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GRASS/GIS Implementation Guide

by
Mary V. Martin
William D. Goran
Robert C. Lozar
Jean M. Messersmith
Marilyn S. Ruiz
James D. Westervelt

The GRASS/GIS Implementation Guide is a manual for the implementation and use of the Geographic Resources Analysis Support System (GRASS).

GRASS is a microcomputer based image processing and geographic information system (GIS) used to develop, manipulate, analyze, and display geographic datasets.

This Implementation Guide identifies procedures and issues relevant to user sites preparing to receive and implement GRASS software. Special attention is given to GRASS software capabilities, supported data types, hardware selection and configuration, and staff selection and training. Also included is a list of support structures and current publications relating to GRASS.

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Foreword

This document was developed for the U.S. Army Engineering and Housing Support Center's (USAEHSC) Facilities Engineering Application Program (FEAP) under work unit F79, entitled "GRASS Implementation". The Technical Monitor was Ms. Jamie Clark, of the USAEHSC Natural and Cultural Resources Division.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

1.1. Background

The Geographic Resources Analysis Support System (GRASS) is a microcomputer based image processing and geographic information system (GIS) used to develop, manipulate, analyze, and display geographical datasets. Initially developed by researchers at USACERL's Environmental Division for environmental planners at military installations, GRASS is now used by a variety of public and private agencies and individuals to assess environmental impacts, evaluate site suitability, detect change, manage resources, and model the effects of environmental phenomena across a landscape.

The system is currently fielded at several military installations and Corps of Engineers districts, divisions, and laboratories, and has also been acquired by other federal and nonfederal organizations. As a result of several programs being implemented throughout the Corps, Army, and/or all sectors of the military, (e.g., Environmental Management Analysis Program [EMAP], Land Condition-Trend Analysis Program [LCTA], Base Realignment), many installations will soon acquire GRASS.

While GRASS has many useful applications, its implementation is complex, and presents many staffing, funding, and logistical problems. This guide attempts to address these issues. It is one of several mechanisms being developed to support GRASS implementation; others include logistical mechanisms, support structures, and other documentation.

1.2. Objective

The objective of this work is to identify procedures and issues relating to GRASS implementation at user sites. Conditions may vary at each site. It is envisioned that sites will use this document as a guide on which to base site-specific GIS implementation plans.

1.3. Approach

GRASS implementation at other installations was examined, as were written materials describing the implementation of geographic information systems (GISs) and other similar systems.

- 2 -

1.4. Scope

Information in this report is current as of the last quarter in FY89.

1.5. Mode of Technology Transfer

The information in this report will aid the technical transfer of USACERL's GRASS geographic information and image processing system. GRASS is being transferred to the field through the following mechanisms: training programs, hands on experience, a user support center, newsletters, extensive documentation, institutional structures at the Army and Interagency levels, communication networks, and other forums.

- 3 -

Chapter 2

Overview of the Implementation Process: Getting Started with GRASS/GIS

Geographic Information Systems (GISs) offer tremendous potential to improve planning, evaluation, and monitoring and management of Army lands. Army installations are now implementing GIS technology. This guide will assist installation staff to understand and address the issues associated with the implementation process. Specifically, it examines the evaluation, selection, and acquisition of necessary hardware, as well as networking issues, software requirements, data base construction, application issues, user training, staffing, and GIS support requirements.

2.1. Initiation of the Implementation Process

The process of GIS implementation on an installation can occur for any of several reasons:

1) The technology may be part of some Army-wide or MACOM-wide program, such as Integrated Training Area Management (ITAM) or Environmental Management Analysis Program (EMAP) that is being implemented on-post.

2) A proponent on the installation may learn about GIS technology and through meetings, literature, etc., become an advocate for its use on-post.

3) A regulatory or supporting organization may use GIS technology to support or evaluate post activities (e.g., development of data bases by the State Historic Preservation Officer [SHPO], and Army Environmental Hygiene Agency [AEHA], etc.).

4) A major action requiring the completion of an environmental impact assessment (EA) may be contemplated on the installation; such actions might include a change of mission, site selection for a major new range complex, selection of new landfill sites, and other actions. A MACOM, Corps District, reviewing agency, or another, may suggest that GIS technology be used to prepare the EA.

However the process is initiated, the installation should follow a series of logical steps to ensure smooth and cost-efficient implementation. A GIS can be applied to many land-related issues, possibly resulting in large cost savings to installations. However, GIS implementation may present its own costs and issues related to staffing, hardware, construction and maintenance of datasets, interfacing the GIS with other software, and long-term data, hardware, software, and system costs. Successful system implementation therefore greatly depends upon proper planning, and upon the existence of support structures, policy guidelines and documentation. The development and use of standard GIS implementation procedures and support structures will result in more cost-effective and timely GIS implementation throughout the military.

Implementation documentation and logistical support will enable those who are considering acquisition to correctly estimate future costs and benefits associated with system implementation. Support structures will provide an ongoing mechanism through which to address users' questions before and after system acquisition. Above

 - 4 -

all, such mechanisms will allow sites to prepare themselves, before the system arrives, for the implementation of a GIS. Implementation steps are outlined below, and shown graphically in Figure 2.1.

In Figure 2.1, one scenario for GRASS GIS Implementation is outlined. Tasks are divided into (1) those performed by the *project sponsor* (e.g., a MACOM), (2) those done by the *GRASS implementation site* (e.g., an installation or District), and (3) tasks performed by a *contractor* (e.g., USACERL, a Corps District, etc.). It is possible that the GRASS implementation site may itself perform some or all of the tasks shown in Figure 2.1 as being done by a contractor. However, it is likely that at least some tasks will be contracted out.

Example Scenario
GRASS IMPLEMENTATION PROCESS

RESPONSIBILITIES OF SPONSOR
Funding & Proposal Review
Selection of Installations
Monitoring Process
Evaluating Program

PHASE	*RESPONSIBILITIES OF IMPLEMENTATION SITE*	*RESPONSIBILITIES OF CONTRACTOR/LAB*
PREPARATION	Assignment of Installation POC Creation of GIS Implementation Committee Cost/Benefit Evaluation of Applications Data Requirements Evaluation Hardware/Software Connections Hiring & Training of GIS/ITAM Personnel Coordination with DOIM Site Identification of & Preparation for System System Management Training (by vendor)	Project Scoping & Proposal Dialogue with Installation POC Data Requirements Personnel Needs Hardware/Software Links Data Acquisition Data Translation & Digitizing Hardware Evaluation & Selection Hardware Procurement Hardware Delivery to Contractor/Lab Installation of Data & Software Configuration Training at Contractor/Lab Site
INSTALLATION	Delivery of System to Installation On-site Training from Contractor/Lab	
ONGOING USE	Enroll in Training Courses Running Applications Ongoing Data Updates & Maintenance Ongoing System Support Advanced Software Training	Ongoing Support Custom Applications Prototyping New Software Releases

Figure 2.1

 - 5 -

2.2. GIS Coordinator

The first step toward GIS implementation at a potential user site is the appointment of a GIS Coordinator (the installation POC in Figure 2.1). Usually, this person will be someone in the installation Environmental Division or Natural Resources branch. This individual should be familiar with environmental analysis. The GIS Coordinator will (a) gather information, (b) educate potential users and coordinate plans for the GIS, (c) develop an implementation plan specific to the installation, (d) address impacts attributable to implementation, and finally (e) secure support for the plan.

This position is critical to the evaluation of GIS technology for an installation and to the successful coordination and maintenance of this technology both on and off the installation. The GIS Coordinator should be a permanent installation employee, with adequate status and authority to accomplish these tasks. Ideally, this person will be familiar with the organization and procedures of the different elements on the installation that may be potential GIS users--such as the land managers, master planners, range managers, environmental planners, and trainers. (Refer to chapter §7 *Staffing and Training Requirements* [p.47], for a more detailed description of the GIS Coordinator's tasks.)

2.3. Information Gathering

GIS Coordinators should first educate themselves about what GISs can do, and then identify potential GIS applications on their installations. (Chapter §*4 GRASS Applications for Military Installations* [p.23] of this guide examines several types of applications commonly performed using GISs.) Next, the Coordinator should identify Army GIS and related policy and programs. Such programs affect acquisition, funding, and support for the GIS at the service and MACOM levels. Logistical support structures have been developed to address issues related to GIS development policy, and to promote the sharing of resources among agencies using GIS. For example, the Army-GIS Steering Committee addresses overall GIS policy and implementation issues for Army GIS users.

Uses of GIS by other sites, including (a) other Army installations, and (b) neighboring organizations, such as the local SCS office, Corps districts, nearby Forest Service units, County planning offices, state offices, etc., should then be identified. Finally, the GIS Coordinator should identify who, at the installation, is interested in GIS. This may include staff in range control, the environmental office, master planning, computer science, fisheries and wildlife, archaeology, etc. The Coordinator should solicit input from these individuals on what requirements a GIS should meet, and on what types of GIS applications each office might perform.

2.4. Education and Coordination

The GIS Coordinator should also educate potential users and their supervisors about GIS technology, and coordinate planning for the GIS. The Coordinator should form an Interim GIS Implementation Committee to guide the Coordinator in developing an

Implementation Plan for the installation, and to educate the committee members on the implementation process and its potential effects on how business is conducted. These plans should be coordinated with implementation of CAD, IFS-M and other related programs. The GIS Coordinator should ensure that GIS data can be exchanged with CAD, AM/FM and other users as needed to support installation requirements, and to ensure that issues involving data standards, and the sharing, updating, and ownership of data are addressed and coordinated among all users. The GIS Coordinator should also provide input to Army GIS Steering and/or Technical Advisory Groups, and participate in local and/or regional GIS user and data sharing groups.

2.5. Develop Site-Specific Implementation Plan

The GIS Coordinator's next task is to develop a GIS implementation plan which is specific to that site, based on the model implementation plan prepared by USACERL's Land Analysis Group.

The Coordinator should first determine who the actual GIS users will be and what hardware, data and software are required to meet these users' needs. Next, the Coordinator should customize the model implementation plan based on users' projected requirements. The GIS Coordinator should then examine the installation's life cycle costs and projected benefits associated with this plan. Cost/benefit ratios can be calculated to prioritize projects, and to assess the financial viability of different methods of implementation. A standard methodology for performing a cost/benefit analysis for GIS implementation is outlined in *Methodology for Performing Return-On-Investment (ROI) Studies for Implementation of GRASS on Military Installations.*[1] The staff's plan should be sent through the installation GIS Implementation Committee and Army GIS Steering Committee. The Coordinator should ensure that the plan is coordinated with other GIS and related activities, to minimize costs and maximize benefits.

2.6. Address Impacts

Staffing and training needs should then be addressed. GIS implementation involves several types of tasks, which can be grouped into a few "skill areas:"

- GIS Coordination
- GIS Analysis
- Data Management
- Cartography/Digitizing
- Systems Management
- Software Integration

[1] Ben Sliwinski (Research Associates, Urbana, IL), *Methodology for Performing Return-On-Investment (ROI) Studies for Implementation of GRASS on Military Installations*, Technical Manuscript N-89/25 (U.S. Army Construction Engineering Research Laboratory [USACERL], May 1989).

- 7 -

The skills required to perform these necessary tasks may be provided by several, or as few as two, persons on an installation. How many individuals perform the needed tasks on any given installation will depend upon how well the areas of expertise held by existing installation personnel mesh with GIS-related tasks, the ease with which new personnel can be acquired, what specific GIS analyses the installation plans to conduct, and other factors. Guidance on GIS staffing and training requirements can come from the Army GIS Steering Committee, and other installations and Districts that have already implemented GIS. These questions are addressed in further detail in chapter §7 *Staffing and Training Requirements* [p.47].

Once a plan has been made, funding to cover at least initial, fixed implementation costs should be secured. Funding strategies for acquisition of GRASS GIS hardware is discussed in chapter §6 *Evaluation Criteria for GRASS Workstation Selection* [p.41]. Once needed equipment and staff have been selected, needed space allocations and improvements, and other environmental requirements (e.g., electrical power, equipment temperature requirements) must be supplied. It is useful at this point to develop a timeline for performing tasks associated with implementation. A contractor may be used to estimate such requirements; acquire needed data; evaluate, select, procure and deliver hardware; install data and software on equipment; and provide initial and ongoing system and user training and software support to staff at the GRASS implementation site.

2.7. Secure Support for the Plan

Support for the implementation plan should be secured from the installation, and from MACOM and Army-level GIS Committees. Implementation support should include commitments of staff, funding, and needed support requirements. Databases, software, and hardware will also require ongoing maintenance and updates. Implementation support should include securing DA and MACOM level policy guidance, administrative support and funding programs for GIS.

- 9 -

Chapter 3

Guidelines in Constructing a GRASS GIS Database

After an installation has decided to establish a GRASS workstation, one crucial step in ensuring successful adaptation of the system is the development of a useful and relevant geographic database. This chapter will help district-level and installation personnel make informed decisions about the planning, building, and maintenance of such databases.

3.1. Introduction

This chapter outlines GRASS database development, which involves the planning, building, and maintenance of geographic datasets. Development can be broken down into four stages: (1) planning, (2) data collection and map preparation, (3) installation of map data into GRASS, and (4) augmenting and altering existing data. Primarily, this text discusses the first of these stages, planning. The problems and issues raised here are discussed in detail in the papers *Cartographic Issues in Database Development*[1] and *Map Preparation*,[2] available upon request from the GRASS Information Center at USACERL.

3.2. Initiating a Database

A database is a collection of map layers on various themes for the same geographic location. Several issues must be resolved when initiating development of a database.

It is first necessary to decide which layers are needed in the database, and then to decide what spatial resolution is necessary to make the data useful. A determination is then made as to which of the desired map layers are available in digital or nondigital formats, at the desired level of detail. If the information is currently unavailable (or requires modification), the possibility of creating (or modifying) the desired map layer is investigated. Finally, for each map layer, the number of category types to be depicted (what level of detail will be represented) is decided upon. All of these decisions will depend on the applications for which a map layer is to be used.

3.3. Map Layers

Preparation and input to the GIS of a single map layer can be quite costly. The needs of an installation should be assessed carefully before development of a database is begun. Specifically, those map layers necessary for future GRASS applications should be listed and prioritized before data is acquired. Chapter §4 *GRASS Applications for*

[1] Marilyn Ruiz, *Cartographic Issues in Database Development*, Technical Manuscript N-89/24 (USACERL, September 1988).

[2] Jean Messersmith, *Map Preparation*, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 (USACERL, September 1988).

- 10 -

Military Installations [p.23] describes some GRASS applications and their utility.

Some map layers, like those of the installation boundary, training areas, hydrography, and soils, are fairly standard. Often, several additional map layers can be derived from one or more original layer(s). For example, in GRASS, slope and aspect layers can both be (automatically) derived from an elevation map; similarly, map layers of soil pH and soil erodibility can be (manually) reclassed from a soils type map layer. A listing of standard map layers is shown in Table 3.1. The actual selection of map layer topics should be installation-specific. Even with a good set of basic map data, most new applications will also require development of one or more new, special layer(s) (which may be based on recent field work or other data). However, planning can decrease unnecessary data development costs.

Standard Map Layers for Military Databases	
Agricultural Outleases	Mapping of agricultural outlease areas and management information
Air Quality	Air Quality Control Region (AQCR) ratings
Crop Production Value	Crop production value for agricultural and grazing outleases
Cross-Country Maneuverability	Suitability of land for conducting military maneuvers
Cultural Resource Sites	Locations of archaeological, historical sites
Cultural Resource Surveys	Location of areas surveyed for archaeological, historical sites
Depth to Bedrock	Depth to bedrock
Easements	Location of easement types
Elevation	Mapping of elevation levels (from which slope and aspect can be derived)
Fire Damage	Index of vegetation damage from fire
Forest Management Units	Mapping of timber types and production for outlease value, etc.
Geology	Map showing geology types
Habitat Value/Type	Habitat types and their values for various species
Housing Stock Data	Mapping of data describing age and condition of housing stock
Hydrography	Depiction of streams, waterways, etc.
Installation Boundaries	Delineation of installation boundaries
Master Planning Indexes	Mapping of areas covered by photo indexes and 1:400 maps
Noise Contours	Mapping of noise contours for installation and surrounding areas
Ownership	Land ownership parcels
Political Boundaries	Mapping of area political jurisdictions
Quadrangles (USGS and DMA)	Outlining of standard USGS 1:24,000, or DMA 1:50,000, map quadrangles
Recreational Sites	Mapping of golf courses, fishing areas, etc.
Restricted Areas	Delineation of areas with restricted access on installation
Service Boundaries	Delineation of boundaries for local water, electrical, sewage services, etc.
Socioeconomic Data	Mapping of such data as population density, sex ratios, birth rates, income, crime rates, etc.
Soils Types	Mapping of soils types across an installation
Soil Erosion Factors	Mapping of areas by soil erosion factors
Township/Range Grid	Delineation of township and range grid boundaries
Training Areas	Mapping of installation training area boundaries
Transportation	Mapping of transportation types and locations
Utilities	Location of local utility lines, branches, and stations
Vegetation	Mapping of vegetation/landcover types and qualities
Weather Data	Mapping of weather data (e.g., rainfall, wind direction and speed, etc.)
Wetlands	Mapping of wetland locations and types across installation
Wildlife Inventories	Inventory and locations of important wildlife sitings
Wildlife Management Units	Delineation of wildlife management units

Table 3.1: Standard Map Layers for Military Databases

- 11 -

3.4. Map Scale and Map Layer Resolution

In addition to choosing map layer topics, the installation must consider the selection of the appropriate scale for the map from which information will be taken when the map layer is input to the GRASS database. This is closely tied to the question of map resolution. In GRASS, raster map layer data are stored in a grid, made up of tiny rectangles (cells).[3] Each cell in the grid represents an area on the Earth. The size of these cells, and correspondingly, the actual area on the Earth which they represent, is determined by the *resolution*[4] chosen for a map layer. A map which has north-south and east-west cell resolutions of 50 meters, for example, is a map layer in which each cell contains a value which represents a 50 X 50 meter square on the Earth. Since a larger scale map contains more information for a given place on the Earth than does a smaller scale map, it is appropriate to choose a corresponding cell size which represents a smaller piece of the Earth (in greater detail) for a larger scale map, and vice versa.

Figures 3.1(a) and 3.1(b) illustrate the storage of data at two different resolutions, for the same geographic area. In Figure 3.1(a), each rectangular cell represents a 20-meter X 20-meter area on the Earth. In Figure 3.1(b), each cell represents a 100-meter X 100-meter area on the Earth. Because, for a given map layer, each rectangular cell can contain only one data value (i.e., only one cell "category"), more cells means more data (and hence more detail) over the same dataset. Figure 3.1(a) contains 25 times the number of cells (and therefore 25 times the number of cell category data values) as appear in Figure 3.1(b). Figure 3.1(a) therefore contains 25 times more detail than Figure 3.1(b).

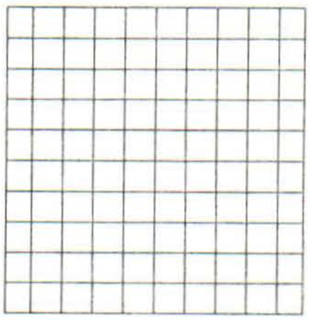

Figure 3.1(a): 20-meter cell resolution (100 cells within a 40,000 square meter area)

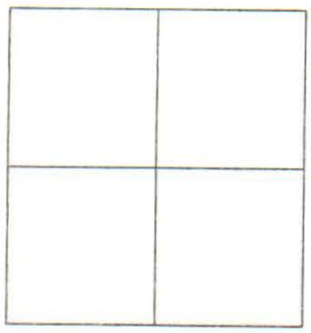

Figure 3.1(b): 100-meter cell resolution (4 cells within a 40,000 square meter area)

[3] Although maps are input to GRASS in *vector* (arc-node) format, most are then internally converted to *raster* (grid cell) format for storage and analysis. Map layers (in raster format) are commonly referred to as *cell files* or *grid cell files*. See chapter §5 *An Introduction to GRASS GIS Software* [p. 33] for a discussion of raster and vector data formats.

[4] Resolution is expressed in a counterintuitive way. *High resolution* denotes greater detail, but is expressed by small numbers. Conversely, *low resolution* denotes low levels of detail, but is expressed by high numbers. For example, 10-meter resolution data is of higher resolution (and will show more detail) than 100-meter resolution data (which will show less detail). Ten-meter resolution data is capable of showing 100 times as much detail as is shown by 100-meter resolution data.

- 12 -

3.5. Variables in Choosing Layers, Scale, and Resolution

The decision that installation personnel must make is thus twofold. First, they must choose **map layer topics**. Second, they must select a **map scale** and a **cell resolution** appropriate for that map layer. Some of the variables to consider when making these decisions are examined below.

Three important issues arise when choosing the resolution of a cell map. One involves the technical *capabilities of the computer* on which GRASS will be run. GRASS cell files can be quite large, and the higher the cell resolution, the larger the cell file will be. This means that the physical size of the dataset, and the distribution of data across the dataset, will also affect the choice of cell resolution. A dataset requiring the limits of the machine's capabilities may be very cumbersome, and tediously slow to work with.

Resolution will also depend on the *use to which the data will be put*. If the user is interested in examining only gross landcover changes over time across a large dataset, for example, low cell resolution may be desirable. If, however, the user intends to manage very small, sensitive islands of habitat, and to chart correlations in species change with minor alterations of variables, it may be necessary to map data at a relatively high resolution. When data will be used in a number of applications requiring different resolutions, data should be obtained at the highest needed resolution, and resampled to any necessary lower (more gross) resolutions. Another alternative is to store data at a low resolution for a large area (e.g., the entire installation), but to develop and store "windows" of high resolution data (e.g., endangered species' habitat areas) for specific regions.

A third issue centers on the question of the *source of digital geographic data*. The relevance of this issue can be examined using the example of satellite imagery. With imagery data, the resolution of the cell map should be the same as the spatial resolution of the original data. This resolution is what is possible given the satellites' technical capabilities; outside of resampling to limit the size of the final cell map, little would be gained by choosing something other than the original resolution when making the GIS cell map. Note that in this case data are recorded directly from the Earth. Although there is virtually no limitation to the detail that is present in features on the Earth, each satellite sensor is limited to a set resolution (e.g., 10 and 20 meters for SPOT, 30 meters for LANDSAT and TM). The GIS user must accept the limit imposed by the original imagery pixel size, or use alternative data sources (e.g., low altitude aircraft images).

This can be contrasted with creation of a cell map from a digital version of an existing paper map. The first tendency might be to use a very high resolution in order to have as much "detail" as possible. There is theoretically no limitation in the resolution choice, since GRASS can create grid cells of virtually any size.

But at this point, the level of detail represented by the original map must be considered. A map is only a **model** of the Earth. Since a map's scale is related to its level of detail, maps which are at a relatively large scale may be safely represented by relatively high resolution cell maps; maps drawn at relatively small scales are safely represented by relatively low resolution cell maps.

- 13 -

The question of cell resolution in this case might be managed by using Table 3.2. The suggested resolutions below are based on the assumption that a paper map may be safely "resolved" to a level of between .75 mm and 1.5 mm on the map, for maps of moderate scale. That is, as measured on the original paper map, an area of about one square millimeter would be included as a single cell in a cell map. These ranges of resolution are not a requirement. They have been determined, for the most part, through experience. In addition, some studies have shown that standard American map production techniques can be expected to result in maps that are accurate to about one millimeter.

The values in Table 3.2 were arrived at in the following way. Given a map with a scale of 1:24,000, a distance of .75 mm (the lower lever given above) on the map would represent 18 meters on the Earth (.75 X 24,000 = 18,000 mm). The value of 18 meters is rounded up to 20 for the table below. The cell resolution might thus be set at 20 meters.

Note that the resultant resolutions (in meters) will vary depending on the map scale. This is unlike the suggested level of .75 mm to 1.5 mm, which is constant for all maps.

Map Scale	Resolution Range
1:15,840	10-25 meters
1:20,000	15-30 meters
1:24,000	20-35 meters
1:31,680	25-50 meters
1:50,000	40-75 meters
1:63,360	50-95 meters
1:75,000	55-110 meters
1:100,000	75-150 meters

Table 3.2: Suggested Range of Resolutions for Common Map Scales

The availability of the original data is another variable to consider. Whenever possible, data should be obtained in digital format. Paper maps come from many sources, although only a few agencies provide standardized maps of large areas. The Soil Conservation Service (SCS) and the United States Geological Survey (USGS) are two sources of large scale maps of good quality. Sources of digital and nondigital data commonly used in GISs are listed in Tables 3.3 and 3.4. The cost of gathering original data and producing a map is so great that, in most cases, the installation is advised to use available maps. Two exceptions arise where: (1) a standard map in a series has not yet been produced for all or part of an installation, or, (2) an installation already has access to some data of special interest. In the first case, arrangements can often be made to share map production costs with the agency responsible for the series. In the second, the installation may have been systematically collecting data on some topic and this data might become a useful map layer in the GIS.

 - 14 -

Data Sources for Cartographic Information													
Map Type	Data Source												
	DMA	EOSAT	EPA	NCDC	NGDC	NGIC	NODC	NTIS	ORNL	SCS	SPOT	USBC	USGS
Agricultural Outleases	X	X	X	X	X				X	X	X		X
Air Quality				X									
Crop Production	X	X	X	X	X					X	X		X
Cross-Country Maneuverability	X	X	X	X	X					X	X		X
Cultural Rsrc Surveys, Sites	X	X	X		X					X	X		X
Depth to Bedrock				X									
Easements	X												
Elevation													
Energy Usage			X										
Fire Damage	X	X	X	X	X					X	X		X
Forestry Mgmt	X	X	X		X					X	X		X
Geology					X								
Habitat Value/Type	X	X	X		X		X			X	X		X
Housing Data									X			X	
Hydrography	X	X	X	X	X		X	X			X		X
Installation Boundaries	X											X	
Master Plan Indexes													
Noise Contours				X									
Ownership												X	X
Political Boundaries												X	
Quadrangles													X
Recreation Sites	X	X	X		X						X		X
Restricted Areas	X												
Service Boundaries													
Socioeconomic Data									X			X	
Soils Types										X			X
Soil Erosion Factors										X			
Twp/Range Grid									X			X	X
Training Areas	X												
Transportation	X	X	X						X		X	X	X
Utilities													
Vegetation	X	X	X		X					X	X		X
Weather Data				X									
Wetlands	X	X	X		X		X			X	X		X
Wildlife Inventories	X	X	X	X	X		X			X	X		X
Wildlife Mgmt	X	X	X	X	X		X			X	X		X

Table 3.3: Data Sources for Cartographic Information

 - 15 -

Sources of Digital Spatial Data for GISs						
Data Type	Data Source	Data Format	Scale/ Resolution	Data Coverage	Media	Acquisition Costs
Elevation	DMA	Raster	1:250,000	Entire U.S. & much else	9-track tape (1600 bpi)	$75/1 deg x 1 deg block + $25 fee
Multispectral: Satellite	EOSAT	MSS (BIL & BSQ) TM (BIL & BSQ) RBV (SSQ)	MSS: 80 m TM: 30 m SSQ: 80 m	Worldwide	9-track tape (1600/6250)	MSS: $660 TM full scene: $3300 RBV 4 subscenes: $1320
Multispectral: Airborne	EPA	MSS (BIL)	Customer-variable	Customer-variable	Custom flights	5-m: $75.84/sq.mi. avg. 10-m: $14.15/sq.mi. avg.
Weather Statistics & Imagery	Natl Climatic Data Center	Digital: Tabular Satellite: Raster	Varies	Mostly U.S., Some Global/Regl	9-track tape (1600/6250)	$99 minimum/order for tape data
Terrestrial & Marine Geophysl Data	National Geophysical Data Center	Varies	Varies	Mostly wldwide, Some U.S. coastal waters data	9-track tape, computer p/o, or plots	Varies
Geodetic Control Information	National Geodetic Info. Center	Tabular	n/a	Entire U.S.	Computer p/o, Tape, or Direct access	$avg. 150-$200/state on 9-track tape (computer print-outs less)
Marine: Physical, Biological, & Chemical Data	National Oceano-graphic Data Center	Mostly Tabular (See NODC Index)	n/a	Mostly Regional, & Much Global Data	1)9-track tape 2)Computer p/o 3)Computer plots	1)$85-$100 minimum 2)$.05/sheet + comp fee 3)$20/hr + $30/roll (or $1/plot) + $3-$10 fee
Small-Scale World Boundaries, Major Rivers	National Technical Information Service	Vector	1:12,000,000 1:3,000,000 and larger	Worldwide	9-track 1600 bpi odd parity EBCIDIC tape	Free from CIA to Federal Agencies, ETIS charges others
County-Level Data	Oak Ridge National Lab	Tabular-- SAS Format	County-Level	Coterminous U.S.	9-track tape in SAS format, or EBCIDIC tape files	Unknown
Soils	Soil Conservation Service	Raster encoded as ascii	Vector:1:24,000 Raster:4-ha cells	Scattered U.S.	9-track tape (800 bpi)	Varies
Multispectral: Satellite	SPOT Image Corp.	Raster	10-m panchro. 20-m multisp.	Worldwide	9-track tape 1600/6250 bpi	Unref: $1475-$1600 Georef: $2425-$2550
Water Quality (STORET)	EPA	Tabular	n/a	~ 200,000 collection points across U.S.	Direct terminal access, Reports, or Magnetic tape	Free one-time use, or Avg Use Cost: $3-$6
Political/Census Boundaries, Streets, Names	U.S. Bureau of the Census	1)GBF/DIME: Vector-lat/lon, & State Plane-refd 2)TIGER: Vector-UTM refd	Mostly 1:24,000	278 SMSAs	1)1600/6250 bpi tapes 2)6250 bpi, & CD packs proposed	1)Varies 2)Not yet set
Topological: Land Use/ Land Cover, Watersheds	USGS	Vector: (in GIRAS format) Raster: (in binary & charac. format)	Vector: 1:100,000, 1:250,000 Raster: 200 m	See NCIC Index	9-track tapes, & Paper maps	Landcover: $100 CTs: $50, CTG: $250 Pol.Bndry,Hydro Units, & Federal Lands: $35
Topological: Boundaries & Transportation	USGS	Vector files in DLG format	1) 1:24,000, 2) 1:100,000, 3) 1:2,000,000	1&2) Partial U.S. (see NCIC Index) 3) Entire U.S.	9-track tapes, Paper maps	1&2): $20-$50/section 3): $100/section + $25/tape fee
Elevation	USGS	Raster	1:24,000	Scattered U.S.	9-track tape, Paper maps	$100/quad + $25/tape fee
Names of: Areas & Maps	USGS	Tabular	n/a	Entire U.S.	9-track tape, 1600 bpi	$50/state

Table 3.4: Sources of Digital Spatial Data for GISs

Potential applications of the data is also a necessary consideration. How will installation personnel make use of the system once it is operating? Although the ideal system might contain all possible information at as large a scale (and as high a resolution) as possible in order to be later used for any desired application, it is better, in a practical sense, to start with only those overlays necessary to complete one or two applications. Other layers can be added as the installation moves ahead in its use of the system. When considering possible applications of the GIS, the installation might usefully assess current practices to examine how these might be done more efficiently using a geographic information system. The kind of training done, the local vegetation and climate, and any special problems at the installation make the needs of each installation unique. Consultation with GRASS GIS support personnel will be helpful in assessing these needs. Refer to chapter *§4 GRASS Applications for Military Installations* [p.23] for a more thorough discussion of potential GRASS applications.

The level of detail to include on the map is another element to consider. If locations of vegetation are sought, but the nature of the vegetation is immaterial to the application, a map layer might be developed which classified all data into one of two categories - *vegetation*, and *nonvegetation*. If, however, the application will be used to evaluate which areas on the installation can be outleased for timber cutting, a map layer distinguishing different vegetation types would be developed.

The *size of the installation* can also have a bearing on the choice of map scale. *Hardware limitations* may not allow easy storage and display of very detailed data for a very large area. Table 3.5 lists file sizes for 1:24,000 USGS quad sheets, for various resolutions. Perhaps only one or two areas of special interest require data at the larger scale.

Approximate Cell File Sizes for One 1/24,000 USGS Quadrangle						
Resolution (meters)	Rows	Columns	(rows) * (cols) * (1 bpc)	(rows) * (cols) * (2 bpc)	(rows) * (cols) * (3 bpc)	(rows) * (cols) * (4 bpc)
10 m	1386	1164	1613304	3226608	4839912	6453216
20 m	693	582	403326	806652	1209978	1613304
30 m	462	388	179256	358512	537768	717024
40 m	346	291	100832	201663	302494	403326
50 m	277	233	64532	129064	193596	258129
60 m	231	194	44814	89628	134442	179256
70 m	198	166	32925	65849	98774	131698
80 m	173	146	25208	50416	75624	100832
90 m	154	129	19917	39835	59752	79669
100 m	139	116	16133	32266	48399	64532

Table 3.5: Approximate Cell File Sizes for One 1:24,000 USGS Quadrangle

Staff time and *cost* are other factors that influence construction of a database. Table 3.6 shows estimated labor requirements associated with the development of common map layers. It states approximate hours of labor required (for one 1:24,000 USGS quadrangle): to prepare, draft, and label a map previous to digitizing or scanning it ; to

- 17 -

Hours of Labor Required for One 1:24,000 USGS Quadrangle										
			Draft/Label**			Digit/Label				
Map Type	Feature	Start-Up*	Low	Med	High	Low	Med	High	Support*	Total
Agricultural Outleases	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Air Quality	Area	3	2	6	15	2	6	15	3	
	Line	3	2	6	15	2	6	15	3	
	Point	3				1	3	5	3	
Crop Production Values	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Cross-Country Maneuverability	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Cultural Rsrc Sites	Area	3	2	6	15	2	6	15	3	
	Line									
	Point	3				1	3	5	3	
Cultural Rsrc Surveys	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Depth to Bedrock	Area	3							3	
	Line									
	Point									
Easements	Area	3	2	6	15	2	6	15	3	
	Line	3	2	6	15	2	6	15	3	
	Point									
Energy Usage	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Fire Damage	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Forestry Management	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Geology	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Habitat Value/Type	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Housing Stock Basemaps	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Housing Stock Reclasses	Area	3							3	
	Line									
	Point									

Table 3.6: Hours of Labor Required for One 1:24,000 USGS Quadrangle (digitized in stream mode)

- 18 -

Hours of Labor Required for One 1:24,000 USGS Quadrangle										
			Draft/Label**			Digit/Label				
Map Type	Feature	Start-Up*	Low	Med	High	Low	Med	High	Support*	Total
Hydrography	Area	3	2	6	15	2	6	15	3	
	Line	3	2	6	15	2	6	15	3	
	Point	3				1	3	5	3	
Installation Boundaries	Area	3	1			1			3	
	Line									
	Point									
Master Planning Indexes	Area	3	2	6		2	6		3	
	Line									
	Point									
Noise Contours	Area	3	2	6	15	2	6	15	3	
	Line	3	2	6	15	2	6	15	3	
	Point									
Ownership	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Pesticide Application Values	Area	3	2	6	15	2	6	15	3	
	Line									
	Point	3				1	3	5	3	
Political Boundaries	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Quadrangles	Area	3				1			3	
	Line									
	Point									
Recreation Areas	Area	3	2	6	15	2	6	15	3	
	Line	3	2	6	15	2	6	15	3	
	Point									
Restricted Areas	Area	3	2	6		2	6		3	
	Line									
	Point									
Service Boundaries	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Socioeconomic Variable Basemap	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Socioeconomic Variable Reclasses	Area	3							3	
	Line									
	Point									
Soils Types**	Area	3	6	10	20	2	6	15	3	
	Line									
	Point									
Soil Erosion Factors	Area	3							3	
	Line									
	Point									

Table 3.6: Hours of Labor Required for One 1:24,000 USGS Quadrangle (digitized in stream mode)

 - 19 -

Hours of Labor Required for One 1:24,000 USGS Quadrangle										
			Draft/Label**			Digit/Label				
Map Type	Feature	Start-Up*	Low	Med	High	Low	Med	High	Support*	Total
Township/ Range Grid	Area	3		3			4		3	
	Line									
	Point									
Training Areas	Area	3	2	6		2	6		3	
	Line									
	Point									
Transportation	Area									
	Line	3	2	6	15	2	6	15	3	
	Point									
Utilities	Area									
	Line	3	2	6	15	2	6	15	3	
	Point									
Vegetation	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Weather Contours (polygons)	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Weather Reclasses	Area	3							3	
	Line									
	Point									
Wetlands	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									
Wildlife Inventories	Area									
	Line									
	Point	3				1	3	5	3	
Wildlife Mgmt Units	Area	3	2	6	15	2	6	15	3	
	Line									
	Point									

Table 3.6: Hours of Labor Required for One 1:24,000 USGS Quadrangle (digitized in stream mode)

* In general, the hours alloted above for maplayer Start-Up and Support activities will often be sufficient to cover all quadrangles in the database. For example, although an individual might spend 3 hours on start-up and 3 hours running map support for one 1:24,000 quad depicting geology, that individual would spend only a total of 3 hours for start-up and 3 hours running map support when doing five 1:24,000 quads depicting geology.

** Hours alloted for drafting and labeling soils maps reflect time used to align soil survey map sheets and to georeference photographs.

- 20 -

digitize, and attach data category labels; and to run GRASS support programs to convert data into GRASS grid cell (raster) format. Labor requirements will vary with the *level of detail* or density of the data, and with *map feature type*.

GRASS recognizes three types of map features: areas (also termed polygons), linear features (also termed lines), and points (a.k.a. sites).[5] Typically, maps containing areas or linear features will be much more detailed (and thus more time consuming to digitize) than those containing only point data. Because it is unnecessary to redraft points, drafting time has been omitted from labor requirements for map layers of site features. Most frequently, a given map type will relate to only a single type of map feature (areal, linear, or point). However, some maps might logically be digitized as a series of polygons, or as a series of linear features, or sometimes as a series of points. For example, although locations of archaeological sites (shown in Table 3.6 under Map Type "Cultural Resource Sites") might be digitized as sites/points, they might also be digitized as areas.

Variations in hours required to draft and label, and to digitize and attach category labels, are given for maps with "low," "medium," and "high" densities of data in Table 3.6. For example, it is estimated that a *highly dense* geology map would require 36 hours of labor: (1) 3 hours for map preparation, (2) 15 hours to be redrafted and labeled (onto mylar), (3) 15 hours for digitizing area edges, and for attachment of GRASS category labels, and (4) 3 hours for running GRASS support routines (converting vector data resulting from digitizing or scanning into a labeled GRASS grid cell map layer). Maps illustrating the general levels of detail associated with "low," "medium," and "high" densities of data are shown in Figures 3.2 and 3.3 (pp 13 and 14).

When estimating labor requirements for data development, only necessary tasks should be included (e.g., if it is unnecessary to redraft a map prior to digitizing or scanning, do not include hours for drafting and labeling). Similarly, if a given map type lists labor requirements for more than one map feature type, but only one layer showing one of these feature types is needed, only hours necessary to prepare the map layer with the relevant feature type should be included (e.g., if a map of cultural resource sites as *point features* is required, but one of cultural resource sites as *area features* is not, only the time necessary to prepare, digitize, label, and run support programs listed in the "Point" row should be included).

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[5] Refer to the *GRASS 3.0 Programmer's Manual* and to the paper *GRASS 3.0 Mapdev Vector Format* for an explanation of these terms. The latter document is available upon request from the GRASS Information Center at the address shown in *§8.7 Points of Contact for GRASS Information and Support* [p. 61]. Michael Shapiro, James Westervelt, Dave Gerdes, Michael Higgins, and Marjorie Larson, *GRASS 3.0 Programmer's Manual*, ADP Report N-89/14 (USACERL, September 1989). Michael Higgins and David Gerdes, *GRASS 3.0 Vector Format*, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al, ADP Report N-87/22 (USACERL, September 1988).

 - 21 -

3.6. Conclusion

Planning for data needs is a crucial part of the GIS implementation process. Initial decisions made about the types of data to order, the formats, resolution, and scales these data will assume for use and later storage, and what map layers are to be created, will determine the types of applications users can perform with GRASS. These decisions will ultimately determine how useful the system is, and how cost effective it will prove.

USACERL personnel working with the GRASS GIS have experience in weighing these variables and are available for extensive consultation as these decisions are made.

- 22 -

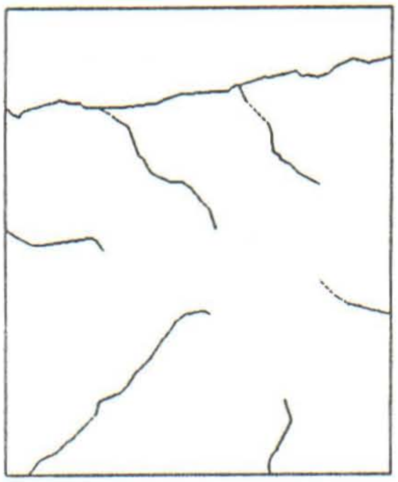

Figure 3.2(a): An example of low density linear features

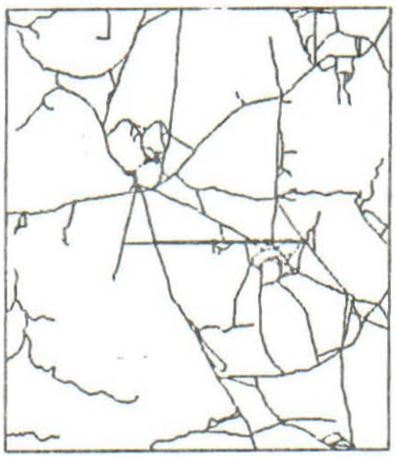

Figure 3.2(b): An example of medium density linear features

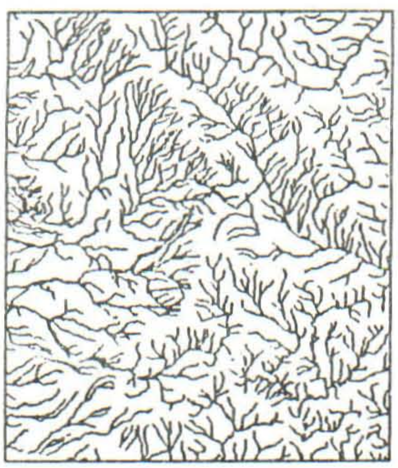

Figure 3.2(c): An example of high density linear features

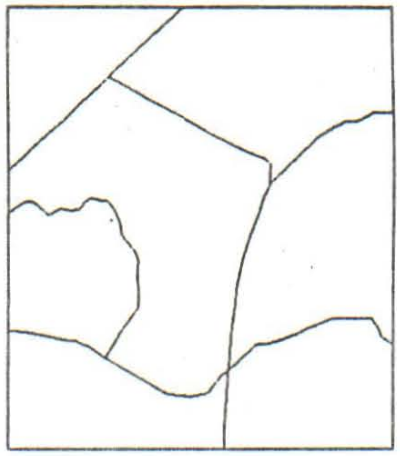

Figure 3.3(a): An example of low density areal features

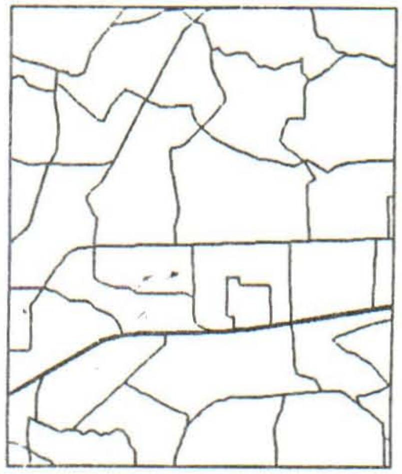

Figure 3.3(b): An example of medium density areal features

Figure 3.3(c): An example of high density areal features

Figures 3.2 - 3.3 illustrate various levels of map detail (low, medium, and high line densities) for an area roughly equal to the size of one 1:24,000 USGS quad

Chapter 4

GRASS Applications for Military Installations

Although GIS applications can only be performed after the system has been set up and all necessary data have been input, the choice of data, staff, and of the system itself must be based on intended uses. The previous chapter discussed considerations relevant to the construction of a GIS database. This chapter discusses the applications to which such data can be put.

4.1. Data and Applications for the GIS

Data arguably represent the single largest investment in a GIS. It is therefore important that the relevance of these data to GIS applications be considered before data are obtained. GRASS was originally designed for environmental planners at military installations. It is now used by both military and other users to assess environmental impacts, evaluate site suitability, detect change, manage resources, and model the effects of environmental changes across a landscape. The range of possible applications is virtually unlimited.

GRASS/GIS applications can be divided into two broad classes:

1) Those which attempt to locate sites(s) meeting specified (user-defined) characteristics,

2) Those which attempt to characterize the nature of certain known (user-defined) sites or phenomena.

The first category includes such applications as facility siting, site allocation, routing analyses, and site prediction. The second category encompasses such applications as site evaluation and change detection.

Applications can also be classified by the element likely to conduct the analysis. On a military installation, the following elements might commonly perform GRASS applications:

- Environmental Office
- Master Planning Office
- Natural Resources/Land Management Office
- Range Management group
- Training Management group

One responsibility of the GIS Coordinator is to list potential uses at the site for the GIS, and to involve others on the installation who might make use of the GIS in the implementation process.

Table 4.1 contains a brief list of some possible GIS applications. These are classified by the installation element likely to perform the analysis, and described briefly in §*4.4 Application Compendium* [p.26]. Many other applications are, of course, possible. Users at each site must determine which applications are relevant.

- 24 -

GRASS can be used to display, manipulate, analyze, and predictively model data which can be spatially represented. Broadly, this has involved the areas of facility siting, locational prediction of phenomena (archaeological sites, crimes done according to pattern, etc.), and the monitoring of change over time and space (as in the monitoring of erosion, live deer weight, and timber production over time across an installation). GRASS searches a data base for the presence of user-specified variables (or combinations of variables), and displays and manipulates the data as requested. Below is a very brief list of *some* of the possible analyses to which GRASS might be applied on an installation.

Energy Office:
Monitoring energy use

Environmental Office:
Cultural resources management
Cultural site prediction
Environmental impact assessment
Facility siting
Groundwater data management
Habitat assessment
Hazardous waste site management
Land condition/trend analysis
Landfill site selection
Noise impact analysis
Permit management
Pesticide program management
Rehabilitation prioritization
Smokes dispersion modeling

Master Planning:
Boundary mapping
Cultural resource management
Facility mapping
Facility siting
Flooding analyses
Land use analyses
Master planning
Resource assessment
Transportation corridor analyses
Visual impact assessment
Zonal maps

Range Management:
Change detection
Range placement
Training area maintenance
Training area scheduling
Training impact assessment

Natural Resources/Land Management:
Allocation of Field Transects
Change detection
Cross-country movement (monitoring)
Endangered species management
Erosion (monitoring and modeling)
Facility siting
Flooding analysis
Forestry (timber management)
Fire damage (monitoring)
Grazing impact assessment
Habitat assessment
Hunting permit management
Integrated Training Area Management (ITAM)
Land condition/trend analysis
Land management plans
Landfill site selection
Maintenance scheduling
Management of outleases
Park trail usage
Pesticide program management
Scheduling the harvesting of resources
Smokes dispersion
Watershed analysis and modeling
Wetlands management
Wildlife sitings (wildlife management)
Wildlife habitat mapping (modeling and analysis)

Trainers:
Change detection
Training area scheduling
Training land design
Training simulation
Training site selection

Table 4.1: Common Applications

4.2. Data Layers

What data must be generated to support the desired applications? Since the data layers in the system are often difficult and expensive to translate from paper (or digital) form into the format used by GRASS, this is an important consideration. There are several ways of determining a configuration of complementary data layers. Often this has been based on professional judgment and previous experience with data versatility. For example, elevation data is regularly used to create three separate map layers, showing elevation, aspect, and slope. Each of these layers has unique uses. Similarly, a map layer of area soil types is frequently reclassed into several map layers showing soil pH, soil permeability, K values, etc. These types of considerations are important in setting priorities for data layer development. Refer to §3 *Guidelines in Constructing a GRASS GIS Database* [p.9] for a more detailed examination of standard database data layers and data sources.

4.3. Application Types

How should the GIS Coordinator decide what applications to perform with the GIS, the order in which they should be conducted, and when they should be scheduled? Table 3.1 (p 10) contains a partial listing of map layers used in support of common applications. An analysis can be performed to indicate the relative costs and benefits associated with the performance of applications (see *Methodology for Performing Return-On-Investment (ROI) Studies for Implementation of GRASS on Military Installations*[1] based in part on the estimated labor costs associated with the map layers used in their production (see Table 3.6 [pp 17-19]). Some common applications are described in further detail below, in §4.4 *Application Compendium* [p.26].

Data Management. By modifying existing datasets, GRASS can be used for ongoing management of spatial and tabular data. Spatial data updates might include: the addition of a newly registered historical district to an existing map of such areas, revision of the installation boundary line, deletion of a recently closed trail from the "roads" data layer, or the addition of a new hospital to the "building" sites file. GRASS can also be used in conjunction with a data base management system to cross reference spatial and tabular data for such applications as forestry management, issuance of hunting permits, archaeological sites, pest control, permit compliance tracking, and wildlife management.

Site Allocation, Facilities Siting, and Route Selection. GRASS can be used to locate sites meeting or maximizing user-specified requirements, for such uses as landfills or new training areas. GRASS can also be used to allocate sites within an area, using a specified sample design (e.g., stratified random sampling). Map layers necessary depend on the criteria pertinent to a particular analysis. Similarly, GRASS can be used to site a corridor meeting user requirements through a least-cost path analysis. This is useful for such applications as pipeline placement, transportation route

[1] Ben Sliwinski (Research Associates, Urbana, IL), *Methodology for Performing Return-On-Investment (ROI) Studies for Implementation of GRASS on Military Installations*, Technical Manuscript N-89/25 (USACERL, May 1989).

- 26 -

selection, planning of cross-country movements, etc.

Site Prediction. Site prediction involves the statistical manipulation of data to correlate the presence of certain factors with the occurrence of specified objects (e.g., the correlation of certain proximities to streams, slopes, and vegetation types, with the location of archaeological sites).

Site Evaluation, and Land Management. Site evaluation involves evaluation of the suitability of a site for some user-defined purpose (including land management). Data layers necessary to any given site evaluation will depend on criteria relevant to the analysis.

Change Detection. GRASS can be used for applications involving detection of changes over time and/or space. For example, satellite imagery can be used to assess changes in landcover over time. Once damage is evaluated, contributing factors can be sought; a predictive model can then be generated to estimate future damage.

4.4. Application Compendium

It is also useful to categorize analyses by the elements likely to perform them. To plan for user demand for GRASS, the GIS Coordinator should contact various groups at the implementation site to learn of the analyses that might be conducted. On a military installation, the following elements might commonly perform GRASS applications:

- Environmental Office
- Master Planning Office
- Natural Resources/Land Management Office
- Range Management group
- Training Management group

Below, some common analyses are listed beneath the installation elements likely to request them.

4.4.1. Environmental Office

Cultural Resource Management: The status of archaeological/historical site surveys, usage restrictions associated with each site/area, condition of site, and site importance can be managed using GRASS.

Cultural Site Prediction: GRASS can be used to search for correlations of environmental attributes (e.g., proximity to surface waters, slope, etc.) indicative of the presence of archaeological or historical sites. Such information can be used to develop installation surveys, issue digging permits, and plan construction sites.

Environmental Impact Assessment: GRASS can be used to model the environmental impacts associated with various actions.

Groundwater Modeling (e.g., water table height, water quality, hazardous material plume dispersal, contamination source): Drill log data can be input to a

GRASS *sites* file, converted to raster format, and run through GRASS surface modeling routines. The surface generated by these routines theoretically might be used to model plume dispersal in GRASS.

Hazardous Waste Sites: Locations of hazardous waste sites can be displayed in relation to access routes, population centers, and sensitive environmental attributes, and used in the development of installation emergency management plans.

Landfill Site Selection: GRASS can be used to locate sites suitable for landfill development, using such criteria as soil type, pH and permeability, slope, depth to groundwater, and other factors.

Noise Dynamics: Modeling of the dynamics of sound movement from blast sources can be performed when the sound properties of the blast source are known. The *Bnoise* program (accessible through GRASS) can be used to to generate Installation Compatible Use Zones (ICUZ). ICUZ can be overlaid with a map layer indicating densities of on- and off-post populations, to determine how noise levels associated with current or proposed activities may impact local populations.

Permit Compliance Tracking: For each permit issued to an installation, data can be stored on its current status, renewal date, lead time needed for renewal, and regulating agency point of contact.

Pesticide Program Management: A comparison of pest infestations over time can indicate the direction and location of spread, potential problem sources, and the relative effectiveness of different treatments. Where pests attack crops, this can also be used to predict crop losses. Information can be stored in a database to record dates infestations were identified, types and quantities of chemicals used to combat pests, and other relevant information.

Recharge Zones: Field survey and/or soils and other data can be used to define primary, secondary, etc., groundwater recharge zones. This data can be used to search for correlations of land use with groundwater quality and to identify areas sensitive to development.

Recreation Site Selection: GRASS can be used to site recreation areas by finding locations within the dataset having desired slopes, vegetation types, access to transportation routes, proximity to population centers, etc.

Rehabilitation Priorities: GRASS can be used to evaluate data on land damage, their correlation with different activities and the success of various rehabilitation strategies, and to determine land rehabilitation priorities.

Sensitive Species Avoidance: Using known and predicted locations of sensitive species and their habitats, a map can be made indicating such areas and buffer zones around them, to regulate their use.

Smokes/Air Pollution Modeling: GRASS can be used to locate sites likely to be impacted by smokes or air pollution. Buffer zones can be drawn around point sources, and examined in relation to terrain, and to population densities, sensitive species and habitats.

Stream-Crossing Site Sensitivity: Map layers of soils, slopes, streams, vegetation and others, can be combined to define sensitive (because highly-erodible, or containing useful habitat) areas at which stream crossings should be limited.

Training Capability: GRASS can be used to determine correlations between land characteristics, land use, weather, and other factors, with the capability of such lands to withstand stress. This information can be used to site new training areas, and evaluate the assignments of new missions to installations. Relevant data includes that on soils, slopes, restrictions imposed by existing land uses, location of UXO areas, noise impacts distribution, location of sensitive wetlands, archaeological sites, historical districts, easements, intergovernmental agreements, availability of a single interconnected area of the minimum size, the effects of topography on the required safety fans, and other factors. Land capability indexes can also be used to schedule range use.

Wildlife Habitat Change: Examination of changes in wildlife habitat over time can be made to evaluate changes in habitat value, and suggest the expansion, contraction, or direction of habitat change. Installation land managers can use such information to monitor, protect, and manage the movement of desirable, undesirable, or protected species.

4.4.2. Master Planning

Boundaries: Boundaries change due to sale, acquisition, land swaps, etc. Knowledge of current boundaries allows faster and easier preparation of outlease contracts, and resolution of liability issues.

Cultural Resource Management: The status of archaeological/historical site surveys, usage restrictions associated with each site/area, condition of site, and site importance can be managed using GRASS.

Off-Limits Areas (e.g., Impact Areas): Often, the simple display of information is useful to land managers. For example, the need for additional training lands can be made apparent by the display of lands to which access is restricted or difficult (including impact zones, firing fans, and sensitive environmental areas).

Easement Management: Identification of easement locations, responsible agencies and points of contact, restrictions associated with the easement, extent of easement buffers, and date of renewal of easement agreements, can all be tracked using GRASS.

Environmentally Sensitive Areas: Relevant criteria can be used to locate environmentally sensitive sites.

Flooding Potential: Land characteristics and ARMSED output can be used to predict locations of areas sensitive to flooding.

Landfill Site Selection: GRASS can be used to locate sites suitable for landfill development, using such criteria as soil type, pH and permeability, slope, depth to groundwater, and other factors.

Non-Ownership Areas: Usage of land is more difficult when the parcels are not contiguous or when different agencies or individuals hold title. Often these imply restrictions on land use. The update and display of this information is critical and often legally significant.

Off-Post Areas: Installation activities can impact adjacent off-post features and uses. Maps of off-post areas (showing population densities, transportation routes, political boundaries, land uses, and zoning) can be used during the planning stages of potentially controversial Army activities to avoid needless impacts.

Quadrangle Boundaries: U.S. Geological Survey quadrangle boundaries are standard and often used. It is therefore useful to designate locations of these boundaries, to facilitate overlays of data.

Recreation Site Selection: GRASS can be used to site recreation areas by finding areas within the dataset having desired slopes, vegetation types, transportation route access, distance from population centers, etc.

Roads: Transportation existence, type, interconnections and quality are all important planning considerations in themselves.

Streams: Stream locations are an important environmental consideration. They influence habitats, erosion and sedimentation, dispersion of pollutants, vehicle stream-crossing restrictions, archaeological site occurrence, utility placement (e.g., water treatment plants), and numerous other factors.

4.4.3. Natural Resources/Land Management Office

Allocation of Field Transects: GRASS can be used to randomly allocate field transects on an installation (for example) in all areas containing unique combinations of soils and land cover which also meet necessary size requirements.

Cemetery Information Management: The identification, locations, and conditions of installation cemetery areas can be recorded using GRASS. Using such information, maps showing specific cemetery sites and their relation to access roads can be produced.

Cross-Country Mobility: Geographic characteristics (including soil type, landcover, slope, and accessibility) can be examined to predict cross-country mobility.

Off-Limits Areas (e.g., Impact Areas): Often, the simple display of information is useful to land managers. For example, the need for additional training lands can be made apparent by the display of nonavailable lands (including impact zones, firing fans, sensitive environmental areas, and noncontiguous areas).

Disease Infestations and Migration Prediction: Given known sites of current infestation, GRASS can be used to determine characteristics common to such sites, and to search for other locations with these characteristics (in order to predict likely future sites of infestation). Similarly, the GRASS tool *distance* can be used to estimate the migration and spread of future infestation.

Erodibility and Erosion Prediction: This application involves the examination of soil and vegetation losses on an installation, and the attempt to correlate such losses with installation activities (e.g., intensity of training range use) and other factors in order to predict the magnitude and location of future losses. Results can be used to develop land management plans to insure the continued viability of the land. Calculation of the Universal Soil Loss Equation is possible with information derived from map layers of soils and land cover. LANDSAT or other spectral image and ground-truth transects are used to determine land cover categories.

Erosion Losses: Site soil and vegetation losses can be examined, and potentially correlated with installation activities (e.g., intensity of training range use) and other factors.

Flooding Potential: Land characteristics and ARMSED output can be used to predict locations of areas sensitive to flooding.

Forest Fire (Burn) Predictions: The user can define factors affecting forest fire potential (e.g., vegetation type, soil, slope, aspect, presence of fire breaks or open areas, etc.), then filter the data based on wind direction to examine fire spread. Results can be input to surface modeling programs, and refined by repetitive filtering.

Forestry Management: Cruise completion, date of last timber sale, scheduled year of next timber sale by forestry compartment, characteristics of stands (probably in conjunction with a forestry DBMS package), and other forestry management applications can be performed using GRASS.

- 30 -

Grazing Impacts: GRASS can be used to estimate the effects of grazing on land condition.

Habitat Assessment: Species sitings (e.g., threatened or endangered species sitings) can be correlated with data layers which imply critical habitat qualities (cover, food source), to develop a coincidence tabulation. The relative habitat values associated with different sites can then be compared. Correlations indicative of habitat value can also be developed and used to search for probable sites of relevant species.

Hazardous Waste Sites: Locations of hazardous waste sites can be displayed in relation to access routes, population centers, and sensitive environmental attributes, and used in the development of installation emergency management plans.

Hunting Permit Management: Hunting permits can be issued on the basis of historical kill data, types of game reported, killed animal weight, age, sex, etc.

Landcover Change Detection: LANDSAT, SPOT, or other spectral image and ground-truth transects can be used to monitor landscape changes over time.

Landfill Site Selection: GRASS can be used to locate sites suitable for landfill development, using such criteria as soil type, pH and permeability, slope, depth to groundwater, and other factors.

Management of Outleases: The government often leases out lands for farming, grazing or other special uses. This limits land utilization, which may vary seasonally. Data on locations and uses of leased properties, lease income amounts and lease renewal dates can be used to manage leased properties, and to estimate future lease requirements.

Off-Limit Areas: GRASS can be used to determine sites to remain off-limits for training, by (for example) combining all those areas which cannot be used (e.g., urban areas, drop zones, impact areas, threatened species' habitats, significant cultural resource sites, etc.).

Pest Control: For each site at which an insect or rodent infestation has been identified, information can be stored as to the date it was first identified, the degree of infestation, types and quantities of chemicals used to combat the pest, and recommended date for next chemical application.

Pest Infestation: A comparison of pest infestations over time can indicate the direction and location of spread, potential problem sources, and the relative effectiveness of different treatments. Where pests attack crops, this can also be used to predict crop losses.

Recreation Site Selection: GRASS can be used to site recreation areas by finding areas within the dataset having desired slopes, vegetation types, transportation route access, distance from population centers, etc.

Rehabilitation Priorities: GRASS can be used to evaluate data on land damage, its correlation with different activities, and the success of various rehabilitation strategies, and to determine land rehabilitation priorities.

Sedimentation Sensitivity: Environmental attributes like soil type, landcover, slope, and landuse, which are correlated with soil erosion can be defined. Such information can be used with data output by the ARMSED sedimentation and runoff model linked to GRASS to identify sites highly susceptible to runoff and erosion.

Sensitive Species Avoidance: Using known and predicted locations of sensitive species and their habitats, a map can be made indicating such areas and buffer zones around them, to regulate their use.

- 31 -

Smokes/Air Pollution Modeling: GRASS can be used to locate sites likely to be impacted by smokes or air pollution. Buffer zones can be drawn around point sources, and examined in relation to terrain, and to population densities, sensitive species and habitats.

Streams: Stream locations are an important environmental consideration. They influence habitats, erosion and sedimentation rates, dispersion of pollutants, vehicle stream-crossing restrictions, archaeological site occurrence, utility placement (e.g., water treatment plants), and numerous other factors.

Subsurface Modeling (e.g., water table height, water quality, hazardous material plume dispersal, contamination source): Drill log data can be input to a GRASS *sites* file, converted to raster format, and run through GRASS surface modeling routines. The surface generated by these routines can be used to model plume dispersal in GRASS.

Timber Stand Density: Detection of changes in timber stand densities can be used to estimate outlease value.

Training Capability: GRASS can be used to determine correlations between land characteristics, land use, weather, and other factors, with the capability of such land to withstand stress. This information can be used to site new training areas, and when assigning new missions to installations. Relevant data includes that on soils, slopes, restrictions imposed by existing land uses, location of UXO areas, noise impacts distribution, existence of off-limit wetlands, archaeological sites, historical districts, easements, intergovernmental agreements, availability of a single interconnected area of the minimum size, the effects of topography on the required safety fans, and other factors. Land capability indexes can also be used to schedule range use.

Watershed Management: Watershed basins can be derived using GRASS, and information on their areas and percentage of vegetation coverage then used to estimate prescribed seeding amounts and dates, predicted sediment yield (from GRASS's ARMSED model), etc.

Wetlands Management: GRASS can be used to create and store data for wetlands management (e.g., wetlands locations, sizes, and distribution). Models can be produced to correlate wetlands damage with certain unit activities. Sensitive and at-risk wetlands areas can be identified, for protection from encroachment or overuse.

Wildlife Management: Examination of changes in wildlife habitat over time can be made to evaluate changes in habitat value, and suggest the expansion, contraction, or direction of habitat change. Installation land managers can use such information to monitor, protect, and manage the movement of desirable, undesirable, or protected species.

4.4.4. Range Management and Training Management

Off-Limit Areas: GRASS can be used to determine sites to remain off-limits for training or other uses. The need for additional training lands can be made apparent, for example, by the display of non-available lands (including impact zones, firing fans, and sensitive environmental areas).

Training Area Maintenance Cost Tracking: As land degradation is identified, required maintenance and recovery costs and actions can be organized and tracked using the system. The scheduling and status of activities, and locations where the prescribed actions are/are not meeting objectives, can be identified.

- 32 -

Training Area Siting: Training areas and ranges can be sited using GRASS, based on the types of activities to be performed on them, and the ability of the land to sustain them. Frequently, installations organize performance of activities by training area. Such activities may include not only training, but seeding, forestry, erosion management, some budgeting arrangements, etc. GRASS can be used for the display, organization, manipulation, and correlation of such data.

Training Land Capacity: GRASS can be used to determine correlations between land characteristics, land use, weather, and other factors, with the capability of such land to withstand stress. This information can be used to site new training areas, and to assign new missions to installations. Relevant data includes that on soils, slopes, restrictions imposed by existing land uses, location of UXO areas, noise impacts distribution, existence of off-limit wetlands, archaeological sites, historical districts, easements, intergovernmental agreements, availability of a single interconnected area of the minimum size, the effects of topography on the required safety fans, and other factors. Land capability indexes can also be used to schedule range use.

Training Usage: The frequency, functions, and intensity of training area use can be managed using GRASS. Such data can be used in conjunction with soils and climatic data to project desired usage locations and intensities.

Trajectory Analysis: Use of elevation data to determine the possible lengths of trajectories at specified heights. Such analyses can be used, for example, to develop a viable line-of-sight for a weapon.

4.5. Summary

This chapter has examined some potential GRASS applications, and considerations relevant to their selection and execution. Which applications can readily be performed at a given user site will be highly dependent on the types of data, supporting software, hardware configuration, funding, and the availability and skills of system staff present there. Applications have the potential to alter the use and management of resources at sites, and are the only visible output from GRASS. It is therefore important that the uses to which GRASS will be put be considered before the system is acquired, and that applications be as fully integrated as possible with other aspects of GRASS implementation, prior to their selection.

 - 33 -

Chapter 5

An Introduction to GRASS GIS Software

This chapter describes the design and development scope of GRASS through its capabilities, operating environment, and design concept.

5.1. Introduction

GIS implementation is a complex procedure, involving several components. One key component is software selection. Software is selected for the intended uses of the system, data requirements, the hardware available, the level of training required, the ease with which the software can be modified, and many other factors.

Software evaluation criteria are not examined here, as it is assumed that the selection of GRASS software has already been made. Instead, this chapter describes the design and development of GRASS GIS software through its functions, operating system, and design concept. GRASS is first defined. Then GRASS data formats and the types of functions able to be performed on the system are examined. Hardware requirements are then outlined, and finally, the GRASS design concept is examined in detail.

5.2. What GRASS Is

Different geographic information systems have different objectives, abilities, operating environments and scope. No single system does everything. GRASS can be briefly defined as:

A geographic information system (GIS) -

It is not a word processor, a statistical system, a database management system, or an automated mapping-facilities management (AM/FM) system. It is possible to interface GRASS to such systems, however.

A program that accommodates raster and vector data formats -

Both raster and vector data formats are accommodated (to different extents) in GRASS. Vector data are used in GRASS for digitizing and the graphic overlay of data. All data analysis is done on raster data, and GRASS is therefore commonly referred to as a raster-based system. GRASS contains conversion programs to translate vector data to a raster format, and vice-versa.

A set of tools -

When arrayed with other systems, GRASS can be employed to successfully manage land resources.

A data input-output system -

GRASS is capable of data digitizing, data read-in and read-out conversions, image processing, data analysis, and data presentation. GRASS continues to grow, and to provide more sophisticated utilities. Cooperative efforts continue to be needed to coordinate the use of GRASS with systems, technologies, personnel, and regulations already involved in the planning process.

System capabilities are described in further detail in section §*5.3 Data and Capabilities* [*p. 34*].

5.3. Data and Capabilities

The way in which computer data is organized defines the potential for its use. Geographic data can be stored in two basic formats: raster (a.k.a. *grid cell*), and vector (a.k.a. *arc-node*). Image analysis systems typically use raster data, while computer-aided design (CAD) packages typically use vector data. GRASS uses both data formats.

Maps which contain distinct linear features (like roads, and streams) or distinct areal features (like county boundaries, training areas, soils polygons, etc.), are input to GRASS in vector format. These features are defined and stored as a series of two-dimensional coordinate pairs (points). This vector data is then converted into raster format, since analysis programs in GRASS work on raster data.

GRASS uses the raster format for the processing of image and geographic data. In a raster format the landscape is divided like a checkerboard into regular rectangular parcels of land. Attached to each parcel are identifying attributes specifying (for example) the particular parcel's soil type, land cover, land use, vegetation, geology, slope, elevation, etc.

GRASS, at the release of version 3.0, consisted of nearly 200 different computer programs which the user can run directly through keyboard commands, or indirectly through menus and other programs. (Refer to the USACERL publication *GRASS 3.0 Programs*,[1] or the *GRASS User's Reference Manual*,[2] for current, verbose listings of GRASS commands.) These capabilities can be placed into the following categories:

- Geographic Analysis
- Image Processing
- Map Display
- Data Input

Each category is discussed briefly below.

5.3.1. Geographic Analysis

GRASS provides several capabilities for map analysis and overlay. These include proximity analyses, logical (and/or/not) reasoning, weighted overlays, and neighborhood processing. It is this capability of bringing data derived from satellite imagery, paper maps, and other computers (e.g., elevation data) together as input to

[1] James Westervelt, *GRASS 3.0 Programs*, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 (USACERL, September 1988).

[2] James Westervelt, Michael Shapiro, William D. Goran, et al., *GRASS User's Reference Manual*, ADP Report N-87/22 (USACERL, September 1988).

some land use question that perhaps best defines a GIS. Maps originally at different scales and resolutions can all provide data which can be considered in some analysis.

5.3.2. Image Processing

Aerial images are important data sources for a GIS. They come in the form of satellite images[3] and high altitude photography[4].

Raw images contain a tremendous amount of information. GRASS image processing tools provide two primary functions necessary to prepare data for inclusion in a geographic information system.

(1) **Geographic referencing.** An image obtained by the above methods is planimetric; i.e., a fixed-length line drawn anywhere on the image covers exactly the same ground distance. Because the earth is curved, the image must be resampled so that the "georeferenced" image reflects the earth's curvature at that location, and so that the image lines up with other existing maps in that location's dataset.

(2) **Classification.** Though the images have sufficient data to provide the eye with a picture that looks realistic, this information content can be interpreted in order to develop land cover classifications which group areas that have similar spectral properties into land cover types.

Finally, the resulting georeferenced and classified image becomes part of a location's database, to be later combined with elevation, slope, ownership, geology, and other maps by the user.

5.3.3. Map Display

Geographic and image processing generally require that the operator have a significant amount of training to ensure useful output. Hence, these tools are not often of interest to the GRASS novice. The most attractive and useful tools for immediate use are the image display capabilities. GRASS provides two separate sets of image generation capabilities. One set (the *d* and *D* tools) allows the user to manipulate the display of data on the computer monitor, while the other (the *p* and *P* tools) enables users to print out paper hardcopies. Each set enables users to generate landscape images and maps. Currently, USACERL supports the use of Epson, Genicom, Shinko, and Tektronix printers with GRASS. Users can also write their own device drivers to enable the use of other printers. Specific information is available in the *GRASS Hardware Configuration Guide,*[5] and from the GRASS Information Center.

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[3] The most common satellites are the United States LANDSAT, and the French SPOT polar orbiters.

[4] GRASS data has already been derived from National High Altitude Photography (NHAP) program images.

[5] Douglas A. Brooks, Michael E. Higgins, and Mark O. Johnson, *GRASS Hardware Configurations Guide*, ADP Report N-89/21 (USACERL, March 1989).

- 36 -

5.3.4. Data Input

Perhaps the most important computer programs in a GIS are those that are used to capture data. GRASS data is derived from paper maps, satellites, and other computers. A powerful array of programs for reading magnetic tapes, manipulating raw data into a form usable within GRASS, and extracting information, allows for the production of quality data. The GRASS end user will likely become very familiar with the digitizing utilities. The processes of entering mapped data into the computer must be understood at every GRASS installation. It provides the user who depends on the data with a means of keeping the data current.

GRASS also provides an array of programs which allow the user to read data in from other sources. Common sources include the digital line graph (DLG) and digital elevation models (DEM) provided by the United States Geological Survey (USGS), and the digital terrain elevation data (DTED) provided by the Defense Mapping Agency (DMA). Because data development is the most expensive component of establishing any geographic information system, new programs are continuously under development to read and translate data originally created for other systems into a form usable by GRASS.

5.4. Computers

GRASS development has been accomplished on a variety of UNIX machines. Written primarily in the C language, it also makes strong use of UNIX system commands. UNIX is available on PCs, workstations, minis, mainframe, and super computers, making GRASS relatively portable.

The computers on which GRASS runs can be divided into two categories: *development* machines, and *ported* machines. Development machines are those on which new programming code is developed. Ported machines are those to which new code is merely ported. At USACERL, GRASS programming is developed on several machines. Iterative porting of new code between these machines ensures that the same code compiles and runs on the different development machines. It also helps make the code more portable overall.

Differences in the implementation of UNIX on the various machines makes programming effort necessary in a port, however. Indeed, even a release of a new and "improved" compiler often requires that significant programming be done on GRASS development machines. Machines other than those used for primary development have GRASS ported primarily in one direction; i.e., when modifications are made to the code on these machines, they are not necessarily brought back to the development machines. Each GRASS release must be re-ported to target (ported) machines. While there are no formal mechanisms to feed such modifications back into the development code, porters are encouraged to communicate changes back to the USACERL GRASS development group (so that such changes can be incorporated into the development code).

Currently, GRASS development work at USACERL is being done on a SUN[6] 3/110

[6] SUN computer corporation.

- 37 -

and a MASSCOMP[7] 5500. While making GRASS run on other SUN or MASSCOMP machines is relatively straightforward, some programming and debugging are always expected. Some public agencies have ported GRASS to other workstations (e.g., the AT&T 3B2 and PC 6300 configurations of the Soil Conservation Service, and the Tektronix workstations used by the National Park Service). Private firms and universities have also done (or are planning to do) other ports. As a growing system, the status of workstation options for GRASS frequently changes. Current information on the availability of GRASS on different computer platforms, and on distribution and support policy for such ports, is available from the GRASS Information Center. The *GRASS Hardware Configuration Guide*[8] is also regularly updated to provide information on configuration options and costs, and on the status of new ports.

5.5. Design Concept

GRASS programs have become increasingly modularized and specialized over the years. For example, GRASS programs can now be readily intermixed with UNIX programs inside shell scripts (batch files or macros). While GRASS developers will maintain the goal of system portability, GRASS users should find it increasingly easy to mix GRASS capabilities with local proprietary and nonproprietary software to address the specific needs of their sites. This creation of new programs by users who intermix appropriate computer resources has been dubbed the "GARDEN" concept.

This section looks first at the different levels of interaction available to the GRASS user. It then explores the GARDEN concept.

5.5.1. GRASS Levels

GRASS can be interfaced at several different levels. Each of these levels is defined by the functions provided. The several distinct design and implementation levels are described below.

GRASS Menu Level. Past GRASS releases provided a custom made menu interface through which the novice and occasional user could access all GRASS tools. GRASS users will recognize this as the "gis" or "grass" program. A series of menus led the user to particular interactive programs. In all releases through version 3.0, menus have been text and keyboard oriented. The GRASS 4.0 release will likely replace this with a portable graphics interface[9].

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[7] MASSCOMP Computer Corporation.

[8] Douglas A. Brooks, Michael E. Higgins, and Mark O. Johnson, *GRASS Hardware Configurations Guide*, ADP Report N-89/21 (USACERL, March 1989).

[9] Investigations conducted during 1988 evaluated the usefulness of the X Window graphic interface package. It is public domain and portable and will allow users to operate GRASS using a mouse or pointer to guide most of the processing through graphic switches, buttons, menus, and slides. X Windows has been developed through Project Athena at the Massachusetts Institute of Technology. The X Window System is a trademark of the Massachusetts Institute of Technology.

- 38 -

Interactive Level. The user who finds the "Menu Level" too cumbersome and restrictive can access interactive GRASS programs more directly by running the commands "GIS" or "GRASS". A standard UNIX shell then prompts the user for the GRASS (or UNIX) command that will be run. These tools defined the heart of the system in the GRASS 1.0 release. Each tool (program) prompted the user for information, and then operated on the data based on the user-provided commands. By GRASS version 3.0, the user prompting and data analysis functions were split (invisibly to the user) into two separate utilities. The data analysis programs formed the next (command) level.

Command Level. Command level programs were introduced in GRASS 2.0. For the most part, these programs are not interactive. Instead, they take all inputs either from an input stream or (more commonly) from the command line. These programs provide a new high-level GRASS programming environment. Used in conjunction with other capabilities, this level permits the development of very powerful land analysis models. Such models will make GRASS more immediately useful to new users. Well designed models and analysis instructions will allow users to address land use planning decisions that require expertise in unfamiliar fields.

Development of command level GRASS programs is encouraged, and must be done in conjunction with the USACERL GRASS development staff. If the code is portable, general, and withstands user abuse, USACERL may include it in future GRASS releases.

Libraries Level. Users interested in more analysis flexibility are provided with a set of libraries with a C binding that provide interfaces to GRASS data, users, and graphics. Using these libraries, programmers can develop and modify interactive and command level utilities. USACERL programmers continue to assume responsibility for these libraries and the data formats they access.

Data Level. GRASS data formats currently accommodate both raster and vector (arc-node) geographic information. Again, USACERL assumes responsibility for these formats. As more appropriate data compression schemes are developed, the data will continue to undergo fundamental modification. It is highly recommended that the user community not access data directly.

5.5.2. GARDEN Concept

The new level in the GRASS hierarchy has been dubbed the "GARDEN" concept. Just as one can put together many salads using items in a vegetable garden, it is possible to pick and choose from a huge assortment of computer programs in the analysis of data. GRASS provides only some of the items to choose from; the others are the standard programs provided with the operating system which may also include other proprietary and nonproprietary software to help the user. The computer garden provides limitless opportunities to combine various programs. While one might mix GRASS with a database management system (DBMS) and a report writer to assist the environmental manager to keep track of oil spill sites, another would mix GRASS with a statistics package, a voice recognition system, a natural language interface, and a

- 39 -

DBMS to allow voice query of a forest management system.

At the GARDEN level, GRASS can remain a solid package of geographic information system programs which provide the horsepower to drive a changing series of user interfaces and a growing array of other computer programs.

At the time of this writing, work was underway through USACERL to create an applications generator that would allow a systems analyst to combine GRASS, UNIX, and other computer programs into a task-specific product. It is projected that many different applications will be created over the coming years.

Such models can be very specific to a given set of software. While one database management system (DBMS) is used on one machine, a different DBMS may be used on another machine. The GARDEN utilities developed on these machines will use software familiar to the user community.

- 41 -

Chapter 6

Evaluation Criteria for GRASS Workstation Selection

GRASS software has been ported to several different computers, and is being ported to myriad others. This chapter offers those acquiring GRASS a set of criteria for evaluating the many hardware options available, and describes sources of existing information.

6.1. Background

GRASS was designed to be widely portable among computers; it is written in C, and runs on the UNIX operating system. Usually, GRASS code can be compiled on a new computer with only one or two days' effort. However, it takes a much longer time to write and test a driver for a new graphics display device. Often, the entire process of moving GRASS software to a new computer requires six to ten months and includes the entire process of (1) hardware selection and acquisition, (2) compiling GRASS code, (3) writing new graphic drivers, (4) testing and refining these drivers, (5) testing peripheral devices and connections, (6) providing initial configuration guidance for potential beta test sites and users, (7) testing all peripherals, (8) writing new GRASS installation instructions specific to the new device, (9) arranging for and coordinating beta testing, (10) completing changes required after the beta test, and (11) further testing and describing configuration options. It takes many months and a significant dollar investment to turn potential host candidates for GRASS into computers which fully support GRASS.

To define current and candidate hosts and peripherals for GRASS, USACERL maintains the *GRASS Hardware Configurations Guide*.[1] This document:

(1) describes essential and optional hardware components for GRASS,

(2) identifies workstations that have completed alpha testing[2] but await completion of beta testing,[3] and

(3) identifies workstations and peripherals that have successfully completed beta testing, fully support GRASS, and for which one or more distribution and support agencies are available.

At any point in time, there are usually several new computers, digitizers, and/or printers being evaluated or tested as possible new hardware options for GRASS. Thus,

[1] Douglas A. Brooks, Michael E. Higgins, and Mark O. Johnson, *GRASS Hardware Configurations Guide*, ADP Report N-89/21 (USACERL, March 1989).

[2] *Alpha-testing* is initial in-house testing, commonly done by the developers of a port, driver, etc.

[3] *Beta-testing* is secondary, independent testing performed out-of-house. Before hardware is added to the *GRASS Hardware Configurations Guide* (Douglas A. Brooks, Michael E. Higgins, and Mark O. Johnson, ADP Report N-89/21 [USACERL, March 1989]), it must either be undergoing, or have satisfied, beta-testing requirements stated in the document *Testing Guidelines for GRASS Ports and Drivers* (William D. Goran, ADP Report N-89/22 [USACERL, January 1989]).

- 42 -

this configuration guide is a very dynamic document. To ensure that users have the latest version of this guide, each revision is dated. The GRASS Information Center (217) 373-7220 or (800) USACERL, extension 220 can provide information on the date of the most recent version of the *GRASS Hardware Configurations Guide*. This guide is a logical starting point for evaluating the options for selecting GRASS workstations.

6.2. Evaluative Criteria

From a user's point of view, it is a great advantage to have so many hardware choices. On the other hand, it is difficult to make an informed decision from the large number of choices available, and it is very difficult for one agency or organization to support users on every possible GRASS workstation configuration. As the hardware choices expand, both selection and support become increasingly difficult.

To address this issue, USACERL has developed a set of evaluative criteria. All of these criteria are important, but some more than others. Because the importance of one evaluative element over another will vary among users, criteria are not weighted. When considering these criteria, we suggest using a matrix, with evaluative elements along one axis, and hardware options along the other axis (see Table 6.1 [p 46]). Hardware options are constantly changing, and many of the evaluative elements (such as cost and availability) also frequently change. Before a final selection is made, hardware vendors should be contacted to confirm price and configuration information, and GIS support organizations should be contacted to confirm elements in the selection process. Suggested hardware evaluation criteria are as follows:

- Cost
- Annual Maintenance Cost
- Performance
- Upgrade Potential
- Acquisition Options
- X Windows Implementation
- Hardware Support Requirements
- Status of GRASS on this Computer
- Availability
- Configuration Options
- Operating System Options and Limits
- Networking Options
- GRASS Software Support Options
- Peripheral Limits
- User Agency or Site "Standards"
- GRASS Linked Software Availability
- Other 3rd Party Software

- 43 -

6.2.1. Cost

Cost is always an important consideration, but is not always easy to compare between systems. Vendors configure systems differently, and this can make it difficult to directly compare different workstation alternatives. Generally, higher costs reflect higher performance, greater growth capacity, or some other important value. But costs are skewed by the marketplace, and vendors with high sales volumes may be able to offer equal value at a lower price. Thus, 300 megabytes of disk on a 386 microcomputer may cost less than the same 300 megabytes of disk on a super-mini computer.

Hardware costs are often the most important evaluative criteria for users. While budget often limits hardware choices, because of their large, initial expense, any system will likely need replacement in only a few years. Factors other than cost may prove to be more important during the life of the system.

6.2.2. Performance

Here, performance refers to how well GRASS software runs on specific hardware. This is now measured by running a suite of benchmarks, published periodically in the newsletter *GRASSClippings*. Another document, entitled *Guidelines for Running GRASS Benchmarks*,[4] describes the procedures used to conduct these tests. Because these benchmarks are generally derived using a single machine, however, readers are warned that results may vary among users.

Despite potential variations, benchmark results provide a valuable and easily comparable criterion for distinguishing machine performance. Essentially, these values identify how long it takes the computer to perform specific GRASS tasks. Users are invited to submit their own benchmark test results to USACERL, in order to refine published values and ensure greater accuracy.

6.2.3. Upgrade Potential

Some computers have significant limits regarding the new peripherals, boards, and power requirements that can be added in the future. For example, the Sun 3/110 has only a few open slots on its bus. A standard GRASS system with peripherals may fill all of these slots. If all the slots on the bus are filled, the workstation essentially has no upgrade potential. However, almost all workstations can be networked to other computers; thus, some upgrades to a GRASS workstation may be achieved through networking and sharing resources along a network.

Some specific areas of concern with upgrade potential include: (1) number of slots on the bus, (2) power supply, (3) serial and other connecting ports, (4) nine-track tape drives, and (5) networking configuration options. Each of these should be considered for specific workstations.

[4] Mark Johnson, *Guidelines for Running GRASS Benchmarks*, Technical Manuscript N-89/23 (USACERL, February 1989).

- 44 -

6.2.4. Acquisition Constraints

In some cases, configuration choices are limited to hardware that can be acquired through some special contract, or which meets some other agency or organization criteria. These types of constraints often limit government agencies, and can become the primary criterion in hardware selection.

From the government perspective, there are three primary mechanisms for hardware acquisition: open-ended contracts (such as the Corps of Engineers award for Intergraph CADD equipment, or the Soil Conservation Service award to EDS for office automation), GSA schedules, and open competitive bidding. Each method has advantages and disadvantages. Sometimes, an open-ended contract limits an agency's ability to acquire any other type of computer equipment, if the function of the desired equipment could be fulfilled by equipment off the contract. This can cause problems for agency offices that would rather use less expensive equipment or have some specialized software need that cannot be easily addressed through the open-ended contract. On the other hand, since these contracts have already been competitively bid and awarded, acquisition of contract equipment is usually a much easier process than acquisition of similar noncontract equipment.

At this point, no special contract has been established for the purchase of GIS equipment in the Army or the Corps of Engineers, but some workstations that will support GRASS can be acquired from the Intergraph CADD contract.

The Government Services Administration (GSA) negotiates contracts with vendors for equipment at some specific discount. Once a contract is negotiated, the vendor will publish a schedule, identifying all available items, prices, discounts, and terms. Since this negotiated price is presumed to be competitive with marketplace prices, hardware items listed on a vendor's GSA schedule can be acquired through these GSA contracts without competitive bidding from numerous vendors. However, if the total dollar value of a GSA purchase exceeds certain limits, then a purchase must be announced in Commerce Business Daily and other vendors are allowed to submit competing proposals to meet the purchase requirements.

Almost all of the workstations that support GRASS are available through GSA contracts. However, the number of configurations available may be more limited than on the open marketplace, and the prices are "fixed" by the schedule, for the duration of the contract, even if marketplace prices are lower.

Open competitive purchases have several advantages. However, specifications for such purchases need to be well written. Small omissions from specifications, or lack of clarity, can result in severe problems. This process is often very time consuming; if the value of the equipment is high and many vendors submit bids, bid evaluation can become a lengthy process.

6.2.5. X Windows Implementation

X Windows is a user and graphics interface language that runs on most of the same computers that support GRASS. Post-3.1 releases of GRASS will take advantage of

- 45 -

the features offered by the X language. Because so many software packages will be using X, almost all vendors with UNIX computers plan to support it. However, considerable effort is required by vendors to implement X, and some vendors' plans to support X may be delayed or cancelled. Further, some implementations of X may prove troublesome for GRASS. Thus, some information about the status of X on each potential workstation is relevant when selecting a computer on which to run GRASS.

6.2.6. Hardware Support Requirements

For many GRASS workstations (e.g., those made by Sun, MASSCOMP [a.k.a. Concurrent Computer Corporation], etc.), one vendor can provide nearly all of the elements a user will require, and will offer support contracts to maintain and update these computers.

6.3. Current Choices

The following list includes only those computers and workstations that fully support GRASS or are currently undergoing beta testing. Where machine series are listed, all machines in the series are capable of supporting GRASS (e.g., the MASSCOMP 5000 series actually includes seven or eight different models of machines, all of which can support GRASS). Although this was done to simplify the evaluation process, it may be desirable in further iterations of this evaluation process to split out different workstations within a series.

The choices at present (May/1989) include:

- Masscomp (Concurrent) 5000 Series
- Masscomp (Concurrent) 6000 Series
- Sun 3 Series
- Sun 4 Series
- Sun 386i Series
- Silicon Graphics IRIS 4D20
- Intergraph Interpro Series
- Apple Macintosh II Series
- PC Compaq 386 (Microport UNIX)
- PC 386 (Interactive UNIX)
- AT&T 386
- AT&T 3B2 Series
- Hewlett Packard 9000
- IBM RT

Two other machines, the Tektronix workstation series and the Dell 386, may be added to this list shortly, but are not yet ready to undergo beta testing.

- 46 -

Evaluation Criteria for GRASS Workstation Options

Evaluation Criteria	Machine Type											
	MASS 5000's	MASS 6000's	Sun 3's	Sun 4's	Sun 386i	IRIS 4D20	Intergraph Interpro	Apple Mac II	Compaq 386	PC 386	ATT 386	ATT 3b2	HP 9000
Cost													
Annual Cost for Maintenance													
Performance													
Upgrade Potential													
Acquisition Options													
X Windows Implementation													
Hardware Support Requirements													
Status of GRASS on this Computer													
Availability													
Configuration Options													
Operating System Options & Limits													
Networking Options													
GRASS Software Support Options													
Peripheral Limits													
User Agency or Site "Standards"													
GRASS-Linked Software Availability													
Other 3rd Party Software													

Table 6.1: Evaluation Criteria for GRASS Workstation Options

 - 47 -

Chapter 7

Staffing and Training Requirements

A major concern in implementing a GIS is staffing. Several of the tasks required to initiate, use and maintain a GIS involve an extensive commitment of personnel. This commitment is critical for the successful initiation and ongoing use of GIS technology.

7.1. Introduction

Often on military installations, there are already more work requirements than personnel to fulfill these requirements. Thus, a new technology that brings additional work requirements just stretches limited staff. To reduce staffing requirements, certain tasks can be contracted, such as preparing complicated map layers for the database or maintaining the hardware. No matter how many tasks are fulfilled by contractors, however, the implementation of a GIS on an installation requires a considerable staff time commitment, if only for planning and coordination efforts.

The advantages of having a GIS workstation on-site must be weighed against this commitment of on-site staff resources. If adequate staff time cannot be allocated for key tasks, such as learning and using the software, verifying the timeliness and accuracy of critical data elements, and maintaining the computer and peripherals, then it would be wiser not to implement an on-site GIS. There are other ways to use GIS technology (such as having GIS applications performed by a Corps district, Corps laboratory, or contractor), and these alternatives avoid many of the staffing requirements for an on-site GIS workstation.

Staffing requirements can be examined to determine both the need for new personnel and the specific tasks they will perform. Below, staffing is divided into the specific task areas associated with GIS implementation. The skills needed to perform each of these tasks may be provided by several individuals, or as few as two individuals on an installation. The number of individuals needed to perform the described tasks on any given installation will depend upon how well the areas of expertise held by existing installation personnel mesh with GIS-related tasks, how easily new personnel can be acquired, what specific GIS analyses the installation plans to conduct, and other factors.

7.2. Specific Task Areas

The types of tasks associated with GIS implementation can be grouped into these "skill areas:"

- GIS coordination
- GIS analysis
- Data management
- Cartography/digitizing

- 48 -

- Systems management
- Software integration

With a large GIS (multiple workstations, many different users and frequent applications), these various task groupings might each be performed by a different person or persons. But for smaller systems, many of these tasks will likely be combined into a single job. If you start with a smaller system, and the number of workstations and applications increases, then it might be appropriate to assign one person to each functional area; however, some overlap in functions is always likely to occur, given the unique capabilities, interests, and requirements of the GIS users at each site.

In terms of personnel, implementing a GIS on a military installation minimally requires a GIS Coordinator to plan for and coordinate the use of the GIS, and a software expert performing applications and assisting others to perform applications. At least two persons knowledgeable about the technology should be on-site and be capable of performing applications.

Once established, the critical element to sustain an on-site system is often the hardware system management. Someone needs to know how to connect cables, create logins, perform backups, and diagnose problems. On most installations, support elements (e.g., the Directorate of Information Management [DOIM]) provide some maintenance support for the computer and peripherals (provided DOIM was involved in the acquisition of these items), but certain hardware maintenance tasks are best performed on a regular basis by someone at the same location as the equipment. GIS System Management tasks may therefore demand that a third person be obtained from existing staff or elsewhere.

The hybrid position of GRASS systems manager/GIS analyst might be filled using either of several different hiring mechanisms. For example, this position might be contracted for through the Intergovernmental Procedures Act (IPA). Alternately, it might be filled as a U.S. civil service post. Each of these hiring methods implies different obligations by employees and employers, and has various advantages and disadvantages. IPA employees are permanent, full-time staff of other governmental agencies (such as state universities), who are temporarily loaned to the federal government for a limited period of time, extendable to up to four years. Personnel hired through IPA agreements maintain the employee benefits granted by the lending institution (e.g., by the university). In contrast, civil service employees obtain all of the benefits associated with federal civil service.

It is assumed that the position of GIS Coordinator will be filled by a permanent government employee already working at the site. Although, for example, an individual able to perform many of the tasks required of the GIS analyst, data manager, and systems manager (and some of those required of the cartographer/digitizer and software integrator), might be sought, this is only an example, suited to a scenario in which only one position (in addition to that of GIS Coordinator) will be filled at an implementation site. The nature of the positions filled will be specific to the needs of the implementation site.

- 49 -

Specific areas of expertise needed to implement an installation GIS are described below, and should be viewed in the context of the entire GIS Implementation process, as depicted in Figure 2.1 [p 4].

7.2.1. GIS Coordination

When a GIS is first considered, one person, already on staff, should be appointed GIS Coordinator. This position is critical to the evaluation of GIS technology for an installation and to the successful coordination and maintenance of this technology both on and off the installation. Specific tasks for the GIS Coordinator include:

- Developing the installation GIS needs (potential returns on investment) evaluation
- Developing/adapting the GIS Implementation Plan for the installation
- Coordinating GIS plans between various organizations on post
- Insuring that DOIM (or counterpart) reviews/approves the hardware selection and acquisition
- Insuring that DOIM (or counterpart) will support hardware
- Providing input to Army GIS Steering and/or Technical Advisory Groups
- Insuring that physical space, electrical power, and environmental requirements for computer hardware are met
- Participating in local and/or regional GIS user and data sharing groups
- Insuring that issues involving data standards, and the sharing, updating, and ownership of data are addressed and coordinated among all users
- Insuring that GIS hardware will be linked to appropriate networks to support user requirements
- Insuring that GIS data can be exchanged with CAD, AM/FM and other users as needed to support installation requirements

The GIS Coordinator should be a permanent installation employee, with adequate status and authority to accomplish these tasks. Ideally, this person will be familiar with the organization and procedures of the different installation elements that may be GIS users--such as the land managers, master planners, range managers, environmental planners, and trainers. This coordinator should already be familiar with GIS technology and potential applications at the installation. If not, the coordinator should be provided opportunities to learn about GIS, and to examine the ways in which other military installations use this technology.

Then the GIS Coordinator should develop a GIS implementation plan for the installation that considers each potential installation GIS user. This plan should initially identify the potential costs and benefits of the GIS, whether the system should be implemented on-site, and whether specific applications should be planned.

- 50 -

7.2.2. GIS Analysis

GIS Analysis must be provided on the installation. Necessary GIS Analysis skills include knowledge of the use of GIS and UNIX software needed to perform GIS analyses, and optimally, expertise in one or more of the GIS application areas relevant to the installation's intended analyses (e.g., natural or cultural resource management, environmental planning or engineering, master planning, forestry, range scheduling). However, since the potential applications of a GIS extend to many areas, these will likely exceed the expertise of any single applications/software expert.

Whether current staff member or new hire, whoever provides these skills should have adequate training. While formal software training courses are useful and recommended, most persons require several months to become proficient in the use of GIS software. If GIS Analysis skills are to be provided by someone newly hired for the purpose, the position description should require at least one year's experience with some GIS. Although it is not necessary that a potential candidate be familiar with GRASS, persons familiar with other GIS's should be provided an opportunity to receive formal GRASS training.

Whoever provides these skills will perform analyses using the GIS. They must structure the preparation of data (or instruct others to do so) to be compatible with subsequent GIS analysis. Analysts with sufficient expertise can also prepare "macros" or "interfaces" that support specific, repeated applications for different users. How the analyst serves installation GIS users will depend on the size and diversity of the user community, and the skills, interests and time availability of other users. Ideally, the GIS Analyst should help others perform analyses so that many users acquire GIS software expertise. The analyst will also write necessary contracts to enhance existing software.

Tasks associated with this skill area include:

- Learning the capabilities and potential applications of the software
- Installing new versions of the software, and learning the new capabilities of these updated versions
- Helping others to understand the capabilities of the software, so that they can conceptualize applications relevant to their needs
- Participating in GIS forums (such as regional agency data exchange and application meetings)
- Identifying additional software requirements needed for specific applications
- Assisting GIS users in preparing for and running applications
- Insuring that the computer system is functioning properly and reporting any problems to System Manager (or fixing the problem)
- Creating applications interfaces (using the GRASS application generator) for users with specific, repeated applications
- Recording and documenting software usage, and the types and frequency of applications, as an aid to future users and for users at other installations

- 51 -

7.2.3. Data Management

Geographic data is often needed and used in different offices by different software for different purposes. To gather, develop, distribute, and "globally" update such data would be convenient and economically wise.

Data Management skills include helping to establish and maintain standards for data quality, maximizing data sharing between users, identifying and resolving data exchange issues, and integrating GIS technology into the installation's data gathering and handling procedures. Like the GIS Coordinator, whoever provides Data Management skills will need adequate status and authority to accomplish these tasks. Further, the individual acting as Data Manager should be familiar with the way that data is gathered, verified, used, shared and reported by potential GIS users on the installation.

The Data Manager can yield tremendous cost savings, by effectively coordinating data sharing between users, and by restructuring data gathering operations to maximize the use of digital technologies. For example, when photography is flown for the installation, the Data Manager should insure that direct digital products are derived from this photography, and that the requirements for these products are reviewed by all potential users.

The development of GIS data layers can be a very time consuming and demanding task. Often, much of this work is done off-site by a Corps district, lab, or contractor. However, even when the actual digitizing and/or scanning is done by contract, staff at the installation must first identify data needs, monitor the data acquisition and interpretation efforts, verify data accuracy and sources, and evaluate the data layers when they are completed. In addition, some data elements are dynamic, and it may be more efficient to update some of these data elements on-site. The Data Manager should know the available sources of data and insure that data is developed to best fit the needs of the intended application(s). The tasks associated with Data Management include:

- Establishing installation standards for verifying data accuracy and documenting data sources
- Establishing working procedures for "ownership" of specific data layers, and sharing of these layers between users
- Determining requirements for sharing data between the installation and surrounding agencies (e.g., local Soil Conservation Service office)
- Identifying procedures for updating data elements, and testing and reviewing these procedures (specific to each data type)
- Learning about the various available data sources, and helping to determine which sources will meet installation needs
- Identifying ways in which pre-digital data forms on the installation might be converted to digital forms, and identifying potential cost savings resulting from this conversion
- Helping coordinate CAD, AM/FM and GIS data requirements to maximize value of installation data investment

- 52 -

7.2.4. Cartography/Digitizing

Cartography and digitizing skills will be needed if any digital map layers are to be created or updated on-site. A person who has data input responsibilities may share time between GIS and CAD and/or AM/FM systems, and provide these skills.

The preparation of maps for digitizing, and digitizing itself, are time consuming procedures that require careful attention to detail. Persons selected for these tasks should have training in cartography and/or drafting. Otherwise, inaccurate maps may be generated, which have no real usefulness. The persons providing these skills should also have extensive hands-on computer experience, and be able to read data tapes, georeference satellite images, and exchange data between systems. Contracts can often be let for these purposes. Since several of these functions involve use of the GIS software, some GIS training, at least on the job, will also be required. Cartography/Digitizing tasks include:

- Digitizing new or updated map information
- Reading updated data from tapes (e.g., new satellite images)
- Drafting maps for digitizing and/or scanning
- Moving data between formats (e.g., GIS to CAD)
- Exchanging data with other agencies and/or installations
- Archiving and retrieving data
- Documenting the procedures used to create/revise data layers
- Maintaining records of data updates
- Maintaining inventories of data in various formats
- Monitoring digitizing by outside contractors
- Working closely with potential users of the data to insure that data is developed to best fit the intended application

7.2.5. Systems Management

Necessary Systems Management skills include maintenance of the computer, the peripherals (e.g., input and output devices), and the connections between GIS workstations and other computers. Often, these tasks will be done by either a contractor or a support agency on the installation. If system management tasks are performed by an on-site staff member, that person often performs these responsibilities in an "other duties as assigned" mode. That is, they are formally trained and hired in some other capacity, but have acquired system management skills on the side. However, with GRASS-GIS workstations, significant system management effort is required - much more extensive than with ordinary personal computers.

There are several reasons why system management is especially demanding with GRASS-GIS workstations. First, GRASS operates in a multi-user, multi-tasking environment, so someone must have responsibility for creating logins, monitoring usage, and balancing resources between users. Second, GIS operation involves use of numerous peripheral devices (the minimal items for a GRASS workstation include digitizer, graphic printer, line printer, terminal, disk, backup device, and graphic display monitor). Managing these items and insuring that they are all connected

 - 53 -

properly requires considerable effort. Third, GRASS is based on the UNIX operating system, which is both powerful and complex; it takes extensive exposure to UNIX to become proficient in systems management on UNIX machines. Finally, GRASS and other GISs involve large datasets, which require large storage and backup devices. A multiple-user system needs a regular and frequent schedule for backup and disk maintenance. Specific tasks under the System Management skill area include:

- Creating user logins
- Performing system backups
- Maintaining the system network
- Testing new equipment
- Connecting and supporting peripherals
- Maintaining supplies of replaceable items (paper, ribbons, mylar)
- Maintaining equipment support contracts
- Writing contracts to acquire new hardware
- Diagnosing system problems
- Maintaining and updating the operating system (as per vendor updates)
- Balancing user requirements with system resources (e.g., "policing" the disk)
- Tracing electronic mail and network communications problems
- Informing users of scheduled downtime, upgrades, system changes, etc.
- Creating and maintaining electronic connections to the outside world
- Providing other user support

7.2.6. Software Integration

The Software Integrator role is not essential for the implementation of GIS technology, but a person with the skills to extend, link and customize software to meet installation needs will prove extremely useful. The Software Integrator could be a programmer, a systems analyst, or someone with another technical background who has acquired skills in learning, using, and extending software capabilities. If that person also has some training in land/resource management, the link between software objectives and programming may be made much tighter.

Since GRASS runs under the UNIX operating system, Software Integrator skills must first include an extensive understanding of UNIX. They would include an understanding of the creation of GRASS macros, the functions within GRASS that join commands into an integrated application. The *application generator* is another feature within GRASS that allows experienced users to create user interfaces (customized menus) that not only function as GRASS macros but also can link GRASS to other software capabilities. Macros and specialized user interfaces can greatly extend the usefulness of GIS technology to installation personnel by creating simple, straightforward paths to accomplish specific tasks, such as updating a training range condition map or evaluating the noise effects of a new firing range.

While software integrator skills do not necessarily include programming skills, any programming involving GRASS should be done in C. However, much of the work of software integration can be done using UNIX functions and GRASS utilities. Links

 - 54 -

can also be created to send or retrieve files between GRASS and relational database management packages, statistical packages, spreadsheets, word processors, and other software systems. Many of these links will be available from other installations and GRASS users, but an on-site software integrator can test, improve, customize and install the links on the installation, and insure that they meet installation user requirements.

One other potential function of Software Integration is to provide, test, improve and manage links between GRASS and other installation-specific systems, such as IFS-M, Intergraph, forest inventory systems, building-wide or post-wide LAN's, Novell's UNISYS, other machines for UNIX-LAN and ethernet connections, etc.

Specific tasks under the Software Integrator skill area include:

- Creation and testing of user interfaces and application macros
- Investigating new and existing software links to GRASS
- Creating and testing links of GRASS with other software (including RDBMS, statistical packages, spreadsheets, word processors, etc.)
- Testing, improving, customizing, installing, and managing these links on the installation
- Ensuring that links meet users' requirements
- Providing other necessary support for users

 - 55 -

Chapter 8

GRASS and GIS Support Structures

To facilitate the development and use of GRASS, several support structures have been developed. These include distribution and support centers, policy-making groups, user group meetings, publications, and written and electronic communication forums. This chapter describes the GRASS support mechanisms currently available.

8.1. Introduction

Successful GRASS implementation depends upon proper planning and upon the existence of support structures, policy guidelines and documentation. User sites require different types of support as system implementation progresses. Such support includes:

- Points of contact and sources for information during planning phases
- Guidance while establishing hardware configurations and networks
- Support during installation of software and hardware
- Training services
- Communication mechanisms to facilitate discussions with other users
- Data and applications support
- Ongoing support during system use

This chapter examines available support structures and mechanisms for GRASS.

8.2. Support Structures, Mechanisms, and Documentation

Support structures, logistical mechanisms, and documents are being developed and improved to support GRASS implementation.

Support structures and communication forums have been developed to address issues related to GRASS development policy, to promote the sharing of resources among agencies using GRASS, and to facilitate communication between users and other interested sites. The GRASS Inter-Agency Steering Committee coordinates GRASS activities among federal organizations using the system (including the military).

The GRASSNET and GISTALK electronic networks facilitate communication and development between user sites. Other communication forums include the Annual GRASS-GIS User Group Meeting, and the quarterly newsletter *GRASSClippings*.[1] These support structures and communication forums are discussed below, in *§8.3 GRASS Communication Forums* [p. 56].

[1] *GRASSClippings*, ISSN 0899-7853, published quarterly by the GRASS Inter-Agency Steering Committee.

- 56 -

The amount of support given to implementation sites can be minimal or comprehensive. Levels and types of support available are described in §*8.4 Support Types Available* [p.57].

Documents specific to GRASS implementation are also being developed, in addition to others which describe the specific use of GRASS tools and other issues. Types of available documents are described in §*8.5 GRASS Publications* [p.58]. A list of such documents can be obtained from the GRASS Information Center at the address shown in §*8.8 GRASS Software Distribution and Information* [p.62].

GRASS training courses, and distribution and support centers have already been established. These structures are being reviewed and strengthened to ensure adequate support for installations implementing GRASS. GRASS and GIS Training Courses and Curricula are offered through a number of institutions across the country. GRASS Distribution and Support Center functions are provided by USACERL and private organizations with whom memorandums of agreement are held. Several of these support mechanisms are discussed below, in §*8.6 Training* [p.60], §*8.7 Points of Contact for GRASS Information and Support* [p.61], and §*8.8 GRASS Software Distribution and Information* [p.62].

8.3. GRASS Communication Forums

Several forums have been established to facilitate the sharing of information among GRASS policy-makers, developers, users, and support sites. These include:

- The GRASS Information Center
- The GRASS Inter-Agency Steering Committee
- The Army Corps GIS Technical Advisory Committee
- An annual GRASS/GIS User Group Meeting
- *GRASSClippings*, a quarterly newsletter
- GRASSNET, an electronic mail and software retrieval forum

The **GRASS Information Center** maintains: (1) a set of publications on GRASS and GRASS-related items, (2) updated information on locations that distribute and support GRASS software and on training courses for GRASS, (3) the mailing list for the newsletter *GRASSClippings*, and (4) updated information on the status of GRASS user group meetings and software releases.

The **GRASS Inter-Agency Steering Committee** is an informal organization with members from government agencies and other organizations that use, support, and enhance GRASS. This organization sponsors the annual User Group Meeting and the quarterly newsletter. It holds at least two meetings annually to share and coordinate GRASS plans among the participating agencies.

The annual **GRASS/GIS User Group Meeting** is hosted each year by one of the member agencies of the Steering Committee. Papers, demonstrations, and discussion panels present GRASS applications and software development issues. The meeting provides opportunities for current and potential users to share and demonstrate new

- 57 -

GRASS software.

The **GRASSClippings** newsletter is published, approximately four times/year, to provide information to those interested in GRASS software. The newsletter includes articles on software development, hardware options and applications of GRASS.

GRASSNET is an electronic mail forum that provides a mechanism through which GRASS user and development sites can exchange messages. It can be reached via Arpanet, Internet, and other networks. GRASSNET also includes a library of contributed software available for users to retrieve and review. Thus, new software is available before it is integrated into a formal release of GRASS code.

8.4. Support Types Available

In addition to the communication forums noted above, GRASS distribution and support services are available from the organizations listed in §8.8 *GRASS Software Distribution and Information* [p. 62]. However, USACERL staff continue to provide distribution, software support, and data assistance services to U.S. Army installations, Corps of Engineers Districts and Divisions, and other U.S. Department of Defense organizations. These services include:

- Introductory information on GRASS and GRASS applications
- Distribution of software and documentation
- Hardware configuration and/or acquisition information
- On-site installation of software and hardware
- On-site software training
- Telephone support for software
- Information on GIS/CADD interface issues
- Data scoping and acquisition assistance
- Data conversions between various formats and media
- Data digitizing, scanning, and interpretation
- Applications and data analysis assistance and services
- New drivers for hardcopy devices, digitizers, and display devices
- Hardware system management support and assistance
- Networking consultation and guidance

A list of specific USACERL points of contact for these services is given in §8.7 *Points of Contact for GRASS Information and Support* [p. 61].

There are numerous possible scenarios for GRASS implementation. One possible scenario, in which implementation responsibilities are divided between the project sponsor (e.g., a MACOM), the implementation site (e.g., an installation or District), and a contractor (e.g., USACERL, or a Corps District), is illustrated in Figure 2.1 *(p 4)*.

Any or all of the GRASS support services from USACERL are available to any DOD organization. There is no minimum support package that an organization is required to maintain, and DOD organizations are not required to obtain these services through

- 58 -

USACERL. Several other GRASS support centers provide similar support services. Also, services provided through USACERL may involve the staff and facilities of other GRASS support centers.

Support can be minimal or comprehensive. Minimally, DOD organizations can elect to request only the *GRASS User's Reference Manual*[2] and a magnetic tape containing GRASS software. These sites would install GRASS on their own systems. At the other end of the support spectrum, sites may elect to have USACERL (and/or contractors or other support organizations) provide everything from software and hardware installation and acquisition, to data development and analysis.

For most Army installations, USACERL has provided complete GRASS turnkey services. These services have included hardware configuration and acquisition, installation of software and hardware, and data development and analysis for installations, districts, etc. However, it is anticipated that Corps Districts and Divisions, and others, will provide more of these services to new GRASS implementation sites in the future.

8.5. GRASS Publications

Several publications exist or are under development to support GRASS Implementation. Documents being developed specific to GRASS implementation include the:

- *GRASS Implementation Guide*,
- *GRASS Problem-Solving Manual*, (John Q. Ressler, William Swain, Sandra Anderson, and Jerry Thompson, ADP Report N-89/15 [USACERL, July 1989]),
- *GRASS User's Guide*,
- *Methodology for Performing Return-On-Investment Studies for Implementation of GRASS on Military Installations*, (Ben Sliwinski, Technical Manuscript N-89/25 [USACERL, May 1989]), and
- *Proceedings of the 1988 Geographical Resources Analysis Support System (GRASS) User Group Meeting* (Robert Lozar, Editor, Technical Manuscript N-89/18 [USACERL, September 1989]).

The *DEH Automated Graphics Guide: Selection, Acquisition, Implementation, and Management* (Gene McDermott, Michael McCulley, Mary Czyszczewski, et al., Technical Report P-88/19 [USACERL, June 1988]) also examines GIS implementation issues, but is not specific to GRASS. The following documents describe the specific use of GRASS tools, and other issues.

An Introduction to GRASS (James Westervelt, in the *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22

[2] James Westervelt, Michael Shapiro, William D. Goran, et al., *GRASS User's Reference Manual*, ADP Report N-87/22 (USACERL, September 1988).

- 59 -

[USACERL, September 1988]) and the *GRASS Fact Sheet* (William D. Goran, Fact Sheet EN-48 [USACERL, January 1989]) provide readers with an Overview of GRASS capabilities.

Hardware Configurations and Specifications are included in the frequently updated *GRASS Hardware Configurations Guide*, (Douglas A. Brooks, Michael E. Higgins, and Mark O. Johnson, ADP Report N-89/21 [USACERL, March 1989]), and *Testing Guidelines for GRASS Ports and Drivers* (William D. Goran, ADP Report N-89/22 (USACERL, January 1989]). The first of these describes computers and peripherals which are undergoing, or have completed, beta testing, while the latter paper describes how these beta tests should be conducted.

GRASS Design and Software Capabilities are described in such documents as *Differences between GRASS 2.0 and GRASS 3.0* (Michael Shapiro, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 [USACERL,September 1988]) (which examines recent changes to the software), and *GRASS 3.0 Programs* (which describes all programs released (James Westervelt, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 [USACERL, September 1988]) with GRASS version 3.0).

Data Development issues are treated in *Cartographic Issues in Database Development* (Marilyn Ruiz, Technical Manuscript N-89/24 [USACERL, September 1988]), *Map Preparation Guide* (Jean Messersmith, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 [USACERL, September 1988]), and *Sources of Digital Spatial Data* (Mark O. Johnson and William D. Goran, Technical Report N-88/01/ADA189788 (USACERL, December 1987]), and other documents.

GRASS Applications are examined in such papers as *An Erosion-Based Land Classification System for Military Installations*, (S. D. Warren, V. E. Diersing, and P. J. Thompson, [paper presented at the 41st Annual Meeting of the Society for Range Management, 21-26 February 1988, Corpus Christi, TX]), and *Linking the ARMSED Watershed Process Model with the GRASS GIS* (Winifred Hodge, Marjorie Larson, and William D. Goran, [paper presented at the 1988 International Symposium "Modeling Agricultural, Forest and Rangeland Hydrology," 12-13 December 1988, Chicago, IL]).

Networking is discussed in *GRASSNET: An Implementation of UNIX Communication Utilities* (Kathryn (Pecknold) Norman, in *GRASS User's Reference Manual*, by James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 [USACERL, September 1988]).

A variety of Reference Manuals (including the *GRASS User's Reference Manual* [James Westervelt, Michael Shapiro, William D. Goran, et al., ADP Report N-87/22 (USACERL, September 1988)], and the *GRASS 3.0 Programmer's Manual* [Michael Shapiro, James Westervelt, Dave Gerdes, Michael Higgins, and Marjorie Larson, ADP Report N-89/14 (USACERL, September 1989)]), Audio-Visual Materials (such as the *GRASS Video*, and several *slide sets*), and information on Support, Training, and Vendors are also available for distribution or loan.

 - 60 -

A list of these and related documents can be obtained from the GRASS Information Center at the address shown in §*8.8 GRASS Software Distribution and Information* [*p.* 62].

8.6. Training

USACERL offers special courses and sessions for Army and Corps District and Division personnel upon request. Other GRASS support organizations offer courses that are open to DOD participants and the general public (Table 8.1). The GRASS Information Center and the newsletter *GRASSClippings* provide specific information on upcoming courses.

ITD Space Remote Sensing Center Building 1103, Suite 118 Stennis Space Center, MS 39529 POC: Melissa Escher 601/688-2509	Soil Conservation Service National Cartographic Center 501 Felix Street P.O. Box 6567 Fort Worth, TX 76115 817/334-5212, -5559 (Workshops for SCS Staff)	Central Washington University Continuing Education/GIS Ellensburg, WA 98926 POC: Martha Duskin-Smith 509/963-1504
	Cook College Remote Sensing Center Department of Environmental Resources College Farm Road, P.O. Box 231 New Brunswick, NJ 08903 POC: Brie Bill 201/932-9631	

Table 8.1. GRASS Training: Periodic Training for General Public

 - 61 -

8.7. Points of Contact for GRASS Information and Support

General points of contact at USACERL (Table 8.2) will respond to questions, comments, and other input related to GRASS distribution, Inter-Agency issues, data development, hardware configurations and benchmarking procedures, submission of contributed software, data applications work, GRASS newsletter distribution, and GRASS documentation and training. Table 8.1 *(p 60)* and Table 8.3 *(p 62)* list groups outside USACERL which also provide GRASS distribution, training, and support services.

GRASS Net: grass@cerl.cecer.army.mil GRASSNET: cerl\grass	
GRASS Information Center Kathy L. Norman 800/USA-CERL ext. 220 217/373-7220 Net: kathy@cerl.cecer.army.mil GRASSNET: cerl\kathy	**Inter-Agency Steering Committee** Facilitator: William Goran 800/USA-CERL ext. 735 217/373-6735 Net: goran@cerl.cecer.army.mil GRASSNET: cerl\goran
GRASSClippings Mary Martin 800/USA-CERL ext. 462 217/352-6511 ext. 462 Net: martin@cerl.cecer.army.mil GRASSNET: cerl\martin	**GRASS Software Contributions** Jim Westervelt 800/USA-CERL ext. 449 217/352-6511 ext. 449 Net: westerve@cerl.cecer.army.mil GRASSNET: cerl\westerve
GRASS Hardware Manager Doug Brooks 800/USA-CERL ext. 752 217/373-6752 Net: brooks@cerl.cecer.army.mil GRASSNET: cerl\brooks	**Data Requirements and Info** Jean Messersmith 800/USA-CERL ext. 474 217/352-6511 ext. 474 Net: obrien@cerl.cecer.army.mil GRASSNET: cerl\obrien
GRASS Software Distribution Mark Johnson 800/USA-CERL ext. 414 217/352-6511 ext. 414 Net: johnson@cerl.cecer.army.mil GRASSNET: cerl\johnson	**GRASS Applications** Robert Lozar 800/USA-CERL ext. 739 217/373-6739 Net: lozar@cerl.cecer.army.mil GRASSNET: cerl\lozar

Table 8.2: GRASSNET & Electronic Mail

 - 62 -

8.8. GRASS Software Distribution and Information

Sites offering GRASS software distribution services and information are listed below:

GRASS INFORMATION CENTER
U.S. Army Construction Engineering Research Laboratory
P.O. Box 4005, 2902 Newmark Drive
Champaign, IL 61824-4005
POC: Kathy Norman
800/USA-CERL ext. 220 *or* 217/373-7220

GRASS SOFTWARE DISTRIBUTION

COMMERCIAL DISTRIBUTION SITES

MASSCOMP, MACINTOSH, & AT&T	SUN, TEKTRONIX & PC 386	SILICON GRAPHICS
ITD Space Remote Sensing Center Building 1103, Suite 118 Stennis Space Center, MS 39529 POC: Melissa Escher 601/688-2509	DBA Systems Redwood One Building 10560 Arrowhead Drive Fairfax, VA 22033 POC: Dave Johnson 703/591-0800	G.W. Hannaway & Associates 839 Pearl Street Boulder, CO 80302 POC: Wyndham Hannaway 303/440-9631

AGENCY DISTRIBUTION SITES

Soil Conservation Service National Cartographic Center 501 Felix Street P.O. Box 6567 Fort Worth, TX 76115 817/334-5212	National Park Service GISFU-WASO P.O. Box 25287 Denver, CO 80225 POC: Harvey Fleet 303/969-2590	U.S. Army CERL P.O. Box 4005 2902 Newmark Drive Champaign, IL 61824-4005 POC: Mark Johnson 800/USA-CERL
	U.S. Geological Survey Mail Stop 915 National Center 12201 Sunrise Valley Drive Reston, VA 22092 POC: Edward Eskowitz 703/648-6505	

Table 8.3: GRASS Software and Information Centers

8.9. GIS in the Army and the Corps

While the first Army installations and Corps Districts were implementing GISs, both the Army Engineers and the Corps Districts developed temporary structures to oversee or recommend procedures for GIS implementation. The Army established the "Army GIS Steering Committee" with the Chief of the Army Environmental Office (AEO) as Chair. This committee functioned intermittently from 1986-89, and has become a "proponent" organization for this document. Other member elements of the committee have included the:

- U.S. Army Engineering & Housing Support Center (EHSC), Natural & Cultural Resources Division

 - 63 -

- EHSC, Planning Division
- Office of the Assistant Secretary of the Army (INL)
- Directorate of Research and Development, HQ USACE
- Directorate of Civil Works, Office of Environmental Overview, HQ USACE
- Office of the Chief of Engineers, Installation Planning Division (ZCI)
- U.S. Army Construction Engineering Research Laboratory

This committee has considered such issues as hardware and software standards, data sharing between Computer-Aided Software Design and Development (CADD) and GIS users, and specific applications that require or could benefit from GIS.

In 1987, the Corps of Engineers established an Ad Hoc Committee on GIS, as a result of a recommendation of the Environmental Advisory Board after their meeting in New Orleans in March/1987. This committee, which was headed by Dr. William Klesch, met several times during 1987 and 1988 and presented final recommendations to the Environmental Advisory Board in October/1988 and shortly after to the Chief of Engineers.

The Ad Hoc Committee included 32 members, representing various Districts, Divisions, Laboratories, and headquarters. Members were divided into eight "subcommittees" to address the following eight technical areas:

- Sensitivity to user needs
- Scoping data requirements and applications
- Intermodal hardware consistency
- Software compatibility
- Quality control
- Technology transfer
- Cost considerations
- Inter- and intragency coordination

Limited numbers of copies of the committee's final report are available through the GRASS Information Center (see §*8.8 GRASS Software Distribution and Information* [*p. 62*]).

8.10. Conclusion

Good documentation and logistical support will help those considering acquisition to estimate costs and benefits associated with system implementation. Support structures will provide an ongoing mechanism to address users' questions before and after system acquisition. Such mechanisms will allow sites to prepare themselves--before the system arrives--for the implementation of GRASS.

- 65 -

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- 67 -

Definition of Terms: Glossary of GIS Terms Commonly Used in Relation to Digitizing[1]

Arc: A line connecting a set of points that form one side of a polygon.

Area: A fundamental unit of geographic information. Portions of the map bounded by lines. See Polygon.

Attribute: Nongraphic information associated with a point, line, or area element in a GIS.

Cathode Ray Tube (CRT): An electronic screen for displaying information or graphics. Also called a visual display device.

Cell: The basic element of spatial information in the raster (grid) description of spatial entities.

Cursor: A visible symbol guided by the mouse or digitizer, usually in the form of a cross or a blinking symbol, that indicates a position on a CRT.

Data Base: A collection of interrelated information, usually stored on some form of mass-storage system such as magnetic tape or disk. A GIS data base includes data about the position and the attributes of geographic features that have been coded as points, lines, areas, or grid cells.

Digital: The ability to represent data in discrete, quantified units or digits.

Digitize: To encode map coordinates in digital form.

Digitizer: A device for entering the spatial coordinates of mapped features from a map or document to the computer.

Edit: To remove errors from, or to modify, a digitized map or a file containing attribute data.

Element: A fundamental geographic unit of information, such as a point, line, area, or pixel. May also be known as an entity.

File: A collection of related information in a computer that can be accessed by a unique name. Files may be stored on tapes or disks.

Graphics Monitor: A CRT capable of displaying maps and results in color.

Grid Map: A map in which the information is carried in the form of grid cells.

Hardcopy: A copy on paper of map information or a graphics image originally displayed on a CRT.

Interactive: A GIS system in which the operator can initiate or modify program execution via an input device and can receive information from the computer about the progress of the job.

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[1] Adapted by Stuart Bradshaw (U.S. Army Construction Engineering Research Laboratory [USACERL]) based on definitions by P. A. Burrough, *Principles of Geographical Information Systems for Land Resources Assessment* (Oxford University Press, Oxford, 1987).

- 68 -

Island: A polygon lying within a parent polygon that contains no connections to the parent polygon. It may consist of one or more arcs.

Join: To connect two or more separately digitized lines or maps.

Keyboard: A device for typing alphanumeric characters into the computer. The arrangement of the keys resembles that of a typewriter, but often has more capabilities.

Layer: A logical separation of mapped information according to theme. Many geographic information systems allow the user to choose and work on a single layer or any combination of layers at the same time.

Legend: The part of the drawn map explaining the meaning of the symbols used to code the depicted geographic elements.

Line: One of the basic geographic elements, defined by an ordered set of points that describes the position and shape of a linear feature on the map. Each line starts at a node and ends at a node. Lines connect at nodes, and no line crosses itself or any other lines.

Map: Cartography: a hand drawn or printed document describing the spatial distribution of geographic features in terms of a recognizable and agreed symbolism. Digital: the collection of digital information about a part of the earth's surface.

Map Generalization: The process of reducing detail on a map as a consequence of reducing the map scale. The process can be semiautomated for certain kinds of data, such as topographic features, but requires more insight for thematic maps.

Map Projection: The basic system of coordinates used to describe the spatial distribution of elements in a GIS. The Universal Transverse Mercator (UTM) is generally used in GRASS.

Menu: A list of available options displayed on the screen that the user can choose from by using the keyboard or a device such as a mouse.

Mouse: A hand-steered device for entering data from a digitizing tablet. See Puck, Cursor.

Node: The point at which any lines in a polygon or linear network are joined. Nodes define the location of the endpoints of every line, and a single node may mark the start and/or end of one or more lines. Nodes carry information about the topology of map features.

Overlay: Mapping: the process of stacking digital representations of various spatial data on top of each other so that each position in the area covered can be analyzed in terms of these data. Map preparation: refers to a separate layer of map information which contains information on the attribute coding for the prepared map.

Point: One of the basic geographic elements. Points are referred to as degenerate lines. A degenerate line starts and ends at the same node and has zero length.

Polygon: A multisided figure representing an area on a map.

Puck: A hand-held device for entering data from a digitizer (see Mouse, Cursor). Usually has a window with accurately engraved crosshairs, and several buttons for entering associated data.

Residual: In map registration, the amount of error a registered point contributes to the overall map registration error.

- 69 -

Resolution: The smallest spacing between two display elements; the smallest size of feature that can be mapped or sampled.

Scale: The relation between the size of an object on a map and its size in the real world.

Snap: To connect two or more separately digitized lines.

Tablet: A small digitizer used for interactive work on a graphics workstation. See Mouse.

Threshold: The level, point, or value above which something will take place and below which something will not.

Topographic Map: A map showing the topography (contours, roads, rivers, houses, etc.) in great accuracy and detail relative to the map scale used.

Topologically Structured: Refers to a digital file of geographic data that maintains the spatial relationships between features inherent in the map.

Topology: The way in which geographic elements are linked together.

Transform: The process of changing the scale, projection, or orientation of a mapped image.

UNIX: A modern, general purpose operating system.

UTM: The Universal Transverse Mercator coordinate system of Eastings and Northings.

Vector: A quantity having both magnitude and direction. Refers to any digitized lines.

Window: A usually rectangular area that is used to view or to transform the original map.

Workstation: The desk, keyboard, digitizing tablet, and CRTs connected together as a unit for working with maps or graphics in interactive GIS.

Zoom: A capability for proportionately enlarging or reducing the scale of a figure or maps displayed on a CRT.