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A Comparison of Manual and Automated Methods for Delimiting Watersheds for Use With GRASS/GIS Software

by
J.J. Lockhart

The Geographic Resources Analysis Support System (GRASS) is a geographic information and image processing system originally designed to serve land managers and environmental planners at Army installations. Among the newer automated processes performed by GRASS is the digital computation of watersheds. This report compares the GRASS version 3.0a watershed module with the manual delineation of watersheds, by applying the two methods to installation data taken from Fort Chaffee, AR, a facility with over 72,000 acres of highly variable terrain.

This study showed that both methods produced similar results, with some exceptions. In areas of pronounced relief, 7.5-minute data and 1-degree data did produce watersheds, but did not indicate subtle saddle-based boundaries. At the installation scale, the 1-degree data produced adequate major watershed delineation, but was not adequate to determine minor watersheds. The more accurate 7.5-minute data produced a large number of subbasins. The automated method produced good sub-watershed basin delineation in areas of greater relief, but unsatisfactory delineation in areas of moderate to lower relief.

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13. ABSTRACT (Maximum 200 words)

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This study showed that both methods produced similar results, with some exceptions. In areas of pronounced relief, 7.5-minute data and 1-degree data did produce watersheds, but did not indicate subtle saddle-based boundaries. At the installation scale, the 1-degree data produced adequate major watershed delineation, but was not adequate to determine minor watersheds. The more accurate 7.5-minute data produced a large number of subbasins. The automated method produced good subwatershed basin delineation in areas of greater relief, but unsatisfactory delineation in areas of moderate to lower relief.

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FOREWORD

This study was performed for Headquarters, Training and Doctrine Command (HQTRADOC), Fort Eustis, VA under MIPR No. EFC9R125, dated December 1988; Work Unit NV9, "Grass Implementation." The TRADOC technical monitor was Paul Green, ATEN-FN.

This report was prepared for the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (USACERL) by J.J. Lockhart, of the University of Arkansas, under Contract No. DACA88-87-D-0008, Delivery Order No 0006. The USACERL principal investigator was William D. Goran. Dr. Edward W. Novak is Acting Chief of USACERL-EN. The USACERL technical editor was William J. Wolfe, Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The Geographic Resources Analysis Support System (GRASS) is a geographic information and image processing system originally designed to serve land managers and environmental planners at Army installations. Among the newer automated processes performed by GRASS is the digital computation of watersheds. A watershed is a catchment area drained by a single stream system and bounded by a divide that separates the catchment from other drainage systems. To prepare map data for computational analysis with GRASS version 3.0a software, watersheds must be either manually delineated, or automatically delineated by the newly developed GRASS 3.0a watershed module.

Manual delineation of watersheds is done using 1:24,000-scale topographic maps. Automatic delineation of watersheds is commonly computed from digital data at two scales. The 1-degree Defense Mapping Agency (DMA) elevation data is derived from USGS 1:250,000-scale maps, providing information at an 80-m cell spacing. Watersheds are also produced using 7.5-minute USGS Digital Elevation Model (DEM) data derived from USGS 1:24,000-scale quadrangle maps at a cell resolution of 30 m. Digital data at both scales are used to determine both major and minor watersheds.

This work was part of a comprehensive set of data layers being developed in support of the Integrated Training Area Management (ITAM) system being initiated at Fort Chaffee, AR. A comparison of the manual and automated methods will show which of the two watershed-determination methods is more accurate or economical for Fort Chaffee land managers to use.

The location for this study was the Fort Chaffee military installation located in west-central Arkansas. The facility contains more than 72,000 acres of variable topography (1 acre = 0.405 hectare). In the northern and northwestern parts of the installation (Figure 1), the land is generally flat to rolling, as it is within the Arkansas River Valley's terrace and floodplain. Throughout this part of the installation, elevation varies from a maximum of approximately 810 ft to a minimum of 390 ft (1 ft = 0.305 m). This area of lower relief will be referred to as the "Cantonment Area." The southern and southeastern portions of the installation, located within the Ouachita Mountains, are characterized by extreme relief. These mountains have a pronounced east-west trending ridge and valley system, with elevations of approximately 1220 ft, and valley elevations of 430 ft. This area of higher relief will be referred to as the "Barber" area since it is located on the USGS Barber 7.5-minute quad (Figure 2). Its variability makes the Fort Chaffee area a good test case for watershed delineation.
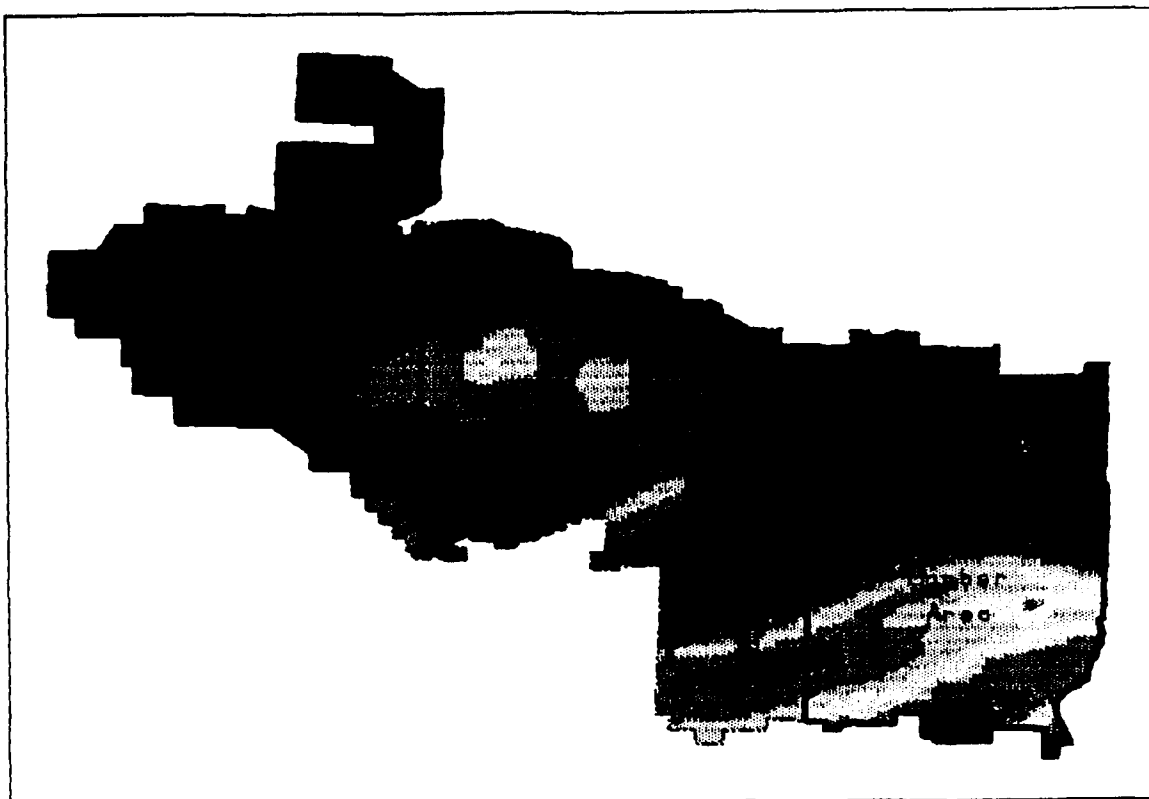
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                                                408060.00
                                3891780.00

bar1.bound (PERMANENT)

barb.bound (PERMANENT)

chaf_boundary (PERMANENT)

1	121 thru 153m	4	219 thru 250	7	316 thru 348
2	154 thru 185	5	251 thru 283	8	349 thru 380
3	186 thru 218	6	284 thru 315		

Figure 1. General Elevation for Fort Chaffee Showing Barber and Cantonment Areas.

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                        3892710.00

chaf_boundary (PERMANENT)

Figure 2. 7.5-Minute DEM in the Barber Area.

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Objective

The objective of this study was to compare the results obtained using the GRASS version 3.0a watershed module with those gathered from a manual delineation of watersheds, for the same area, to determine which was the more accurate or economical method for use at Fort Chaffee.

Approach

The processes involved in manual and automated delineation of watersheds were detailed. To perform the manual process, mylar separates of the study were obtained from the National Cartographic Information Center (NCIC) for each data theme, on 1:24,000-scale quadrangle maps. Drainage features were highlighted, and watershed boundaries were drafted onto work sheets. Manually delineated watersheds were drafted onto mylar separates and digitized for computer analysis.

For the automated method, USGS 1-degree and 7.5-minute Digital Elevation Models were obtained from the National Cartographic Information Center in Rolla, MO. The GRASS version 3.0a watershed module was run on both data sets.

The results drawn from the application of the automated method to the two data sets were compared for accuracy in delineating both major and minor watersheds. The results drawn from both automated applications were also compared with the results from the manual method. A cost comparison between the automated and manual methods was also made. Computations were performed on a MASSCOMP 5600 with 4 megabytes of random access memory (RAM), using GRASS 3.0a software.

Scope

It should be noted that the GRASS watershed module used in this study has since been updated. The current version of GRASS uses an automated module for delineating watersheds called r.watershed, which is substantially different from the program tested here.

Mode of Technology Transfer

Army organizations can acquire GRASS software from USACERL. Several other federal organizations provide distribution and support services for GRASS within their own agencies, and several other educational institutions and private firms also provide distribution, training, and support services for GRASS. Current information on the status and availability of services for GRASS can be obtained from the GRASS Information Center, USACERL, P.O. Box 9005, Champaign, IL 61826-9005 (800)-USA-CERL (ext. 220), or (217)-373-7220, or by electronic mail at: grass@cerl.cecer.army.mil.

2   MANUAL DELINEATION OF WATERSHEDS
FROM 7.5-MINUTE TOPOGRAPHY

Obtaining and Preparing Base Materials

The USGS, through the NCIC, makes available mylar separates for each of the data themes shown on its 1:24,000-scale quadrangle maps. Each color used on these paper maps represents a different theme (e.g., transportation, hydrography, topography, etc.). The mylar separates represent the individual photographic plates used in an overlay composite to make each quadrangle. These separates also make excellent base maps because of their singular themes, the stability of the mylar material, and the fact that each sheet can be prepunched for pin registry (thereby simplifying registration when digitizing multiple data layers). The use of prepunched acetate overlays of a Universal Transverse Mercator (UTM) grid and 10 registration points can reduce residual errors to less than 2 m on the ground for an area the size of one 7.5-minute quad sheet. Mylar separates can also be ordered for a composite that shows any combination of features. Manual watershed delineation can be done from complete quadrangle maps, but because of the other information printed on quadrangle maps, delineation using a separate can be much easier and less prone to error.

Mylars of the study area's topography and hydrography were obtained from the NCIC. Since the mylars were to be used for manual delineation of watersheds, the first step in the preparation of the base map was to make photocopies or blue line copies of the separates. These copies were used as work sheets and were spliced together to represent the entire area within the installation boundaries.

Manual Watershed Delineation Process

Highlighting of Drainage Features

Depending on the available source materials, either of two processes might be employed to manually identify drainage features. First, if the separates for hydrography are available (as they were in this situation) they can be combined with the topography to produce work prints showing both features. Streams can then be highlighted to make drainage features clearer. If the hydrography separates are not available, streams can be determined from the topography and sketched onto the work sheets to show the drainage patterns.

Delineation of Major Watersheds

Once the drainage patterns are shown on the worksheets, the direction of flow can be determined and the stream hierarchies become apparent. The streams can then be grouped into major conterminous networks. Next, topographic features operating the major stream networks are identified. These features can range from prominent ridge systems to less obvious saddles in the terrain, which are more readily apparent when drainage direction has been determined.

When the major stream networks and the features separating them are known, the watershed boundaries can be drafted onto the work sheets by identifying the actual divides at which water will run. Conceptually, this is done by determining the highest points along the features separating major watersheds and drawing a line connecting those points.

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Watershed boundaries are polygonal, and it should be noted that, in this study, all watersheds were bounded by the installation. Although actual watersheds need not coincide with surveyed boundaries, for the purposes of this study, the installation boundary serves as a watershed boundary.

Delineation of Minor Watersheds

The procedures used for identifying the minor watersheds are similar to those used to delineate major watersheds. However, the scale for minor watersheds may vary between studies. In other words, minor watersheds might be highly detailed subdivisions based on individual tributaries, large subdivisions within major networks, or entire minor networks, as in this study.

Generally speaking, the first task 'n defining the major watersheds establishes the direction of flow and the stream hierarchy. Next, stream hierarchies can be grouped into smaller related networks within major watersheds. After identifying the topographic features separating these smaller networks, the minor watershed boundaries are marked along the natural divides. The same work prints were used because in many cases segments of major watersheds comprised parts of the minor watershed boundaries.

Digitizing Manually Delineated Watersheds

Minor watersheds were digitized first because they combine to make the major watersheds. This order was chosen because, when completed, the vector file for the minor watersheds can be copied and the resulting file can be edited within the GRASS 3.0a module digit to remove the lines comprising the minor watersheds, while leaving boundary lines defining major watersheds. This sequence was thought to be more efficient than its reverse, which would have required breaking and adding lines. This sequence also saves an additional iteration of point registration for each quad sheet.

In preparing to digitize, watersheds were drafted onto the mylar separates with a nonphotoreproducible pencil, to preserve the utility of the topographic data for any future uses. Each mylar was then taped to the digitizing tablet with registration pins in place so that the acetate separate of the UTM grid could be accurately overlaid. Using the appropriate paper quads as reference, eight nonredundant, widely spaced registration points and their accompanying UTM coordinates were determined for each of the six base maps. Inside the digit module, each quad was registered with residuals under 2 (ground) m, and individual vectors were digitized as area edges in digit stream mode. Four of the quads were digitized as one map. The Barber and Cantonment Area quads, however, were digitized separately, since they were to be used specifically in the comparison report. The GRASS program Vpatch was used to add these two quads to the minor watershed map; the resulting map therefore encompassed the entire installation. The patched map and the two separate maps were then brought up in d'·it for such editing as snapping of nodes and categorizing data. The vector maps were run through the GRASS program vect.to.cell, and the resulting cell files were created with necessary support files.

Rather than redigitize the major watersheds, the GRASS program Gcopy was used to create a copy of the vector map showing minor watersheds. This copy was then run through digit ("no digitizer" was specified); unwanted minor boundaries were removed, leaving only major watershed boundaries. This file was then categorized, rasterized using vect.to.cell, and supported.

Figures 3 and 4 display the manually delimited major and minor watersheds for the entire installation, and Figure 5 shows the major watersheds for the Barber area quad.
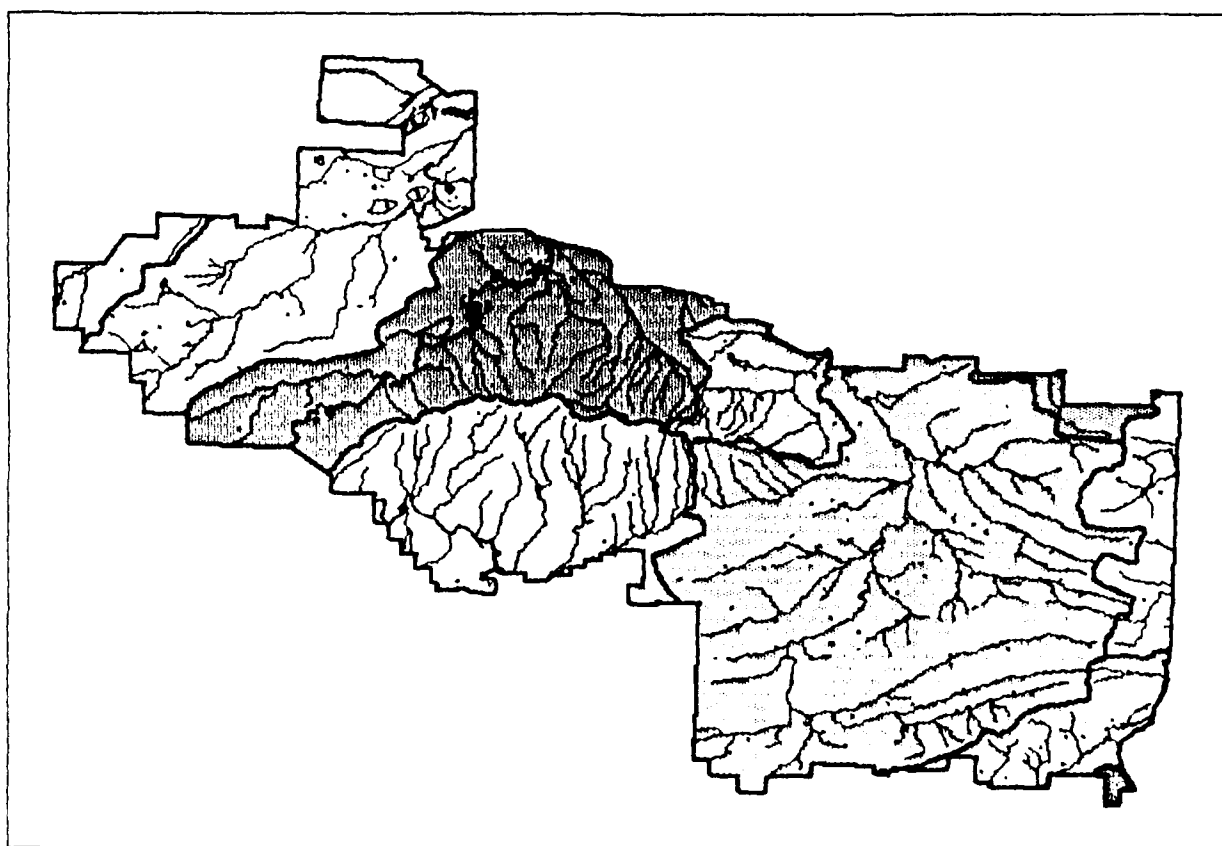
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chaf.wat.maj (PERMANENT)


streams (PERMANENT)
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Figure 3. Manually Delimited Major Watersheds and Hydrography for Fort Chaffee.
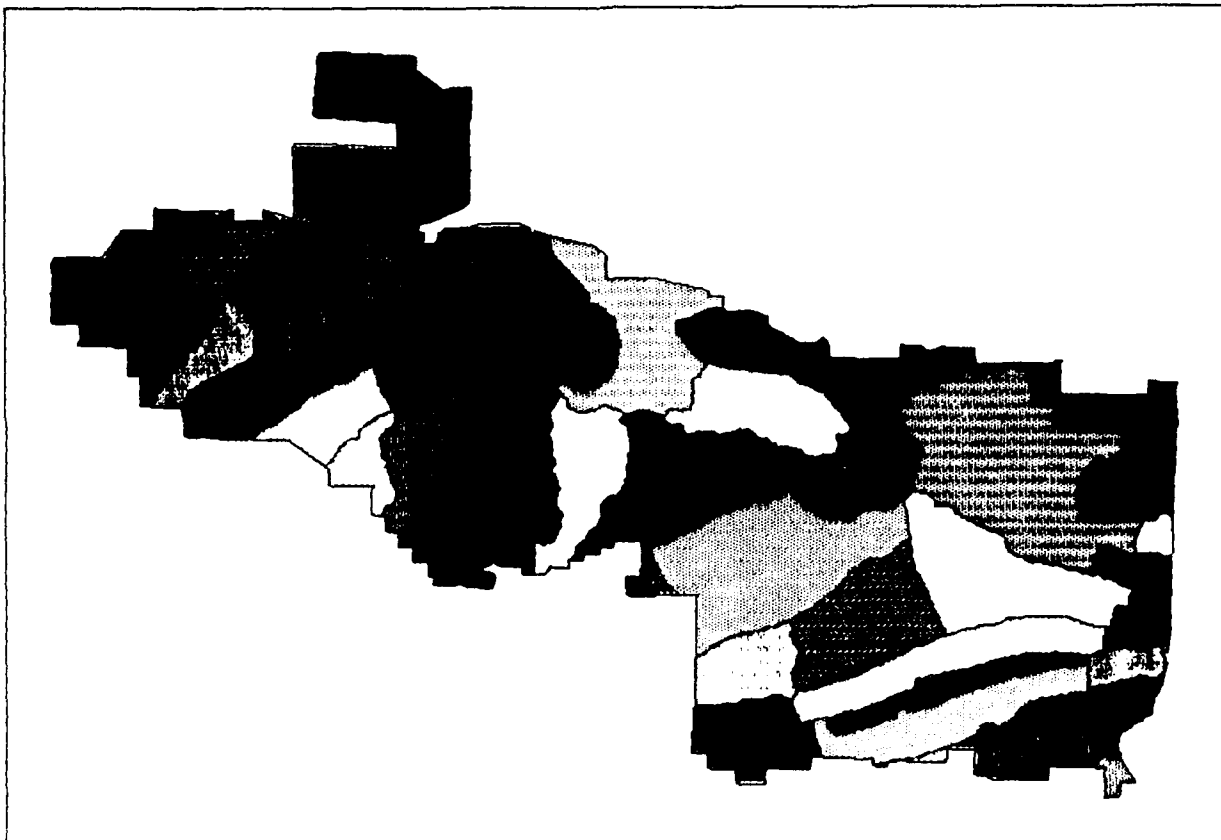
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                        3891780.00
chaf.wat.min  (PERMANENT)
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Figure 4. Manually Delimited Minor Watersheds at Fort Chaffee.
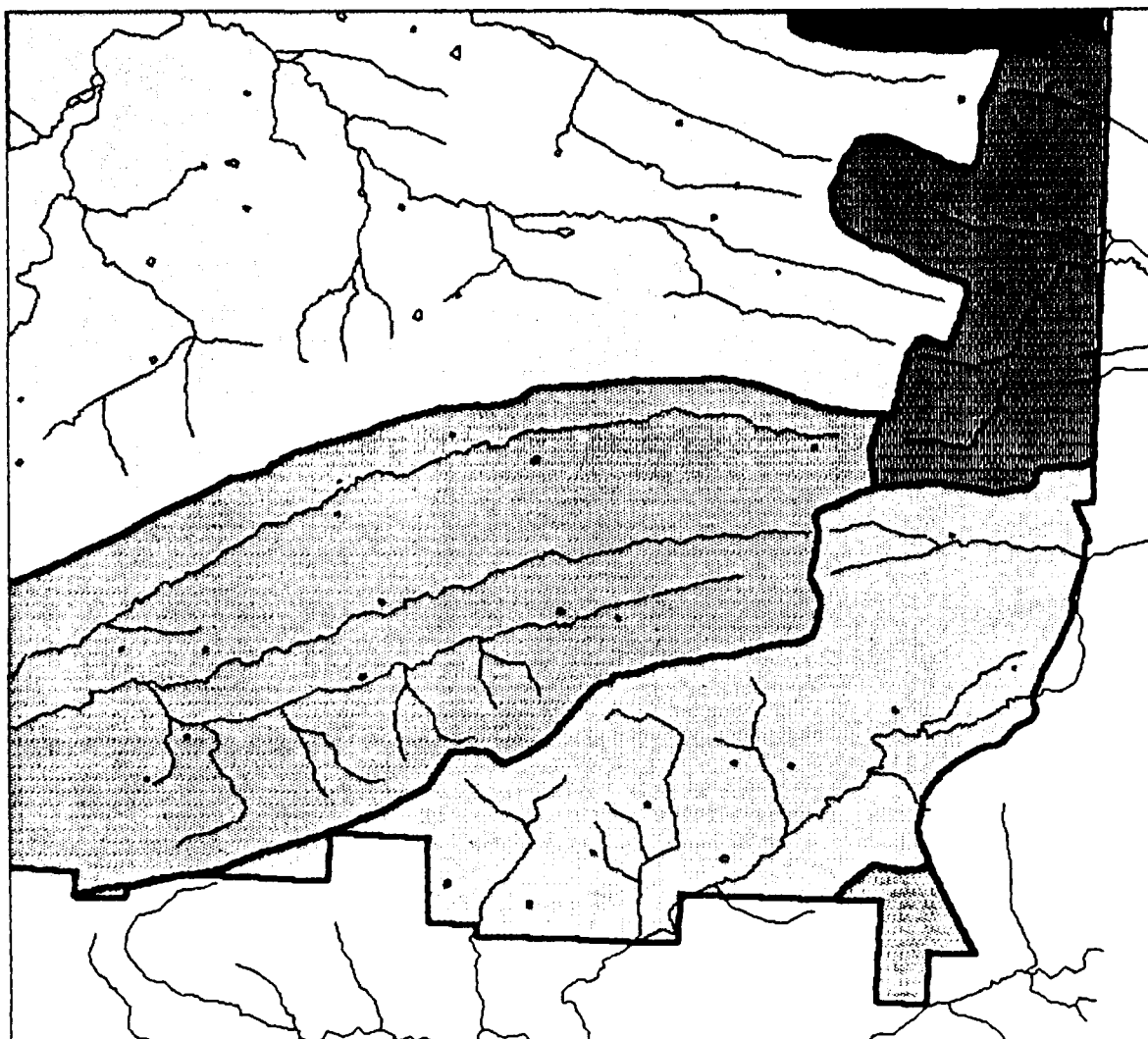
12

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WINDOW:    397650.00                      406890.00
                           3892710.00

barb.wat.maj (PERMANENT)


streams (PERMANENT)
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Figure 5. Manually Delimited Major Watersheds in the Barber Area.

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3   AUTOMATED DELINEATION OF WATERSHEDS USING GRASS SOFTWARE

Obtaining and Preparing Digital Data

Both the USGS 1-degree and the 7.5-minute Digital Elevation Models were obtained through the National Cartographic Information Center in Rolla, MO.

Preparing the 1-Degree Fort Smith East DEM

The 1-degree Fort Smith East digital elevation data were obtained in ASCII format on 1/2-in., 9-track magnetic tape. After the tape was mounted and the tape density assigned, the tape was advanced to the correct position (following the tape instructions) using the command "mt fsf 1".

Next, the raw data were copied into the current directory using "dd if=/dev/rmt0 of=[somename.raw] ibs=1024 obs=1024 files=1". (Note: The input block size (ibs) must equal the BLKSIZE on the tape.) These raw data were then converted into the GRASS-readable file "dem_data". The file "dem_data" was rotated using Mrot90, and Mimport.11 was then used to create the GRASS cell file. After conversion, the raw elevation data were removed from the hard disk to conserve disk space.

Preparing the 7.5-Minute Barber DEM

The 7.5-minute Barber DEM was also obtained in ASCII format on 1/2-in., 9-track magnetic tape. The raw DEM was loaded onto the hard disk in the same manner as the 1-degree data. The appropriate GRASS location and mapset were then entered, and the GRASS command Mdem.extract was entered from the raw data's directory, to convert the raw DEM data into a cell file to reside in the cell directory under the current GRASS mapset. The raw data were then removed from the hard disk to conserve disk space. Figure 2 shows the Barber DEM data.

Running watershed on the 1-Degree Data in the Barber Area

In order to work on the 1-degree elevation data, the appropriate window was set and a cell resolution of 80 m was specified. Also, a mask of the installation boundary was put in place. However, in locating pits within the watershed module, a bad exit status and a core dump were received because an excessive number of pits (over 1.7 million) had been identified. Upon further investigation, it was discovered that a large .tmp directory had also been created under the mapset directory. Removal of this .tmp directory created sufficient disk space to continue. It appears that the existence of the mask had caused this condition, and that the identification of an excessive number of pits was due to the absence of data in the masked areas.

After removing the mask, the data were filtered within watershed and the cell file created by this step was read by the second menu item ("locating pits"), which found 736,020 pits and sorted them in approximately 15 min without error.

At this point, the third menu item ("Calculating drainage accumulation/outlining watershed") was invoked. Since the watersheds had already been delineated manually, the approximate locations of the outlet points were already known. However, for purposes of comparison, it was decided to proceed as if the outlet locations had not been previously identified. The outlet positions were determined by entering Dcolormode float, displaying the 1-degree DEM, and using d.colors to highlight each category to find the first (lowest) cells at the installation's edges. Because the elevations represented by the 1-degree data were too generalized for this purpose, a 7.5-minute DEM was used instead. By sequentially highlighting each category in the color table in this manner, the lowest cells highlighted at the edges of the Fort boundary that did not belong to a previous watershed were defined as outlet points. Dwhere was then used to determine the actual coordinates of these outlet points. This method identified outlets at approximately the same locations as those shown in the manually delineated watersheds. Because of the topography and presence of major east-west trending ridges, no single outlet served the entire area. As a result, multiple outlets were necessary to drain all portions of the installation.

In watershed, using the 1-degree data as the analysis layer, the pit threshold was set at 10 (as suggested in the GRASS 3.0 User's Reference Manual).[1] However, the program failed to prompt for the slope threshold. Names were supplied for the drainage accumulation, aspect, and lakes map layers. It took approximately 5 min to run all iterations performed on the 1-degree data.

The fourth step, "Creating stream networks," iterated three times with an accumulation threshold of "30." Each iteration ran in less than a minute. The fifth and sixth steps, "Coding stream segments/finding segment lengths" and "Finding subwatershed basins," created their attendant cell files in less than a minute. The same procedures were followed to locate three more watersheds from outlets identified earlier.

The next step was to combine the separate watersheds generated by the watershed module. The drainage accumulation map layers outline each watershed; however, because these layers contain up to 10,000 categories, all categories within a layer were reclassed into a single category (defining the watershed) before individual watersheds were combined. These reclassed map layers were added together using the GRASS program Gmapcalc to generate one cell map showing all the major watersheds in the Barber area. At this point, it became apparent that there was some overlap among watersheds as calculated by the module. Watersheds associated with one outlet overlapped with watersheds associated with another. The cell map generated by Gmapcalc was then operated on by the GRASS program Gclump to produce polygons (watersheds and areas of overlap) with unique category numbers. Figure 6 displays the combined major watersheds.

Running watershed on the 1-Degree Data in the Cantonment Area

Three iterations of watershed were run on the 1-degree elevation data in the cantonment area. Although each iteration specified different outlets, each run created a single watershed that filled the entire window. Specifying a mask encompassing the Fort Chaffee installation also had no effect. Possible explanations will be discussed in Chapter 5.

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[1] Marjorie Larson, "GRASS Tutorial: Watershed," in *GRASS: User's & Programmer's Manual for the Geographical Resource Analysis Support System*, ADP Report N-87/22 (U.S. Army Construction Engineering Research Laboratory [USACERL], rev. September 1988).
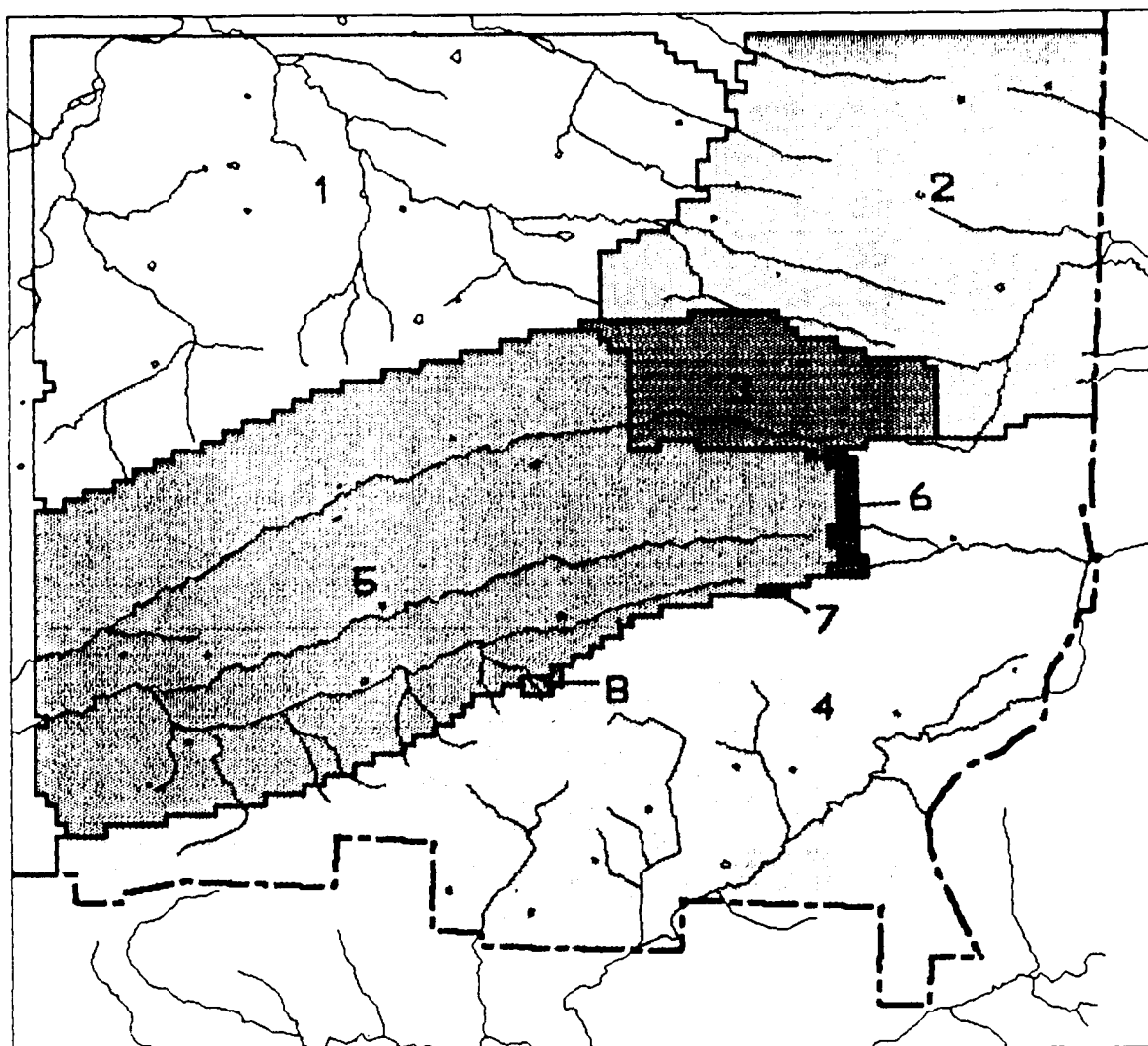
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b1-4_250.clump (PERMANENT)

streams (PERMANENT)

chai_boundary (PERMANENT)

1 bar250.accum   6 b2... and b3...
2 bar250.accum and b4_250.accum   7 b2... and b3...
3 b1_250.accum, b3.... and b4...   8 b2... and b3...
4 b2...
5 b3...

Figure 6. Major Watersheds in the Barber Area Generated From 1-Degree Data.

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Running watershed on the 7.5-Minute DEM Data in the Barber Area

With the exception of changing the cell resolution to 30 m, all of the same procedures used for the 1-degree data were used for the 7.5-minute DEM. The filtering and pit location processes ran in just under 4 min and located 37,457 pits. The drainage accumulation/watershed identification operated on 279 rows and 300 columns in approximately 13 min with the recommended pit threshold of five. In creating the stream networks, the recommended accumulation threshold of 60 was used.

The process just described underwent five iterations, one for each of the five identified outlets. The separate watershed map layers were then combined and clumped. Figure 7 displays the major watersheds produced by this process for the Barber quad. Figure 8 shows the minor watersheds produced for the Barber quad using automated delineation methods.

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Figure 7. Major Watersheds for the Barber Area Derived From 7.5-Minute Data.

SCALE: 1 : 60000
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WINDOW: 397650.00   406890.00
                              3892710.00
▬▬.▬
chaf_boundary (PERMANENT)

Figure 8. Minor Watersheds for the Barber Area as Automatically Delimited From 7.5-Minute Data.

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4 COMPARISON OF METHODS

Generally speaking, the watershed module was able to discern essentially comparable major drainage patterns at both the 1-degree and 7.5-minute scales. As both cell maps depict (compare Figures 6 and 7), the areas of pronounced relief within the east-west trending ridges were assigned roughly comparable watersheds. But, while this area was delineated as a single watershed in the western half of the 1-degree layer, on the 7.5-minute layer it was represented by two largely overlapping watersheds. This situation is in keeping with the minor watershed delineation (Figure 8). In both maps, a large watershed was located in the northern one-third of the window. Although an outlet was specified for both data scales, an overlapping watershed occurs on the 1-degree data layer. There is also a disparity in the eastern one-third of the images; neither reflects the actual change in the direction of the flow occurring in the eastern portion of the ridge system. In the southern and southeastern areas there is generally good agreement between the two maps.

In sum, the two digital sources produced roughly comparable major watersheds, but both generated inadequate results in the areas of more limited elevation differences.

Comparison of Manually Delineated Major Watersheds With 7.5-Minute and 1-Degree Watersheds Created by the watershed Module

The Barber Area

Figure 9 displays the 1-degree derived major watersheds overlaid by the vector outline of the manually delineated major watersheds. Figure 10 shows a similar comparison for the 7.5-minute derived major watersheds.

There is generally a good correspondence between the manually defined major watersheds and those derived by the watershed module from the 7.5-minute data. However, exceptions occur in two major areas. The automated approach derived a narrow corridor extending from the southwest corner of the Barber area completely across the study area to the eastern edge. This corridor represents the area of overlap of the watersheds to the south and north. As will be discussed later, this area of overlap is also identified as a subbasin. In this case, disregarding the encroachment of the southern watershed, the northern watershed boundaries compare favorably with the manually delimited watershed in that particular area. However, in the east-central map area, the manual process identified a watershed divide not shown in the automated version.

The second area, where results produced by the two methods disagree, is in the northeastern one-third of the study area. Apparently watershed was unable to discern from the DEM data the change in the flow direction that occurs in this quadrant of the image. There is no ridge to mark the divide between the watersheds, but there are several saddles in the terrain. The problem in recognizing these divides may be that these saddles are characterized by subtle differences in relief and elevation.

The comparison between boundaries generated by the 1-degree data and the manually defined watershed is not as exact as that for the 7.5-minute data, but there is a good rough correspondence. The 1-degree data did produce a watershed divide in the northeast quadrant, but its location does not correspond closely with that defined in the manually derived watersheds.
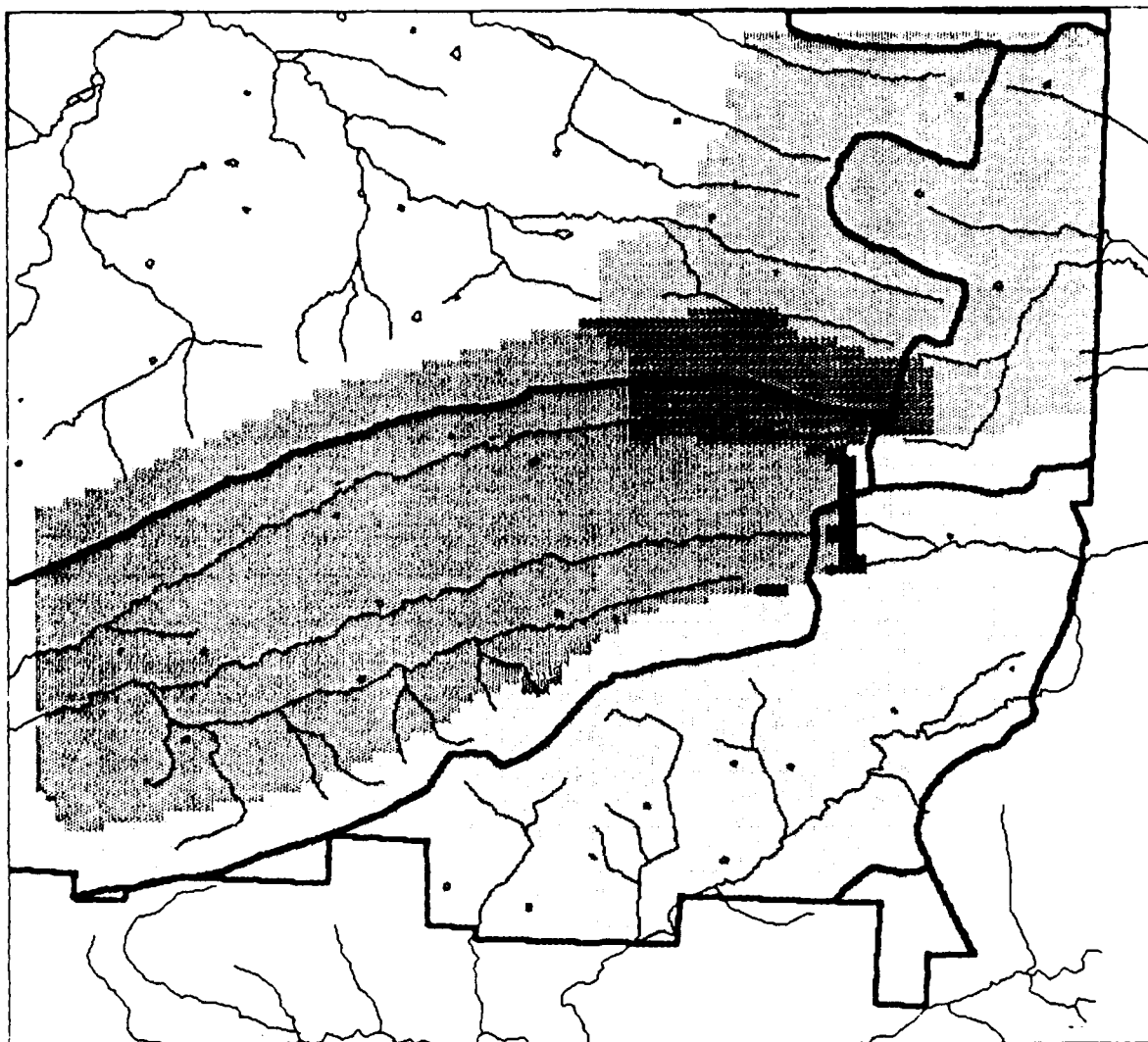
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barb.wat.maj (PERMANENT)

streams (PERMANENT)

1 bar250.accum   6 b2... and b3...
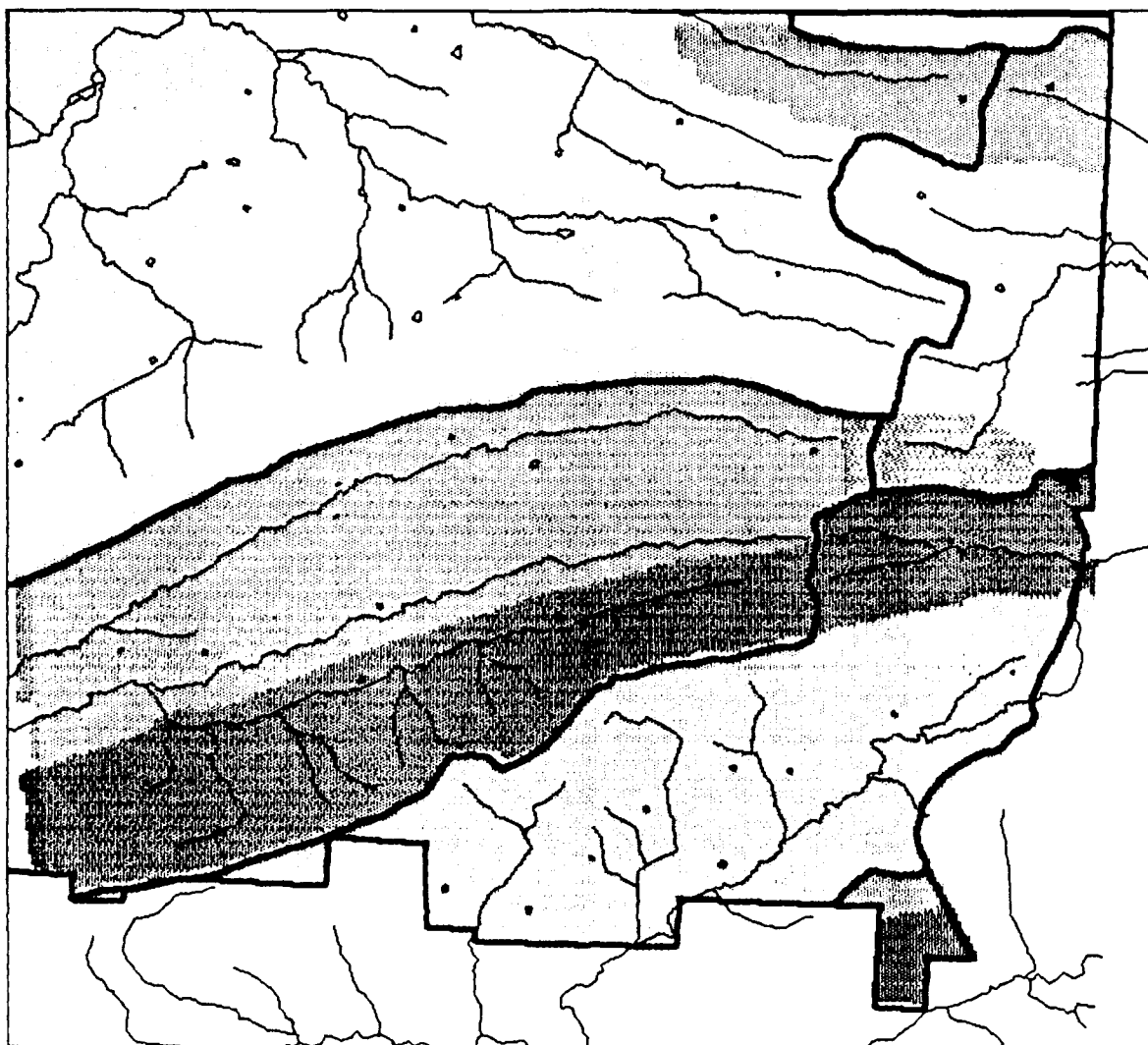2 bar250.accum and b4_250.accum   7 b2... and b3...
3 b1_250.accum, b3..., and b4...   8 b2... and b3...
4 b2...
5 b3...

Figure 9. Major Watersheds From 1-Degree Data Overlaid by Vector Map of Manually Derived Watersheds in the Barber Area.

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SCALE: 1 : 60000
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WINDOW: 397650.00   406890.00
                          3892710.00

barb.wat.maj (PERMANENT)

streams (PERMANENT)

1 b1_24.accum and b4_24.accum   6 b2... and b4...
2 b1...   7 b2...
3 b3...   9 b5...
4 b1... and b3...   12 b2... and b5...
5 b2... and b3...

Figure 10.   Major Watersheds From 7.5-Minute Data Overlaid by Manually Derived Watersheds
              in the Barber Area.

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In sum, the diagonally trending ridges, which constitute the major divides, produce watersheds recognizable at both scales as generated by the watershed module. The prominent difference occurs in the eastern part of this ridge system (where the flow direction was not correctly interpreted by watershed at the 7.5-minute scale), and in the northeastern quadrant (where a subtle watershed divide was not recognized in the 7.5-minute data and was incorrectly located in the 1-degree data).

Comparison of Manual Watersheds and 1-Degree Watersheds in the Cantonment Area

Although three different outlets were specified for the 1-degree DEM data within watershed, each run produced a watershed that filled the entire cantonment area window encompassing the eastern one-third of the Fort Chaffee installation. This result have been caused by the proximity of the Arkansas River, which runs through the extreme northern part of the installation. Running the module with an installation mask produced the same results.

It would be inappropriate to generalize from this single case, but the 1-degree data seems insufficiently detailed to locate accurate major watershed boundaries in areas of slight relief.

Manually Produced Minor Watersheds vs. 7.5-Minute Minor Watersheds Produced by watershed

Unlike the delineation of major watersheds within a bounded area, which is an objective process, the delineation of minor watersheds is much more subjective, and is scale- and goal-specific. Generally speaking, the determination of minor watersheds is probably more effective when associated with a specific project of defined scale. Figure 11 illustrates the manually delimited minor watershed for the Barber area. Figure 8 shows subwatershed basins for two watersheds determined by the watershed module from 7.5-minute data in the Barber area. This second map was generated using an accumulation threshold of 60. In the area of the diagonally trending ridges, the cell map generated by watershed is much more detailed than the one which was manually produced. However, watershed features of the ridges are recognizable in the watershed version, and categories could be aggregated if less-detailed subwatershed basins were desired, as in the case of the manually produced data layer.

The area of overlap located between the two major watersheds is clearly delimited on the minor watershed map as its own basin. In contrast to the potentially close correspondence in the ridge area, in the northern half of the watershed-derived map, no subwatershed basins have been defined that would correspond to those manually delimited.

Manually Produced Minor Watersheds vs. 1-Degree Minor Watersheds Produced by watershed

Although some topographic patterns are discernible in the 1-degree subwatershed basins that correspond to those manually defined (Figure 12), in general there is very little correspondence. For example, in the 1-degree subwatershed basins there are basins that cut across the major ridge divides. Of interest is the fact that, while the correspondence is not great, the 1-degree subwatershed basins in the northwest part of the area do correspond more closely to the manually defined basins than do those derived from 7.5-minute data.
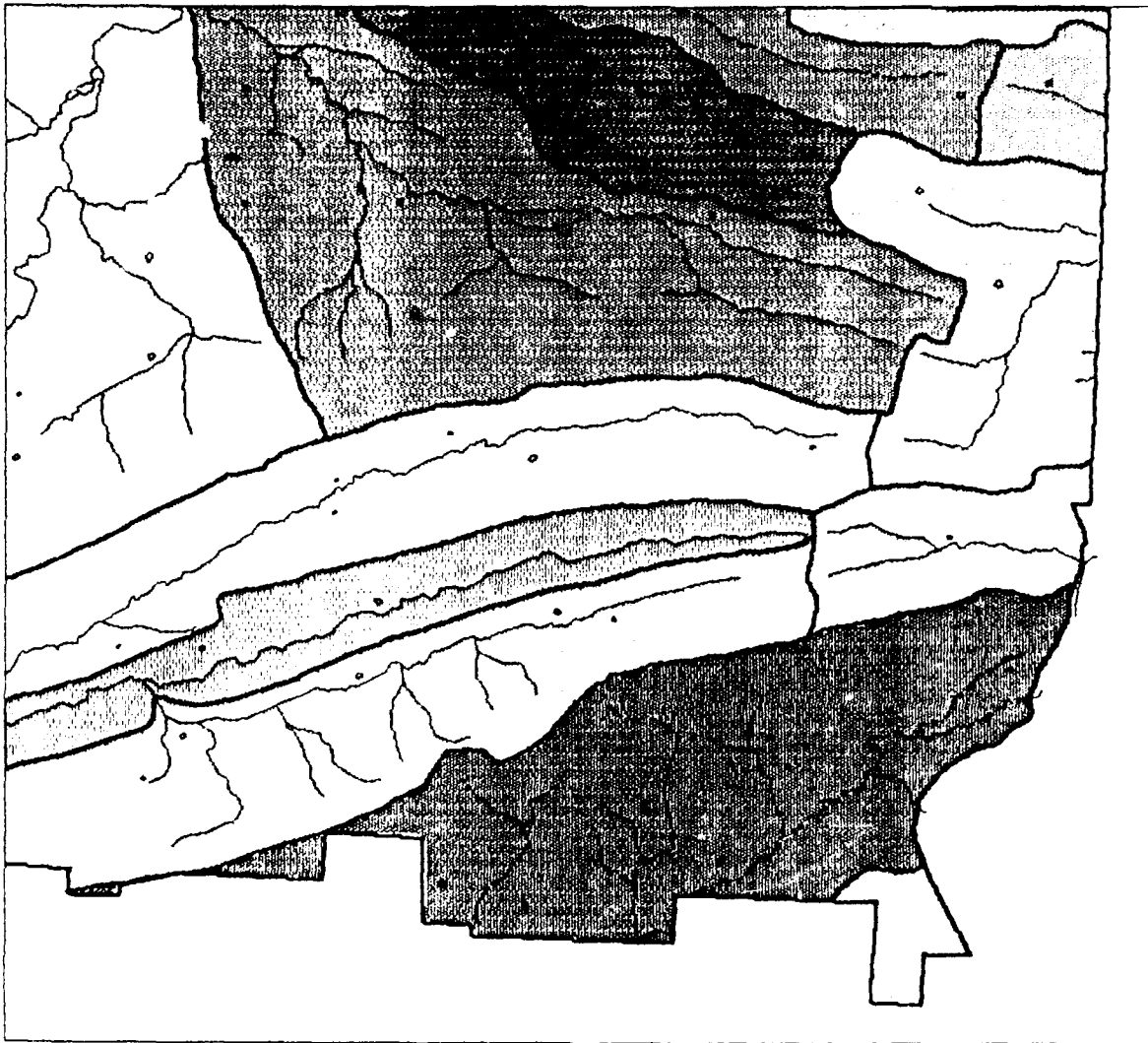
```
SCALE:     1 : 60000
                        3901080.00
WINDOW:    397650.00                    406890.00
                        3892710.00
streams  (PERMANENT)

barb.wat.min  (PERMANENT)
```

Figure 11. Minor Watersheds for the Barber Area as Determined Manually.
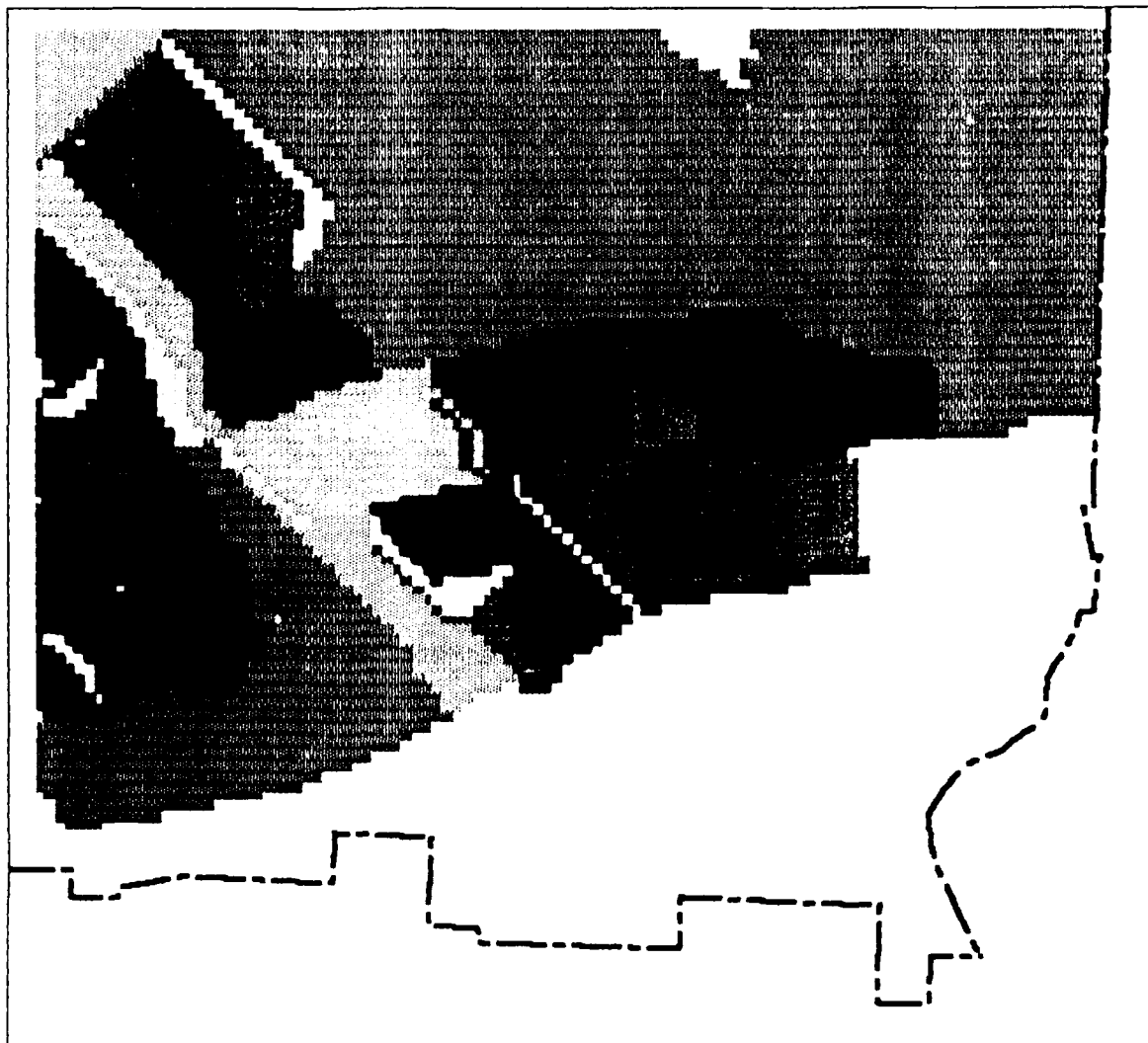
```
SCALE:     1 : 60000
                        3901080.00
WINDOW:    397650.00                    406890.00
                        3892710.00
```

chaf_boundary (PERMANENT)

Figure 12. Subwatershed Basins Delineated by the watershed Module Using 1-Degree Data.

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Comparison of Labor and Material Costs Associated With Manual and Automated Watershed Delineation

Manually Delineated Watersheds

The labor involved in producing the manually delineated watershed layers for the entire installation was composed of ordering the mylar separates, producing the base map, delineating the actual watershed, digitizing the watersheds, and making and supporting the cell maps. The tasks required a total of approximately 52 hours. Added to that would be the cost of a minimum of six mylar separates (topography only) at $36 each and 12 copies at $2 each. There were also about 14 hours of computer time consumed.

Automatically Delineated Watersheds From 7.5-Minute DEMs

Watersheds were not created for the entire installation at the 7.5-minute scale, since the digital data were not available. However, the following estimates were extrapolated from the single quad that was used. The labor estimate involved in the automated delineation of the watersheds for this project includes a minimal amount of learning time for first-time users, acquiring and loading raw DEM data, converting the data into GRASS cell files, determining the appropriate GRASS windows, determining all outlet points, running watershed for each of the outlets, clumping and combining cell files, and supporting all of the cell maps. These tasks required approximately 60 hours. Materials included six DEM files at $7 per file and a NCIC service/media charge of $90. In addition, there were approximately 40 hours of computer time required. Similar procedures characterize the use of 1-degree data, except that these data involve fewer files.

Cost Comparison

For computation purposes, a labor cost of $15 per hour and a computer services charge of $24 per hour have been assumed. Table 1 shows the costs using these assumed rates.

Using these assumed rates, the automated approach is nearly 50 percent more expensive than the manual approach. If larger areas were to be studied, the manual labor costs would rise in proportion, but the computer and labor costs for the automated approach would probably not rise as rapidly. In addition, the one-time $90 tape charge would be amortized over more area. Here the effort is assumed to be a one-time project. If the tasks were done repetitively, through experience and development of computer scripting, the costs would be expected to decline. Finally, it must be emphasized that the automated approach produces a much more extensive suite of "minor" watersheds, which should perhaps be called "micro" subbasins. Had the manual approach attempted to indicate subbasins of a similarly small scale as those delineated by the automated methods, the manual approach would have been much more time-consuming and correspondingly more costly.

Table 1

Cost Comparison

Method/Breakdown	Quantity	Unit Costs ($)	Total Costs ($)
Manual			
USGS mylar separates	6	36.00	216.00
Working copies	12	2.00	24.00
Labor (h)	52	15.00	780.00
Computer services (h)	14	25.00	350.00
Total			1370.00
Automated (Using 7.5-Minute Data)			
USGS DEM files	6	7.00	42.00
USGS tape charge	1	90.00	90.00
Labor (h)	60	15.00	900.00
Computer services (h)	40	25.00	1000.00
Total			2032.00

5 CONCLUSIONS

Comparisons of manually derived major watersheds with those derived by the GRASS watershed module from 1-degree and 7.5-minute data showed the methods to be roughly equivalent, with a few exceptions. In areas of pronounced relief, the 7.5-minute and 1-degree data produced watersheds that were in good general agreement with manually derived boundaries, but did not indicate relatively subtle saddle-based divides. Also, when the products of different outlet specifications where combined using electronic data, watershed boundaries overlapped. In areas of low relief (e.g., river floodplains) the 1-degree data produced only a single watershed while the manual system recognized a number of subtle divides.

The 1-degree data were unacceptable for delineating minor watersheds. The 7.5-minute data produced a large number of subwatershed basins in areas of more pronounced relief. These subwatershed basins could be "lumped" according to a variety of approaches and compared favorably with the manually derived minor watersheds. In areas of moderate relief, the manual methods yielded more watersheds than the automated method.

It must be recognized that watershed basin delineation is scale-dependent and should be designed to address specific problems. Based on the Fort Chaffee test, at the installation scale, the use of 1-degree data and the watershed module can produce adequate major watersheds. However, the 1-degree data are not adequate for delineation of minor watersheds. Whenever possible, the 7.5-minute data should be used to produce more accurate results. Using the automated method, the 7.5-minute data produced a large number of subbasins, an especially useful feature for pursuing application-specific goals. For 7.5-minute data, subwatershed basin production was satisfactory to excellent in areas of greater relief (in comparison to manually defined subbasins), but was not satisfactory in areas of moderate to lower relief.

A cost analysis showed that, for this study, the automated approach was roughly 50 percent more expensive based on the assumed costs for the study area. But, as the area increased in size, or as computer costs declined, the automated approach would be increasingly more cost-favored.

Other facts to be considered are the general advantages that automated data processing methods have over manual methods. GRASS programs are continuously being updated. Electronic map data are being improved, can be updated automatically, and are easily transported between installations. Lastly, manual delineation of watershed is a highly skilled labor process; the manipulation of electronic data is an operator's function that requires less training.

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