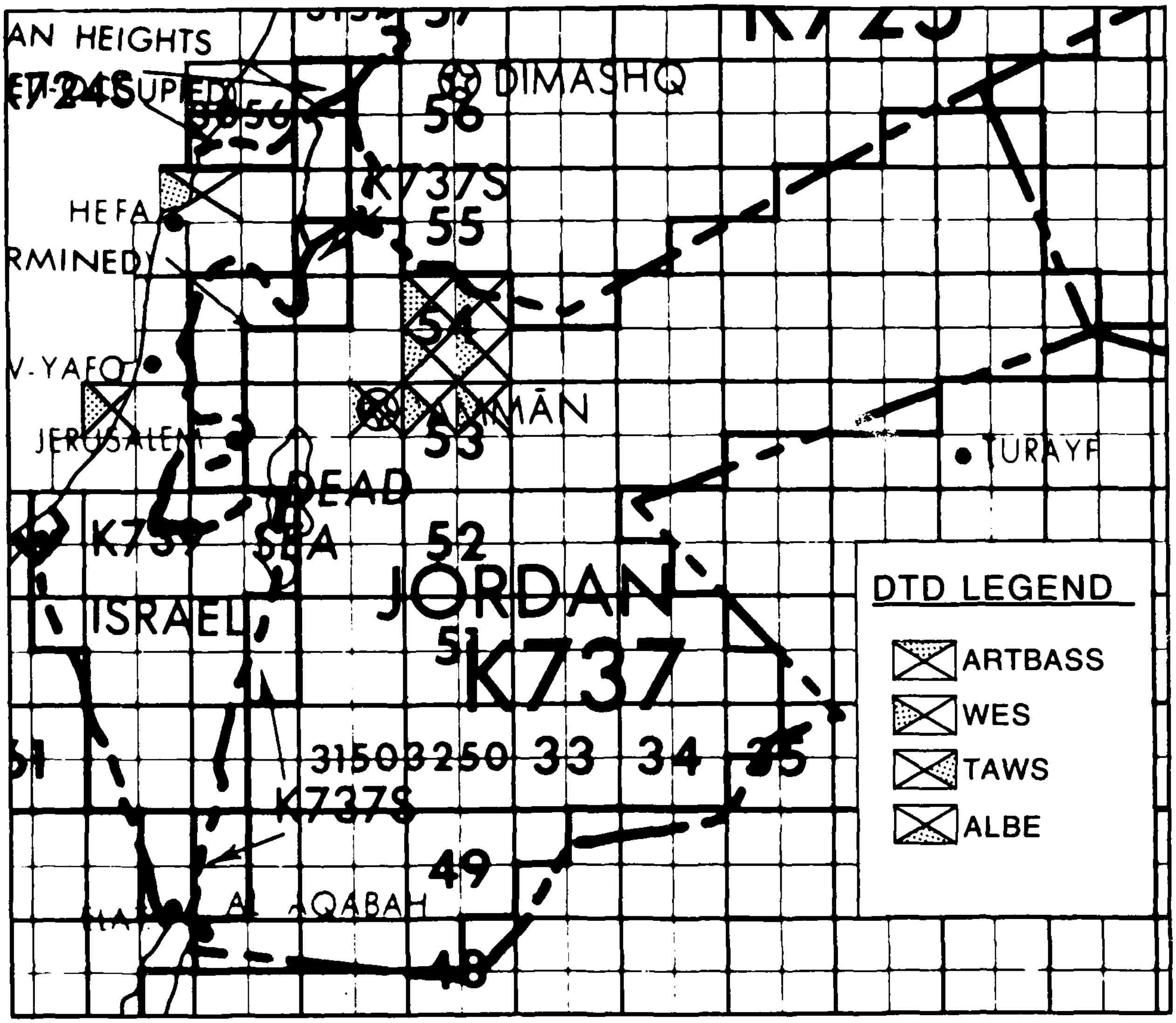
Army DTD Production in Israel and Jordan

JORDAN

Quad No.	Quad Name
3254 IV	Al Mafraq
3254 I	Khirbat um el Jima
3254 III	Az Zarqa
3254 II	Qasr az Hallabat
3153 I	Amman
3253 IV	Sahab
3253 I	Qasr Mushash

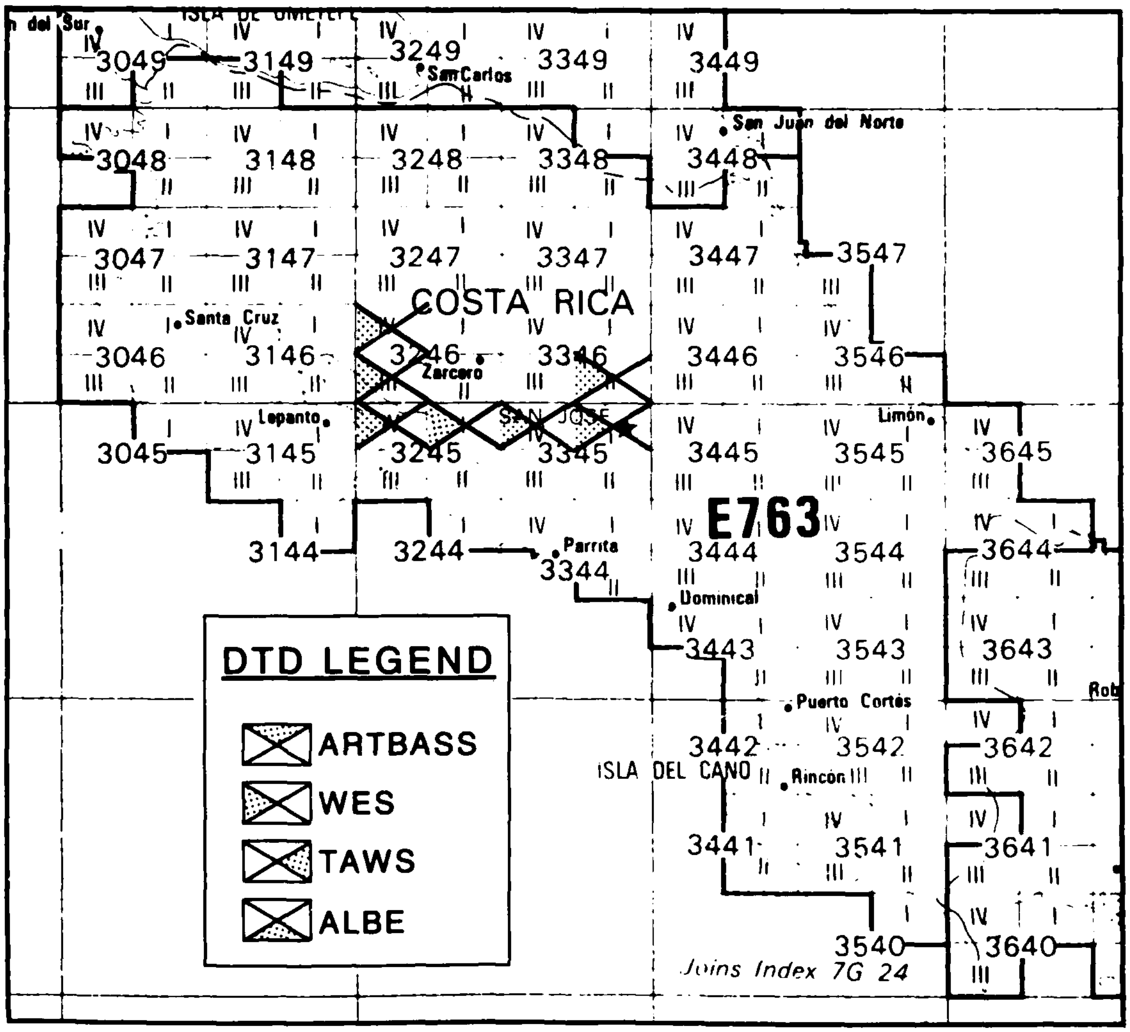
ISRAEL

Quad No.	Quad Name
2953 IV	Yavne
3055 IV	Acre

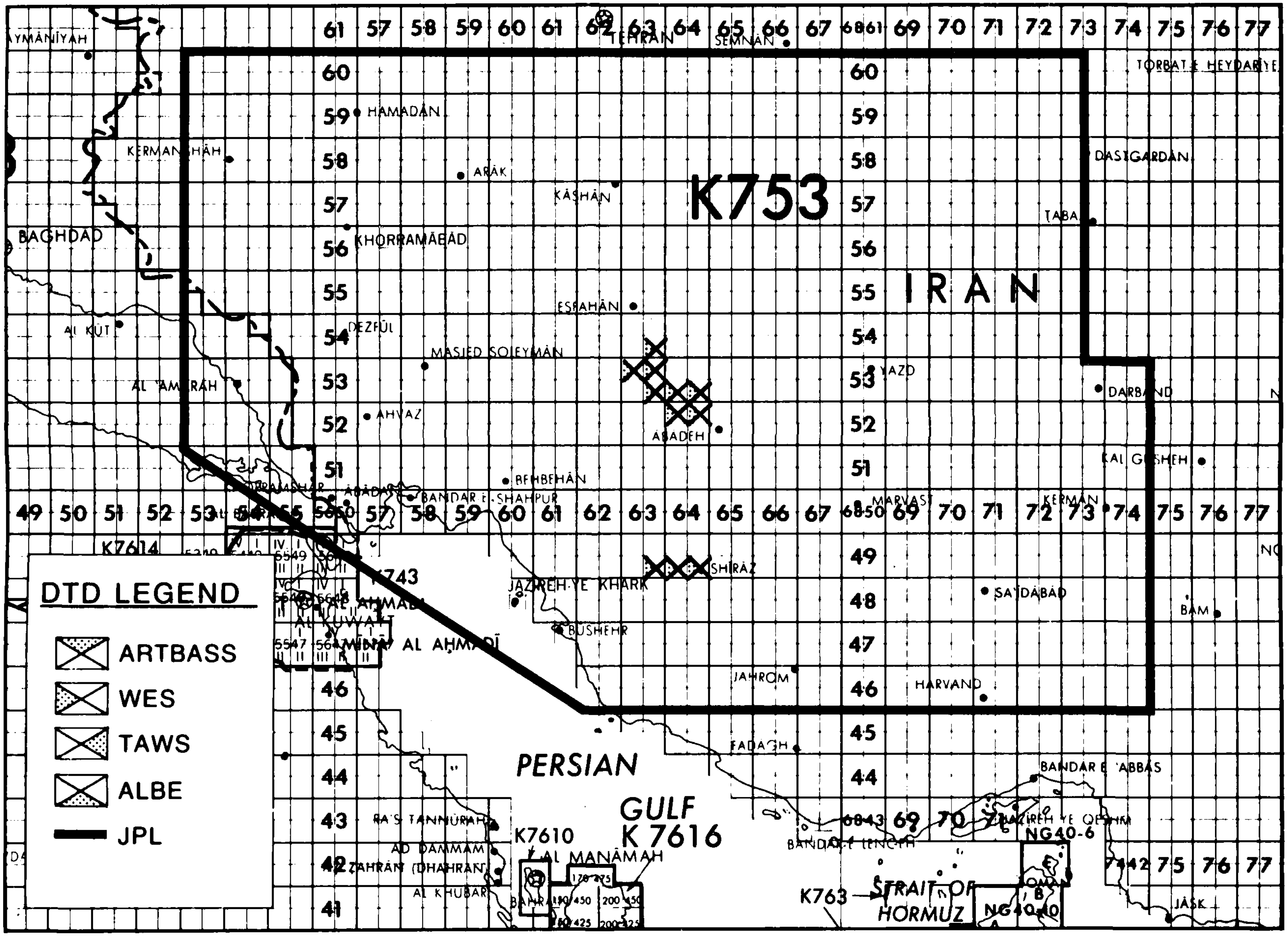


Army DTD Production in Costa Rica

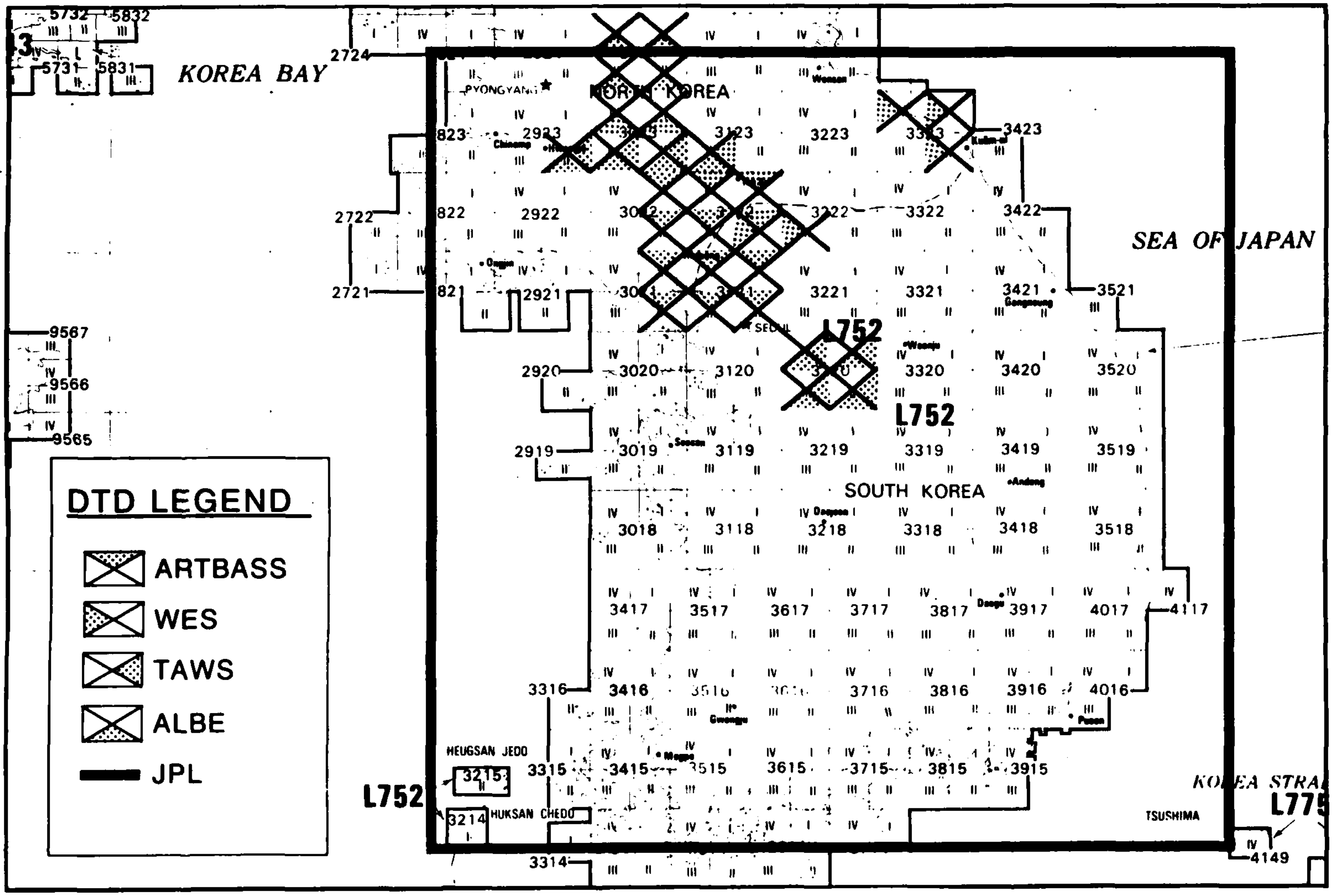
Quad No.	Quad Name
3245 I	Barranca
3245 IV	Golfo
3246 III	Chomes
3246 IV	Juntas
3345 I	Abra
3345 IV	Santiago
3346 II	Miramar



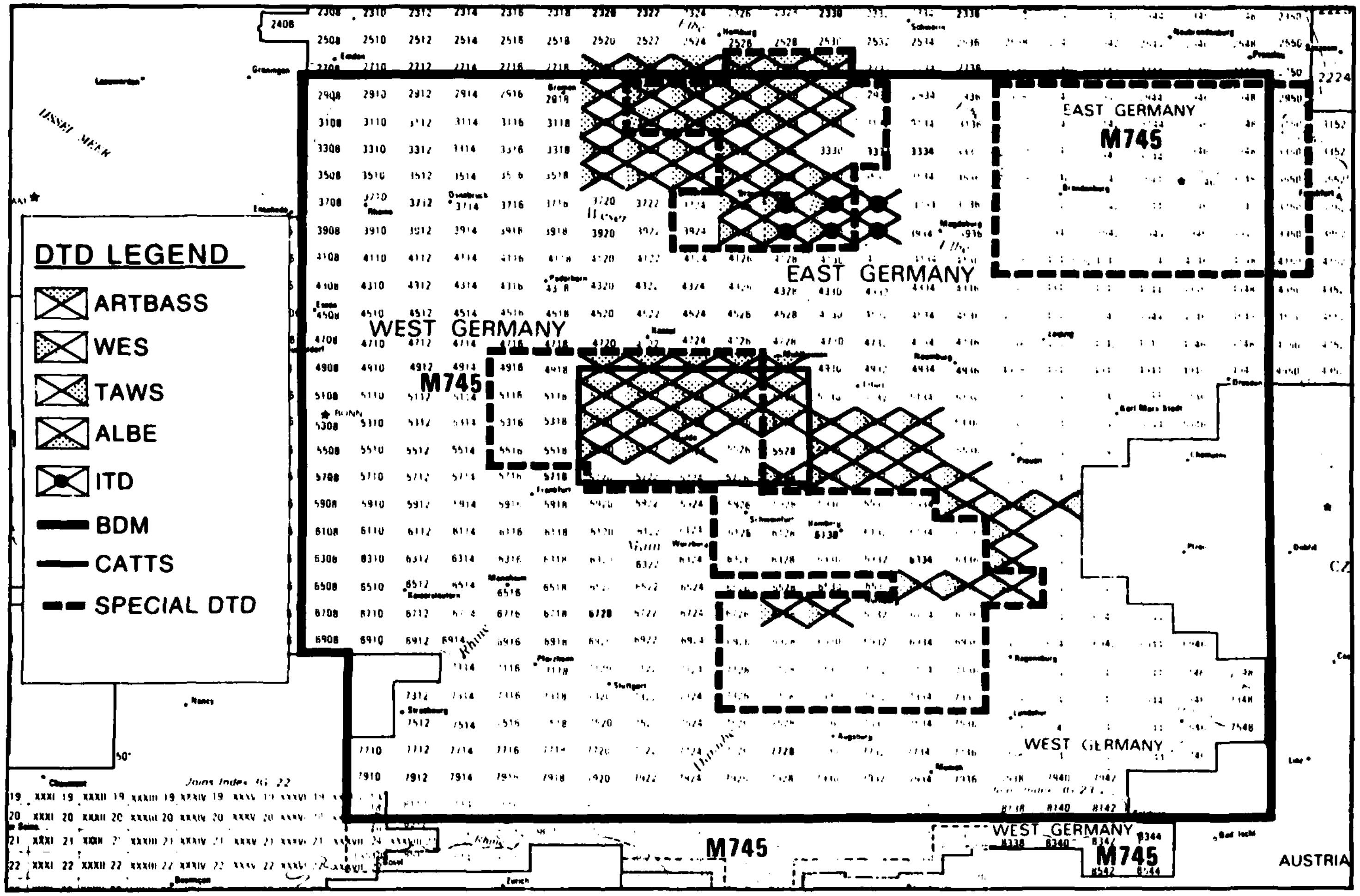
Army DTD Production in Iran



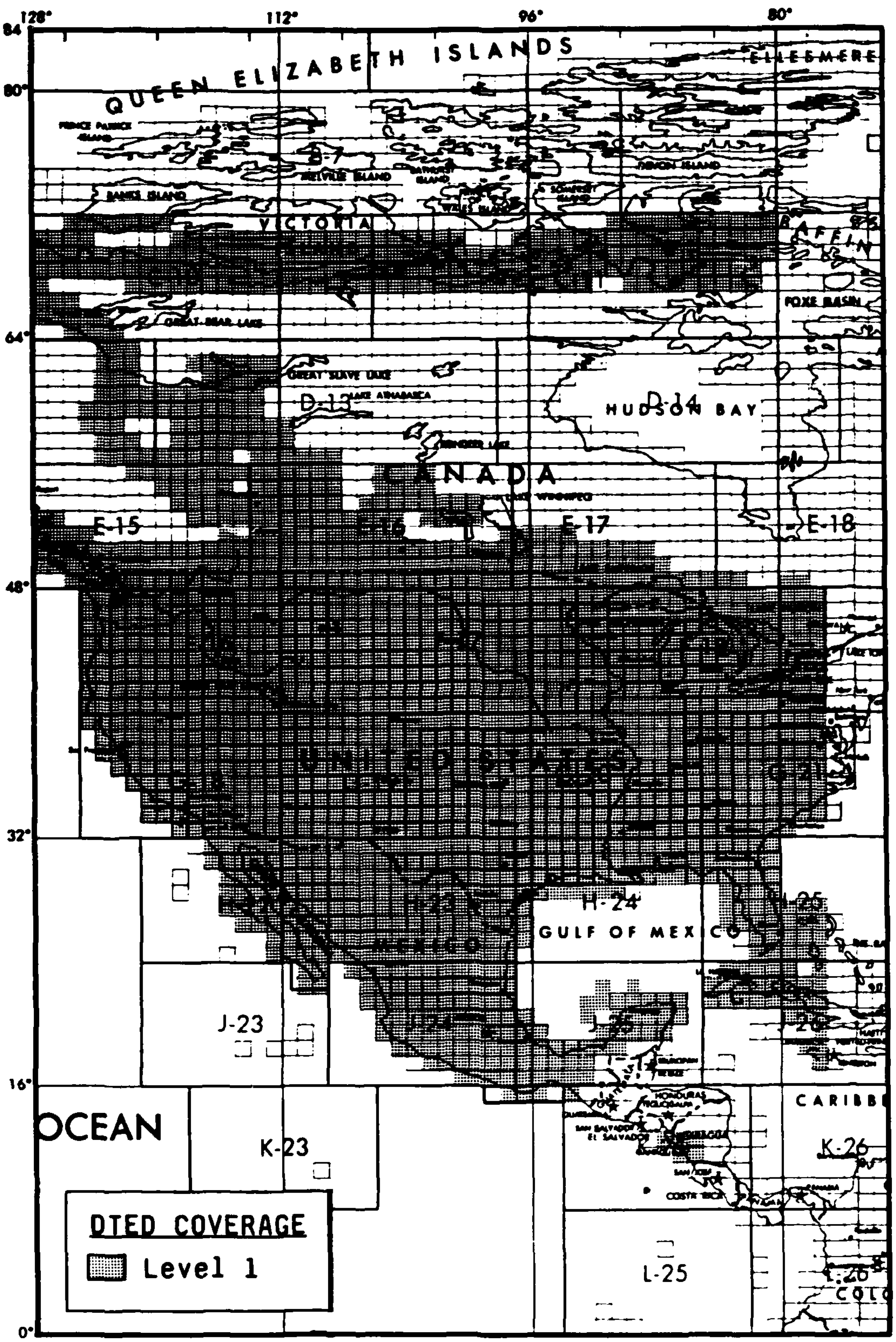
Army DTD Production in the Republic of Korea (ROK)



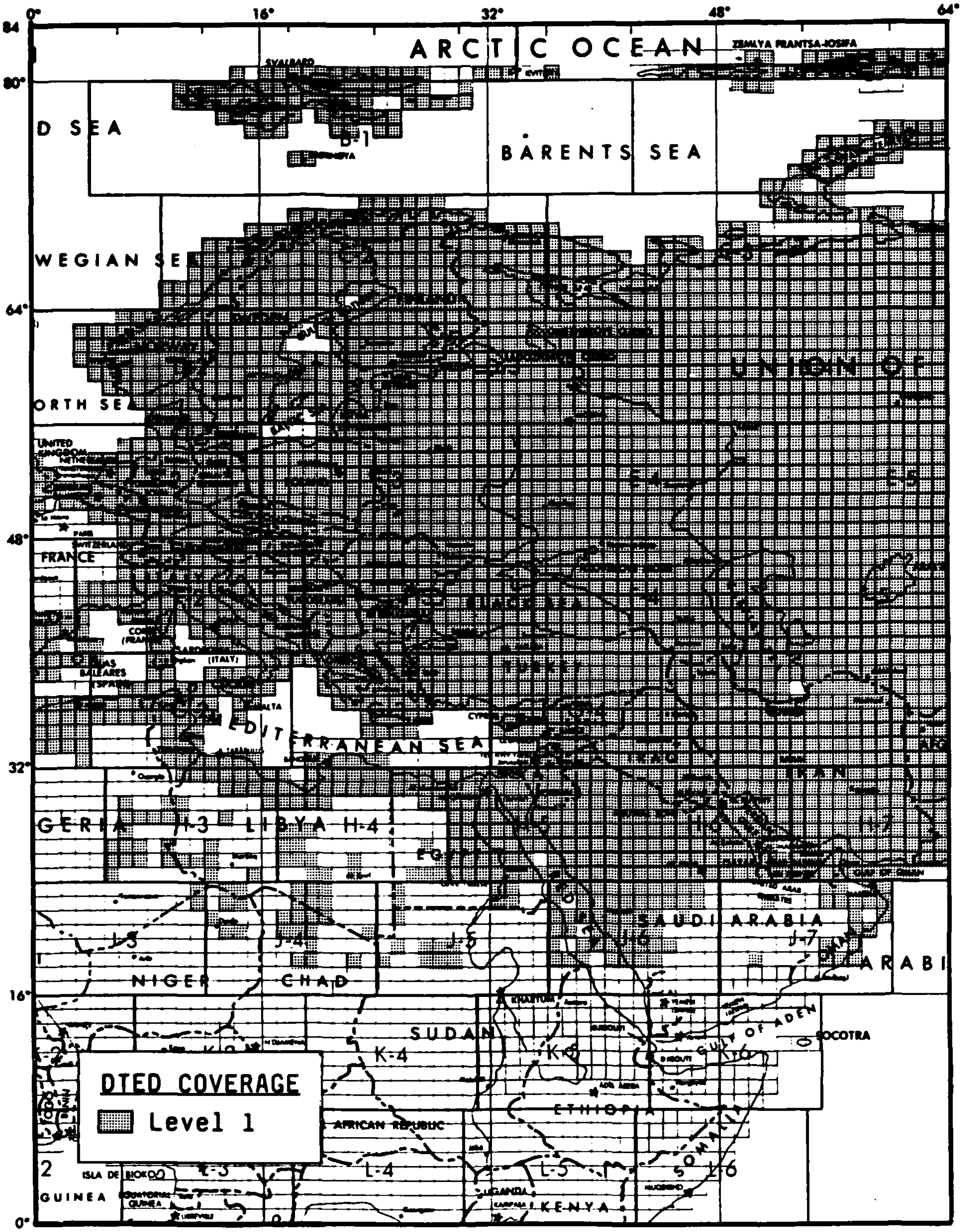
Army DTD Production in the Federal Republic of Germany (FRG)



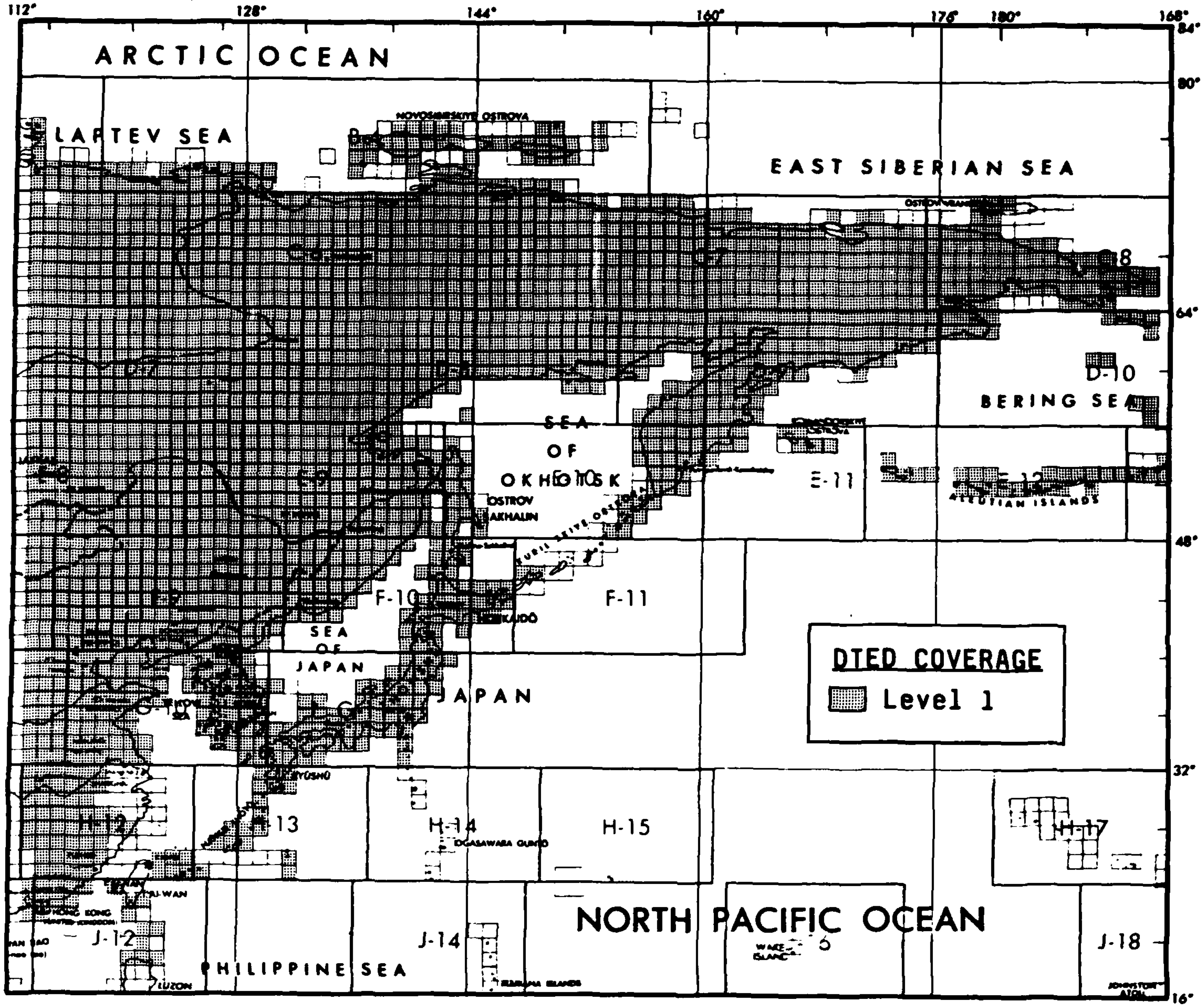
DTED Production in the Americas



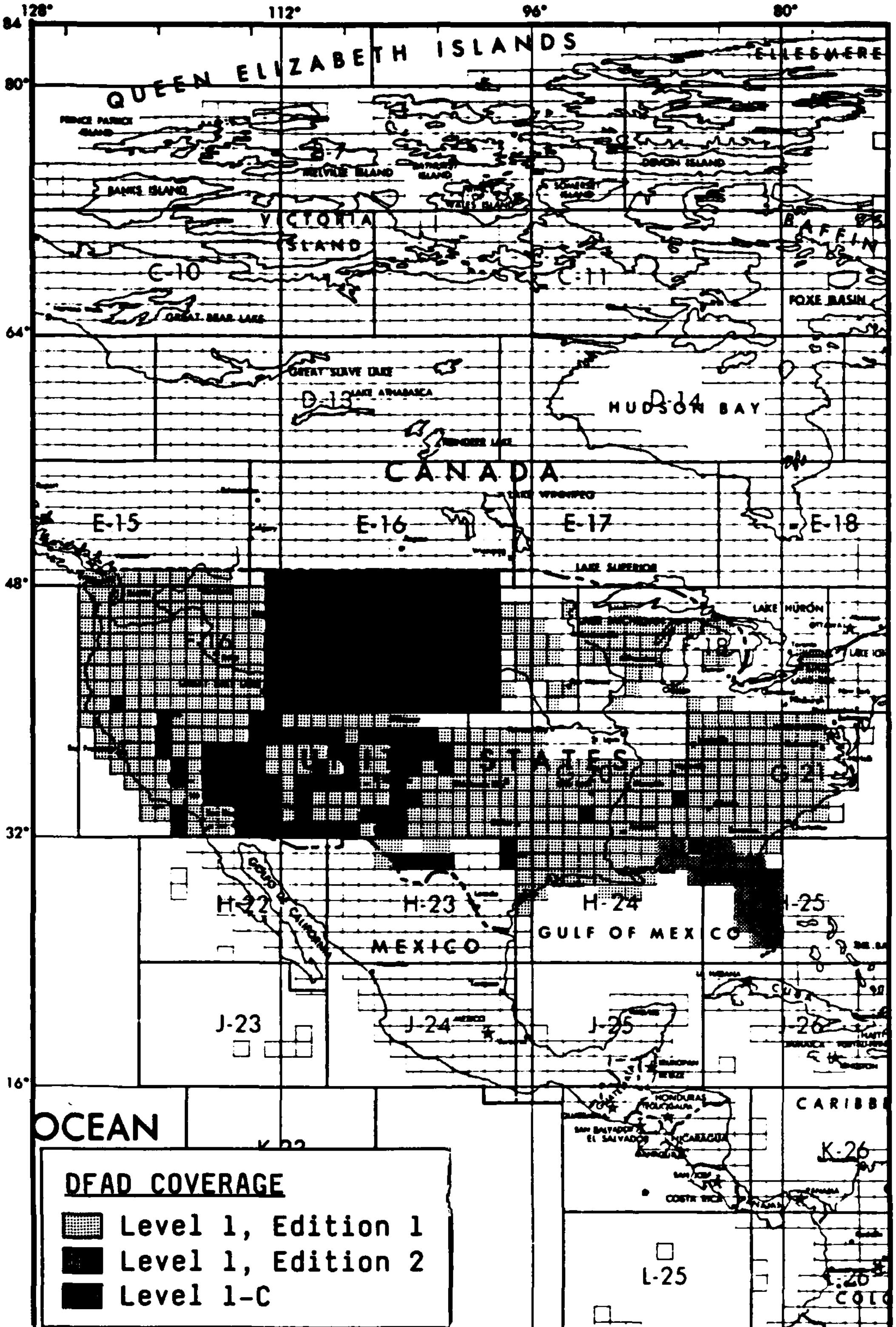
DTED Production in Europe



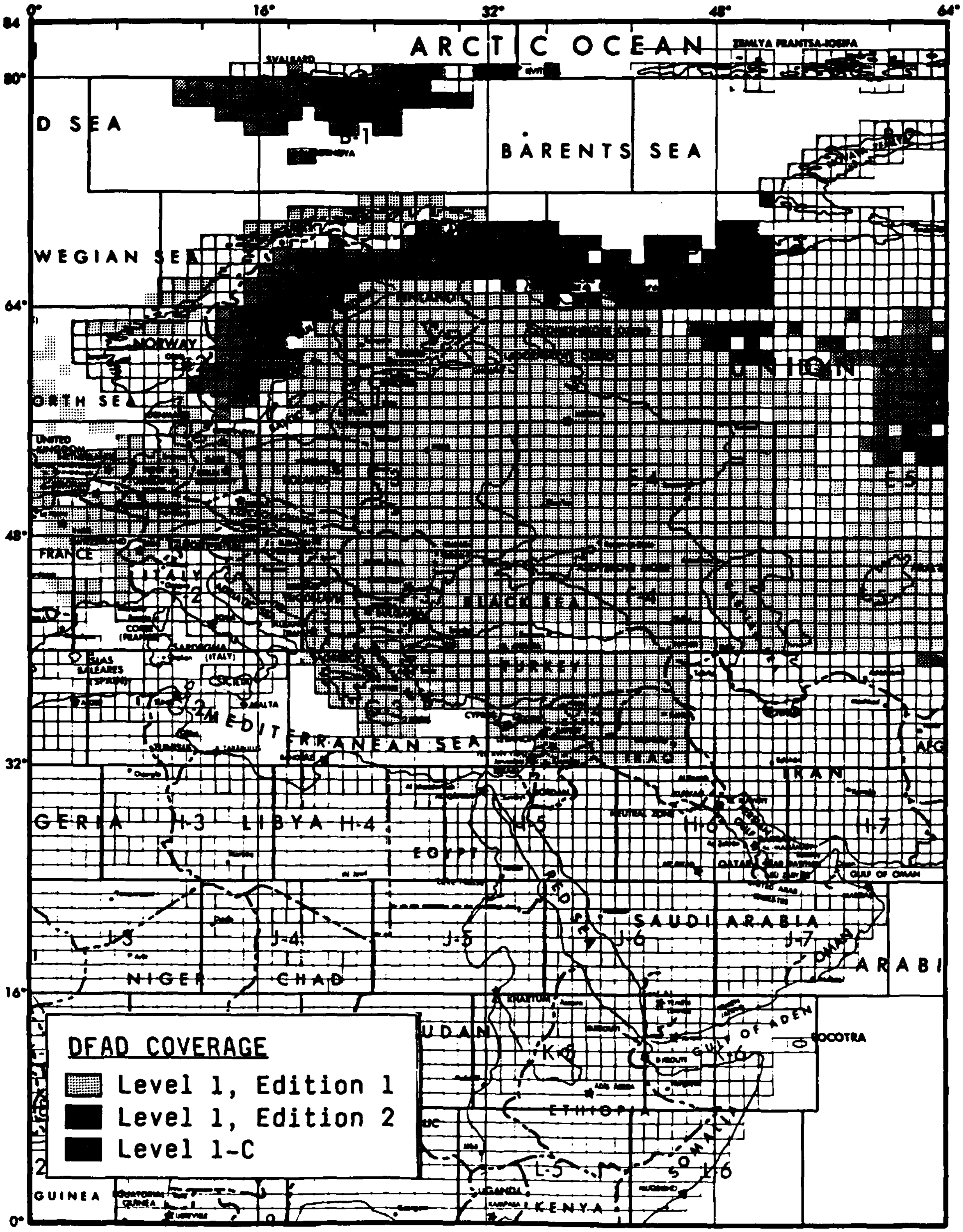
DTED Production in Asia



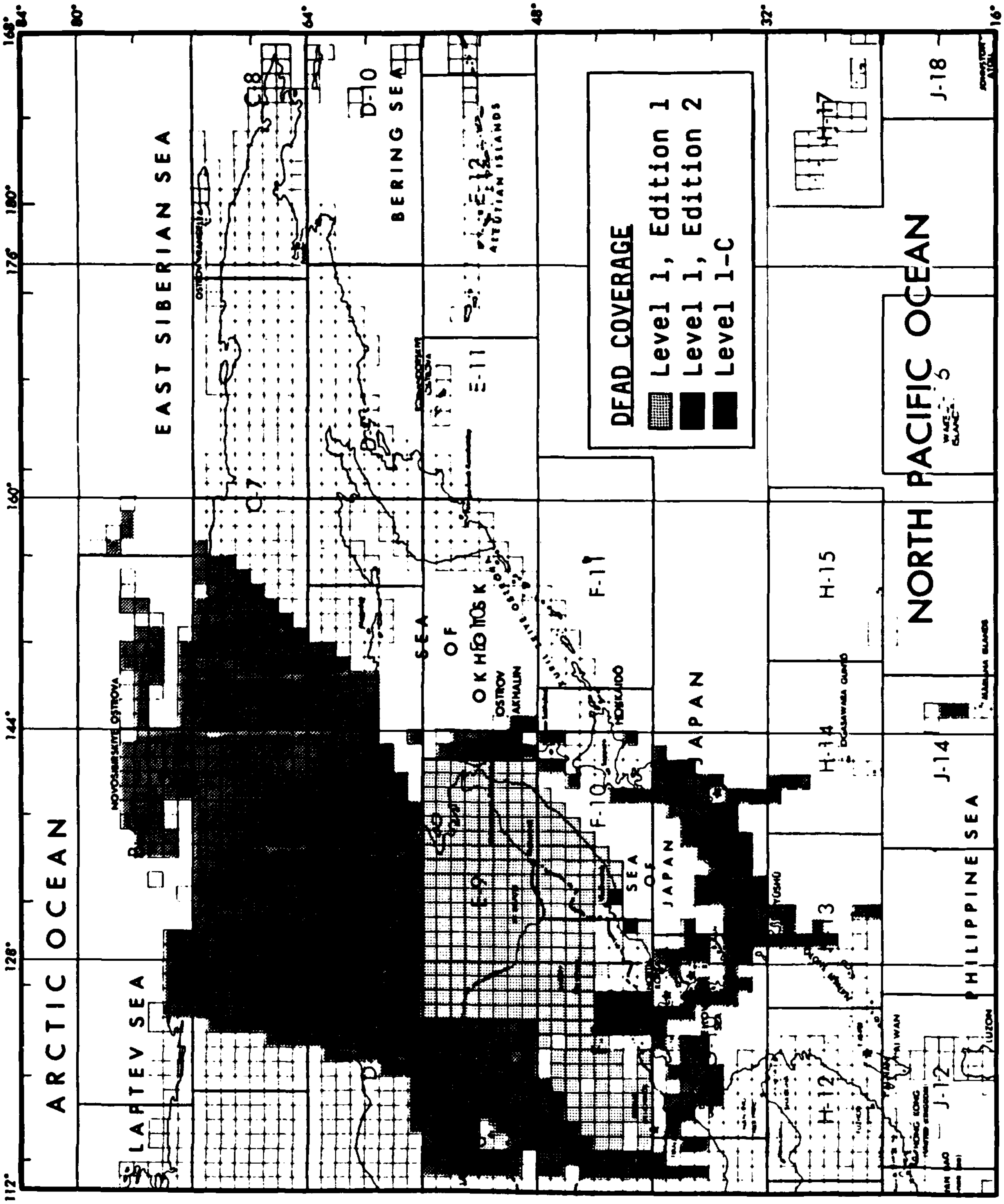
DFAD Production in the Americas



DFAD Production in Europe



DFAD Production in Asia



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ANNEX B

GLOSSARY OF TERMS

ANNEX B

GLOSSARY OF TERMS

AirLand Battlefield Environment (ALBE) Program. USACE has instituted the ALBE program to focus upon two activities. One, to provide the Army material acquisition activities with the capability of assessing and exploiting realistic battlefield environmental effects. Second, to provide the Army in the field with the capability to assess and exploit battlefield environmental effects for tactical advantage. Demonstrations of the ALBE program have been conducted recently on Fort Hood (1986) and in Korea (1987). These preliminary demonstrations have used a computer test bed system to produce tactical decision aids (TDA) to help the battlefield commander make better decisions. The ALBE test bed system uses a GIS which processes DTD. This GIS uses a digital data base, using digitized information from TTADBs and other sources.

Areal Feature. An area completely enclosed by a delimiting line of the feature manuscript.

Army Training Battle Simulation System (ARTBASS). ARTBASS can model a tactical environment which can encompass a surface area of 500 square kilometers to an altitude of 10 kilometers. The ARTBASS is capable of modeling a total of 200 units simultaneously during a simulated exercise. Natural environmental factors are included in the model, for example: weather, vegetation/forestation, ground surface, soil type, wind, and visibility. Each DTD data base created for use on ARTBASS is produced in a 64-bit fixed field, raster format with Universal Transverse Mercator (UTM) coordinates using 12.5 or 25-meter post spacing. The actual digital scale is 1:49,212. The ARTBASS DTD set consists of a UTM digital terrain elevation data (DTED) file, a vegetation feature file containing the vegetation type, canopy closure, height, a surface material file, a surface drainage file, an obstacle file, a transportation file, and a CCM file for several vehicles, both wet and dry.

Collateral Sources. Outside agencies, both national and foreign, from which information and data may be obtained.

Critical. Failure of unit operations; increased probability of defeat; paramount to success in pivotal situations.

Data Base (DB). An organized set of evaluated MC&G data stored in either graphic, textual, or digital form. A data base may contain one file of data (DTED), or several data files.

Digitize. To translate an analogue measurement of data into a numerical description expressed in digits in a scale of notation.

Digital Data. Data represented by digits, perhaps with special characters and the space character.

Digital Data Base (off-line). A digital data base maintained in a common format that supports different user systems. Normally, the data must be transformed before they can be used by a specific user system.

Digital Data Base (on-line). A digital data base in the format needed by a user system and which can be directly loaded into the used system. This term is commonly referred to as the on-line data base.

Digital Feature Analysis Data (DFAD). DFAD Level I consists of selected natural and man-made planimetric features, type classified as point, line, or area features as function of their size and composition. The data is stored in polygon formate and segregated into 1 degree X 1 degree geographic cells. DFAD level 1 is available in several levels and editions.

Digital Landmass System (DLMS) Data Base. DLMS contains two digital data bases, Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD), and generally has an accuracy and resolution similar to a 1:250,000 scale topographic line map.

Digital Map. A map expressed and stored in digital form. It can also be a representation in digital form of discrete points on the earth's surface. Also called a numerical map.

Digital Terrain Data (DTD). DTD is a generic term used to describe any machine readable file and or data base of topographic date, either feature data, elevation data, or both. DTD is commonly used to refer to DLMS, DFAD, DLMS DTED, TTD, STD.

Digital Terrain Elevation Data (DTED). DTED Level I consists of a uniform matrix of terrain elevation values. The standard DTED file size is a 1 degree X 1 degree cell. Each elevation data record contains 1201 elevation values along a single meridian with 3 arc seconds (latitude) spacing. Elevation posts are spaced approximately every 100 meters.

Digital Terrain Elevation Matrix. Elevation posts, non-specific with respect to editing and smoothing, and evenly distributed in a rectangular pattern.

Digital Terrain Model. A statistical representation of the continuous surface of the earth by a large number of selected points with known X,Y, Z coordinated in an arbitrary coordinate field.

Digital Topographic Data (DTD). A generic term used to describe the combination of both elevation and feature data (see also Digital Terrain Data).

Digital Topographic Support System (DTSS). The DTSS will put the speed and flexibility of automation to work for the terrain analyst. DTSS will supply digital topographic support for the field Army in the 1990's. It will supply data for such tactical users as the all-source analysis system, and the FIREFINDER counter artillery counter-mortar radar.

Environment. Consists of five elements: atmosphere, terrain, battlefield induced contaminants, background signature, and illumination.

Elevation Post. A point with known horizontal and vertical position with respect to some defined reference system.

Feature Analysis. The process of locating, examining, and classifying the physical characteristics of natural and cultural features on the earth's surface.

Feature Extraction. The process of transferring or encoding feature analysis data to a digital or analog mode.

Feature Type. A classification of feature into categories of point, linear (line) or areal features.

Geodetic Datum. A particular association of an ellipsoid to some physical monument on the earth. It represents the fixing of an origin and the orientation from which location on the earth is measured.

Grid. A reference system applied to maps to provide a uniform system for referencing and making measurements.

Interim Terrain Data (ITD). ITD will consist of digitized TTADBs and PTADBs, together with DTED Level I. ITD format and content will be designed to allow it to meet interim Army needs until DMA can produce TTD. To the extent possible, ITD will be designed to be a compatible subset of TTD, so that systems using ITD can easily transition to TTD when it becomes available.

Linear Feature. A feature that is portrayed by a line that does not represent an area.

Near-Term Requirement. A DTD requirement generated by an operational system to be fielded in the FY 1987-FY 1993 time period.

Mid-Term Requirement. A DTD requirement generated by an operational system to be fielded in the FY 1993-FY 2002 time period.

Far-Term Requirement. A DTD requirement generated by an operational system to be fielded in the FY 2002-FY 2011 time period.

Operational System. A system that has passed the first unit equipped state of development and is either fielded or in the process of being fielded.

Planning Terrain Analysis Data Base (PTADB). The PTADB is a set of hard copy overlays keyed to a 1:250,000 scale topographic line map. The PTADB is limited to a few key natural and man-made features used to satisfy military planning requirements. These features include: surface configuration (slope), vegetation, surface materials, surface drainage, transportation, obstacles, and water resources.

Point Feature. An object whose location can be described by a single set of coordinates.

Resolution. A measure of the smallest possible difference in value or position. In a computer system, this may be numerical resolution or physical resolution of the hardware; e.g., plotter step size or digitizer resolution.

Raster. A regular, two dimensional arrangement of physical or conceptual elements; e.g., addressable points. Sometimes synonymous with grid, and also matrix.

Special Terrain Data (STD). STD contains elevation and feature data sets similar to TTD. This data base, however, is much more detailed and accurate than TTD, with resolution requirements relatively equivalent to a 1:12,500 scale topographic line map and associated terrain analysis products. While STD is a stated Army requirement, DMA has said it will not address this requirement until after the Mark 90 system is operational and TTD requirements are being met.

Tactical Terrain Analysis Data Base (TTADB). The TTADB is a set of hard copy topical overlays keyed to a 1:50,000 scale topographic line map. This data base is limited to those natural and man-made features of tactical military significance. These features consist of surface configuration (slope), vegetation, surface materials, surface drainage, transportation, and obstacles.

Tactical Terrain Data (TTD). TTD is a data set similar in content, accuracy, and resolution to a Class B, 1:50,000 scale topographic map/terrain analysis study. TTD will contain unsynthesized and unsymbolized feature and attribute data, plus elevation data. Feature and attribute data will include information about the size, shape, location, and height of extracted features. The elevation matrix will contain elevation posts every 30 meters (1 arc second) referenced to the World Geodetic system. TTD is considered the Army's operational support data base and will meet most user requirements when it becomes available. However, DMA will not begin producing TTD until the Mark 90 system becomes operational.

Terrain Analysis Work Station (TAWS). TAWS is a prototype of the DTSS. TAWS includes four major components: data base development, terrain analysis and product generation, intervisibility analysis and product generation, and environmental effects software. The data base development is a terrain analysis data base which typically includes factor overlays covering soil, drainage, transportation, vegetation, slope and obstacles.

Terrain Modeling. The mathematical modeling of the physical shape of a portion of the earth's surface (terrain) by fitting functions to the elevation data.

Transformation program. A computer program used to change digital data from one format to another (e.g., from planar to DMA standard).

Vital. Jeopardizes the existence of the division; high loss of life, and early defeat of the unit.

VIC Terrain Classification Algorithm. VIC classifies relief into three classes: mountains, hills, and flat areas. This is accomplished by a three-step process. First DTED is read, reduced, and synthesized into a cell (4 km X 4 km) value. Second, cell values are then referenced to a terrain look-up table based on the Natick Landform classification system. This system describes surface roughness within a landform compartment by specifying three characteristics: maximum local relief, modal local relief, and average number of positive features per unit distance. A code is assigned based on these characteristics. Finally, these codes are then reduced to a plains, hills, or mountain rating.

WES-Mobility Terrain Data Bases. Development of mobility-terrain data bases has been supported in part by funds from TRAC to provide realistic mobility input to the CARMONETTE Model for wargaming. The data bases are generally referenced to groups of 1:50,000 topographic line maps. The data are at 100 meter resolution and represent those terrain factors and seasonal conditions that influence vehicle performance. Five major DTD features have been developed for CARMONETTE/CASTFOREM: road code, tree heights, CCM code, elevation, and vehicle speeds. These five features are derived from the digital terrain data base which is composed of many factors, a few of which are soil types, slope, urban code, surface roughness, vegetation spacing, road codes, bridge codes, tunnel codes, river and stream widths, and water-gap bank conditions.

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ANNEX C

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ANNEX C

BIBLIOGRAPHY

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