A GUIDE FOR THE USE OF DIGITAL ELEVATION MODEL DATA FOR MAKING SOIL SURVEYS

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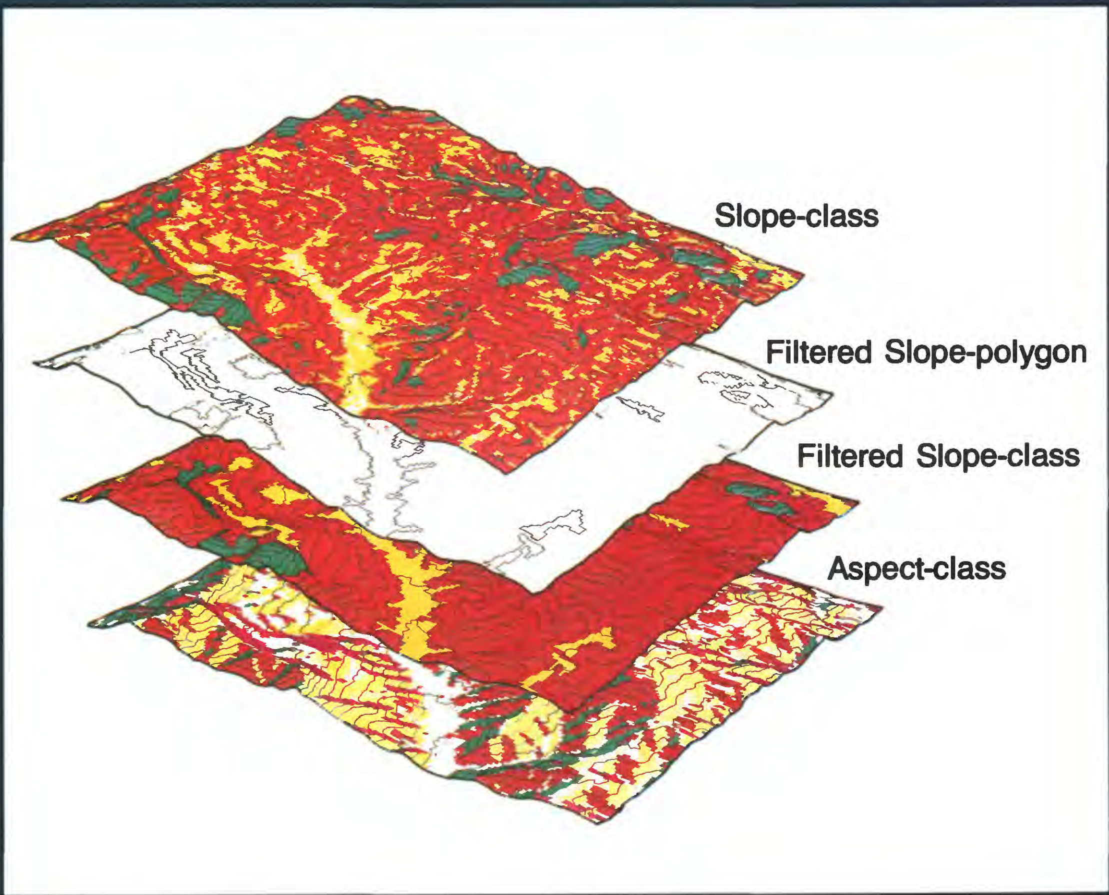

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of Agriculture
Soil Conservation Service

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Open-File Report No. 88-102

In cooperation with:

U.S. Department of Agriculture
Soil Conservation Service

UNITED STATES DEPARTMENT
OF AGRICULTURE
SOIL CONSERVATION SERVICE

and
Forest Service

and
U.S. Department of the Interior
U.S. Geological Survey

and
Bureau of Land Management

Sioux Falls, South Dakota

1988

PREFACE

The intent of this publication is twofold: (1) to serve as a user guide for soil scientists and others interested in learning about the value and use of digital elevation model (DEM) data in making soil surveys and (2) to provide documentation of the Soil Landscape Analysis Project (SLAP).

This publication provides a step-by-step guide on how digital slope-class maps are adjusted to topographic maps and orthophotoquads to obtain accurate slope-class maps, and how these derivative maps can be used as a base for soil survey pre-maps. In addition, guidance is given on the use of aspect-class maps and other resource data in making pre-maps. The value and use of tabular summaries are discussed. Examples of the use of DEM products by the authors and by selected field soil scientists are also given. Additional information on SLAP procedures may be obtained from USDA, Soil Conservation Service, Soil Survey Division, P.O. Box 2890, Washington, D.C. 20013, and from references *(Horvath and others, 1987; Horvath and others, 1983; Klingebiel and others, 1987; and Young, 1987)* listed in this publication.

The slope and aspect products and the procedures for using these products have evolved during 5 years of cooperative research with the USDA, Soil Conservation Service and Forest Service, and the USDI, Bureau of Land Management.

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GUIDE FOR THE USE OF DIGITAL ELEVATION MODEL DATA FOR MAKING SOIL SURVEYS

By A.A. Klingebiel[1], E.H. Horvath[2], W.U. Reybold[3], D.G. Moore[4], E.A. Fosnight[2], and T.R. Loveland[2]

INTRODUCTION

The importance of parent material, climate, relief, biological activity, and time have long been recognized by soil scientists as principal factors in soil formation. Slope- and aspect-class maps, derived from digital elevation model (DEM) data, have potential for providing some of this information. Since slope and aspect influence soil and vegetation types, it seems logical to use these maps for making soil surveys together with topographic maps and orthophotoquads.

The U.S. Geological Survey's (USGS) Earth Resources Observations Systems (EROS) Data Center (EDC), in cooperation with the Bureau of Land Management (BLM), Forest Service (FS) and the Soil Conservation Service (SCS), has developed a procedure that uses spatial and tabular data bases to generate elevation, slope, aspect, and spectral map and tabular products that can be used during soil mapping *(Horvath and others, 1987)*. The tabular data are indexed to soil landscape delineations and help quantify soil map unit composition. The data are also available in computer format for entry in microcomputer data bases. These data help soil scientists evaluate and describe mapping units and provide valuable information to users of soil surveys in resource planning and management.

The USGS, as a part of its National Mapping Program, has developed digital elevation data products in a standard DEM tape format (USGS, 1987). Methods have been developed to convert these 7.5-minute DEM data to slope- and aspect-class maps at 1:24,000-scale.

Maps derived from DEM data have been checked in the field to determine their accuracy. The quadrangles selected to test the accuracy of the slope- and aspect-class maps covered areas that ranged from level to steep and mountainous. Climatic conditions ranged from hot arid areas receiving less than 200mm of precipitation annually to cold wet areas receiving precipitation of over 600mm annually. Fourteen 7.5-minute quadrangles were evaluated: three in northwest Wyoming, one in southeast Idaho, and ten in south-central Nevada. In each of the 14 quadrangles, sample sites were selected at random and checked in the field to determine the accuracy of the slope and aspect maps. The information from over 90 percent of the samples was sufficiently accurate to be used in soil surveys. Most inaccuracies occurred on slopes ranging from 0-5 percent and on terrain where slopes were short, complex, and irregular.

The slope, aspect, and elevation maps derived from DEM data, and the tabular summaries from these data were evaluated on over 600,000 hectares in Wyoming, Nevada, and Idaho under varying climatic/vegetative and topographic conditions. These products were found to be most effective for making order-3 soil surveys. When making these surveys, soil scientists normally cannot verify the soil boundaries throughout their entire course; many mapped boundary locations are based on judgment decisions after consulting aerial photographs and evaluating vegetation and terrain. Slope, aspect, and elevation maps provide information in areas of dense vegetation where aspect and elevation often influence the kind of soil and vegetation. Though DEM products can be used in different ways when making soil surveys, it is routinely necessary to adjust the digital slope-class map to fit the topographic map and the orthophotoquad if the slope- and aspect-class maps are to fit the landscape accurately.

DESCRIPTION OF PRODUCTS

Development of Products

DEM data are available from the USGS's National Mapping Division (NMD) as part of a series of digital products termed U.S. GeoData *(Elassal and Caruso, 1983)*, although national coverage is not complete. Most of the present coverage is in areas of high relief. DEM data *(Doyle, 1978)* are available on a 7.5-minute quadrangle basis in a 30-by-30-meter grid-cell format. The array of elevation values is referenced to the Universal Transverse Mercator (UTM) coordinate system *(Horvath and others, 1987)*. The 7.5-minute series of DEM products has a source scale of 1:24,000. When the data are used to generate a 1:24,000-scale graphic, the graphic will correctly overlay the corresponding standard 7.5-minute quadrangle topographic map and orthophotoquad.

The slope and aspect products produced at the EROS Data Center (EDC) are derived from the elevation values using root-mean-square calculations and are grouped according to selected slope, aspect,

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[4] U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota 57198.

and elevation classes. The slope algorithm calculates percent slope and the aspect algorithm provides slope direction data expressed in compass coordinates *(Doyle, 1978; Horvath and others, 1983; and ESL, Inc., 1984)*. The slope-class intervals, aspect-class intervals, and critical elevation contours are selected by the field soil scientist according to the terrain and potential uses of the area that is being mapped. It is essential that the slope-classes fit the landscape and be meaningful in separating soils for potential use and management.

Slope-Class Maps

Four to six slope classes are commonly selected for mapping, although as many as seven may be selected. Two slope-class maps, for example, filtered and unfiltered, are generally produced for each 7.5-minute quad.

Since the DEM data are in grid cell format, the derived slope-class maps do not have smooth lines that represent landscape boundaries *(fig. 1)*. The computer outputs one character representing each 30-meter square cell, which often results in too much detail, thereby confusing the interpretation of general slope patterns and important slope breaks. To avoid displaying unwanted detail, a "filtering" algorithm *(Mayers and others, 1987)* incorporating areas smaller than 4 hectares (10 acres) is generally applied to the images before printing the slope-class maps *(fig. 2)*. Since small areas are not normally shown on order-3 soil surveys, the 4-hectare filtering has given the best results for generalizing excessive detail. Where an 8-10 hectare filtering is used, some of the important slope detail is lost resulting in questionable slope boundaries; however, in very rough terrain this broader filtering may be preferable. When ordering slope-class maps from EDC, the field soil scientist can select the number of hectares for the minimum-size slope-class delineation. However, if filtered slope-class maps are ordered and a number is not selected, the slope-class data will be filtered to 4 hectares.

Both filtered and unfiltered slope class maps are reproduced on transparent mylar with classes differentiated by discrete colors.

Apect-Class Maps

When ordering aspect-class maps, the aspect classes mapped are selected to be most useful in the area. Two to four classes are commonly used. The most common request in the more mountainous western States is for two classes, namely, north/east and south/west; in azimuth degrees, 310 to 110 and 111 to 309, respectively.

Generally, slope must be greater than 15 percent for aspect to be a noticeable factor in soil formation and to influence vegetation; thus, the field soil scientist should be able to select the percent-slope break to eliminate aspect classification in relatively level areas. However, if a specific break is not selected, the aspect-class maps will be produced using a 15-percent slope mask. The aspect-class maps are output on mylar and display a discrete color for each class. The more level areas not assigned to an aspect class remain clear *(fig. 3)*.

Critical Elevation Contours

Critical elevation contours can be generated from the DEM elevation data. Two to six elevation contours are commonly selected by the field soil scientist, although as many as eight may be selected. The elevation contours selected should be those that coincide with soil temperature breaks, kinds of soil-geomorphic features, vegetation, and land use management boundaries. Where a relationship exists between elevation and aspect, or elevation and slope, such information can be useful.

Black elevation-class lines, as selected by the field scientist, are superimposed over slope-class maps or aspect-class maps as shown in figures 1-3, for Soapy Dale Peak. The critical elevation contour was selected to separate areas higher than 2,255 m from those lower than 2,255 m.

Tabular Summaries

After the DEM data have been filtered (for example, to display only polygons of 4 hectares or greater), tables can be generated from slope class maps that summarize the individual 30 x 30-meter cells within each slope-class polygon. Each polygon for a 7.5-minute quadrangle is given a unique consecutive number. The numbers are placed within the polygons and are shown on a slope-class polygon map *(fig. 4)*. Tables are generated that show the percentage of cells in each slope and aspect class within each polygon. They also show the highest and lowest elevation within each polygon, together with other statistical data.

Landsat Spectral Data

Landsat multispectral scanner (MSS) imagery can be used at a scale of 1:24,000 with the maps derived from DEM data for making order-3 soil surveys. An unsupervised classification can be performed on a brightness/greenness transformation of the Landsat MSS data to reduce the information to the most dominant patterns in the survey area *(Horvath and others, 1983)*. The classified spectral data are geometrically corrected and divided into separate 7.5-minute quadrangles. Ten to twenty classes are commonly used to indicate degrees of brightness and greenness.

Figure 1.
Slope-class map showing unfiltered individual cells of four slope classes and critical elevation contours.

Figure 2.
Slope-class map generated using 4-hectare filtering showing four slope classes and critical elevation contours.

Figure 3.
Aspect-class map showing four aspect classes and critical elevation contours.

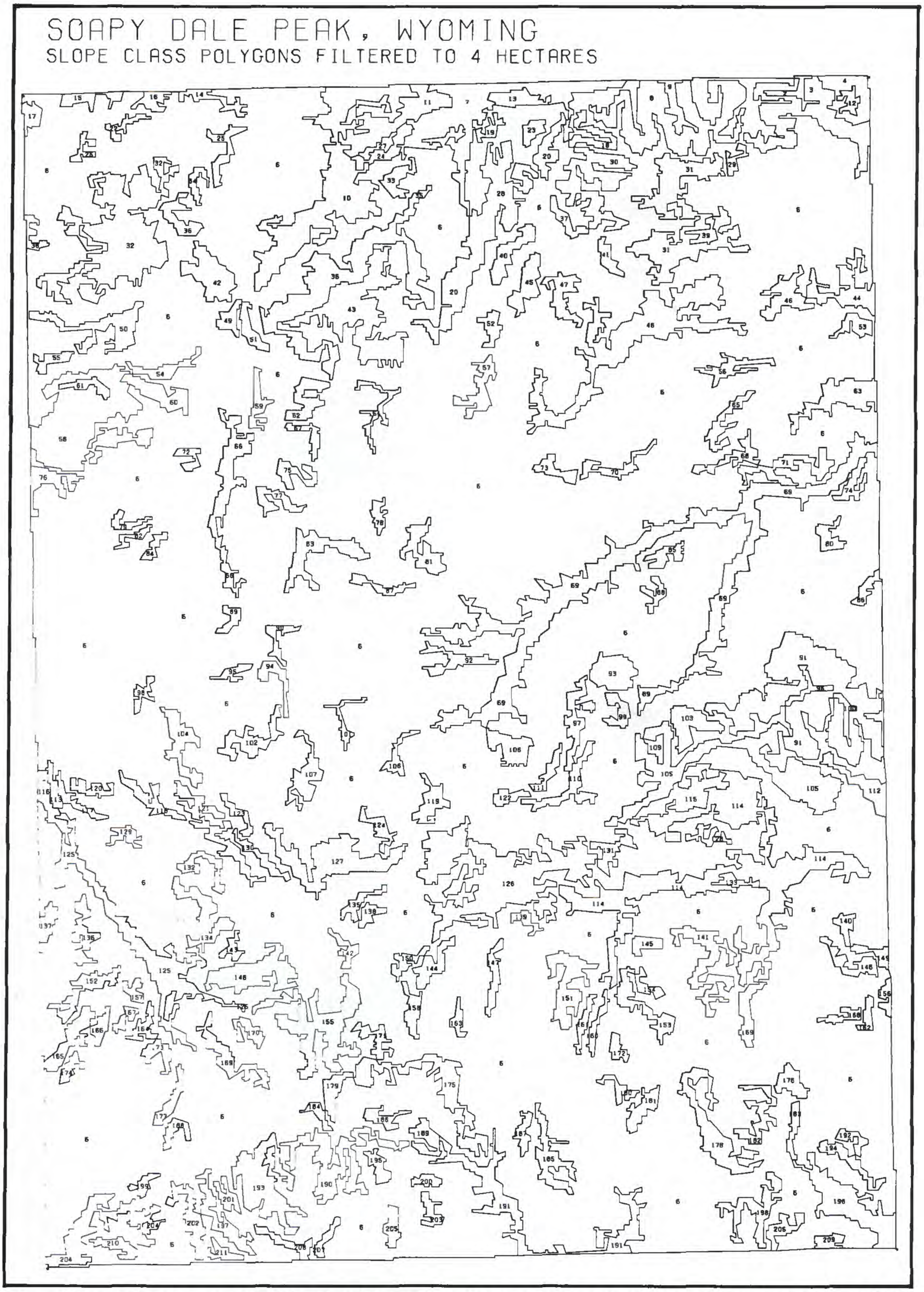

Figure 4. — Slope-polygon map after 4-hectare filtering showing consecutive numbering of the slope-class polygons.

PROCEDURE FOR USING PRODUCTS

Most soil scientists study and annotate orthophotoquads or aerial photographs before going to the field to make a soil map. Many will do photo-interpretation to determine vegetative and landform boundaries, and will use a stereoscope to delineate slope breaks. In addition, they refer to geologic maps and other resource data that are helpful in identifying the soils and their potential use. A brief reconnaissance of the area is commonly made to verify selected observations noted on the photograph. Before the scientist goes to the field, some lines are often drawn on the photograph to be used as a field mapping base. These preliminary delineations forming a premap, made prior to the field survey, speed the field mapping. Making pre-maps using DEM products provides the soil scientist with quantitative reference data for slope and aspect. For example, without slope-class maps, the soil scientist does not know the actual slope in areas delineated on a photo even using a stereoscope.

To utilize fully the value of the DEM-derived maps in making pre-maps, it is necessary to adjust the slope-class map to the topographic map and to the orthophotoquad.

Slope-Map Adjustments

Even with a 4-hectare filtering, it is necessary to adjust the slope-class lines to fit the landscape *(Klingebiel and others, 1987) (fig. 5)*. First, the interpreter must compare the digital slope-class boundaries with some of the lines on the topographic map. It is essential to adjust the slope-class boundaries to fit the topographic lines if the slope-class map is to fit the landscape and to provide accurate information about the slope. To make this adjust-

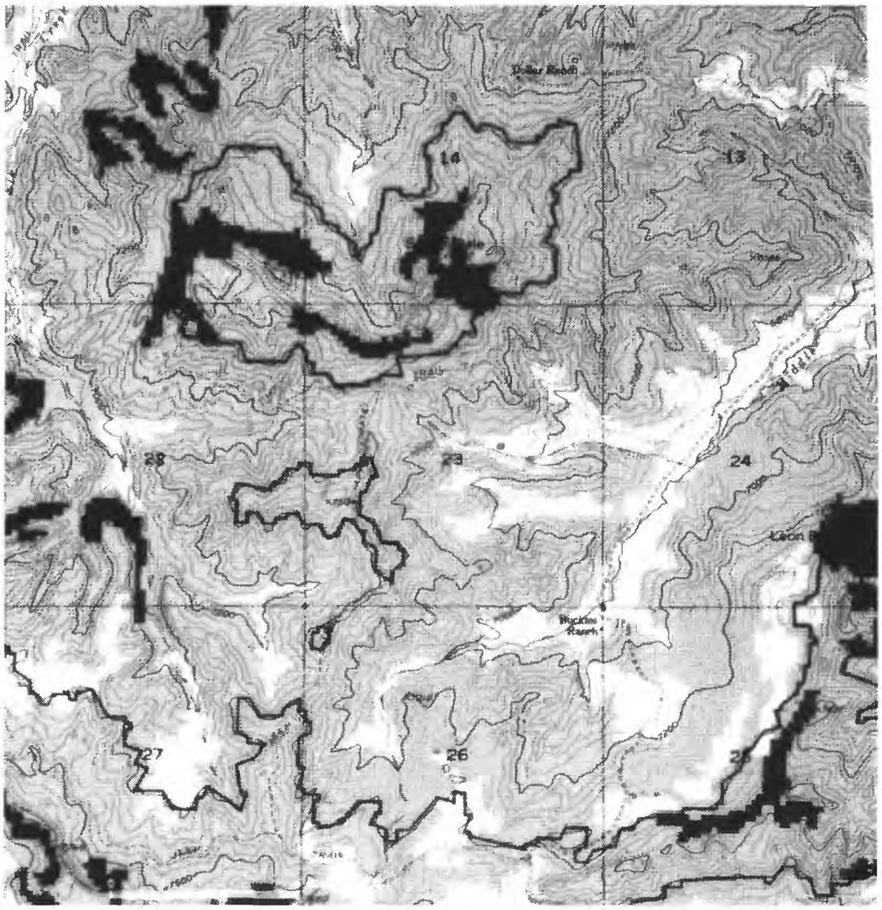

Figure 5. — Slope-polygon map after 4-hectare filtering overlayed on the 7.5-minute topographic quadrangle. This map is a black-and-white enlargement from the center of figure 2. Slope legend: white 0-5%, light gray 6-15%, medium gray 16-40%, black 41+%. The lowest class (white) does not occur.

ment, the slope-class map is overlayed on the topographic map, and those slope-class polygons significant to the survey are carefully transferred to a clear overlay that is placed on these maps *(fig. 6)*. This step eliminates unnecessary detail in the slope-class map. The objective, much like the use of the stereoscope and the aerial photograph, is to delineate significant areas of similar slopes. Relief is an important factor in soil formation and in soil use and management; thus it provides a basis for potential soil delineations. The resulting map is a slope-class map adapted to the landscape. If an accurate slope class map is to be obtained, it is essential that this adjustment step be followed.

To assure that the slope classes fit the landscape as shown on the orthophotoquad, it is necessary to overlay the adjusted slope-class map on the orthophotoquad and further adjust the lines to fit slopes as interpreted from the imagery *(fig. 7)*. Often only minor adjustments are needed, such as deleting small areas, connecting ridgetops, valley bottoms, steep slopes, and adding or deleting isolated

Figure 6. — Clear overlay with 4-hectare filtered slope-polygon boundaries adjusted manually to fit the terrain on the 7.5-minute topographic quadrangle. This map is a black-and-white enlargement from the center of figure 2. Slope legend: (B) 0-15%, (B-C) 0-40%, (C) 16-40%, (C-D) 16+%, (D) 41+%.

delineations. Again, this step is essential if these maps are to be used as the basis for pre-maps or for the final soil map.

At this stage in the map-development process, the adjusted slope class is a suitable basis for preparing a pre-map prior to making the final soil map, or as a reference map only for slope information. In the latter case, a filtered or unfiltered slope-class map could be used directly with the orthophotoquad in determining the slope class for individual areas. A word of caution in this latter case: unless slope-class boundaries coincide with the soil-delineation boundaries, the prediction of a slope class within the soil boundary may not be accurate.

Making Pre-Maps

After the computer-generated slope-class map has been adjusted to the topographic map and the orthophotoquad, the soil scientist can use the adjusted slope-class map as a base for preparing a pre-map. Interpretation of the orthophotoquad and other reference information such as aspect, elevation, parent material, and vegetation, help in the place-

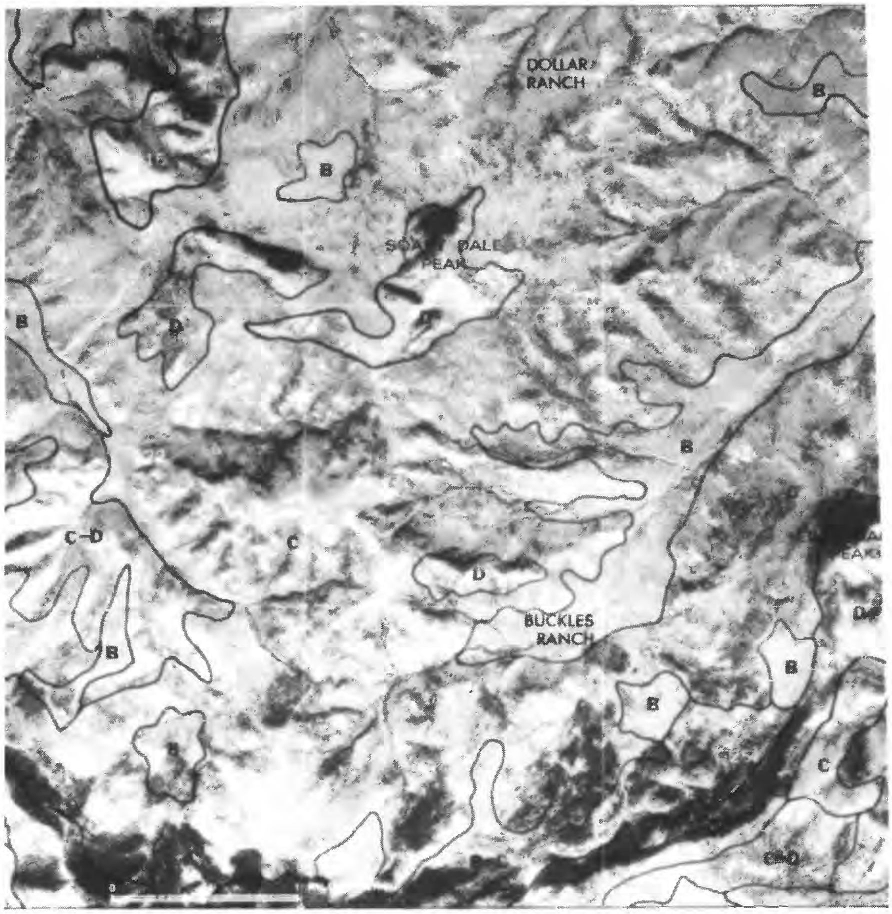

Figure 7. — Clear overlay with slope-polygon boundaries further adjusted manually to fit significant landscape/vegetation features on orthophoto. This map is a black-and-white enlargement from the center of figure 2. Slope legend: (B) 0-15%, (B-C) 0-40%, (C) 16-40%, (C-D) 16+%, (D) 41+%.

ment of lines. Further adjustments can be made to the slope boundaries and combinations of slope classes that seem appropriate for the survey area, as well as to the delineation of areas that appear to be different on the orthophotoquad. The pre-map evolves from the adjusted slope-class polygon map through the incorporation of whatever resource information the soil scientist judges is critical to the soil survey *(fig. 8)*. With some knowledge of the area, an experienced soil scientist can include in each delineation a symbol that represents the slope class, the landform, and possible geologic materials, and can predict the kind of soil at some level in the classification system.

Soils can be identified at levels ranging from the Great Group to phases of Families or Series. Landforms identified are commonly recognized in the area and related to either kinds of soil or management.

In making a pre-map, one of the major objectives is to have the delineations approximate those on the final soil map. In most instances, because of the influence of the slope-class delineations, the pre-map will contain more delineations than conventional pre-maps or final soil maps. Judgment is required to combine or eliminate delineations not significant to the soil survey.

Soil moisture and soil temperature are criteria used in classifying soils. In many areas, these two factors are closely related to aspect and elevation; thus, aspect-class maps and critical-elevation contours can be helpful in delineating significant types

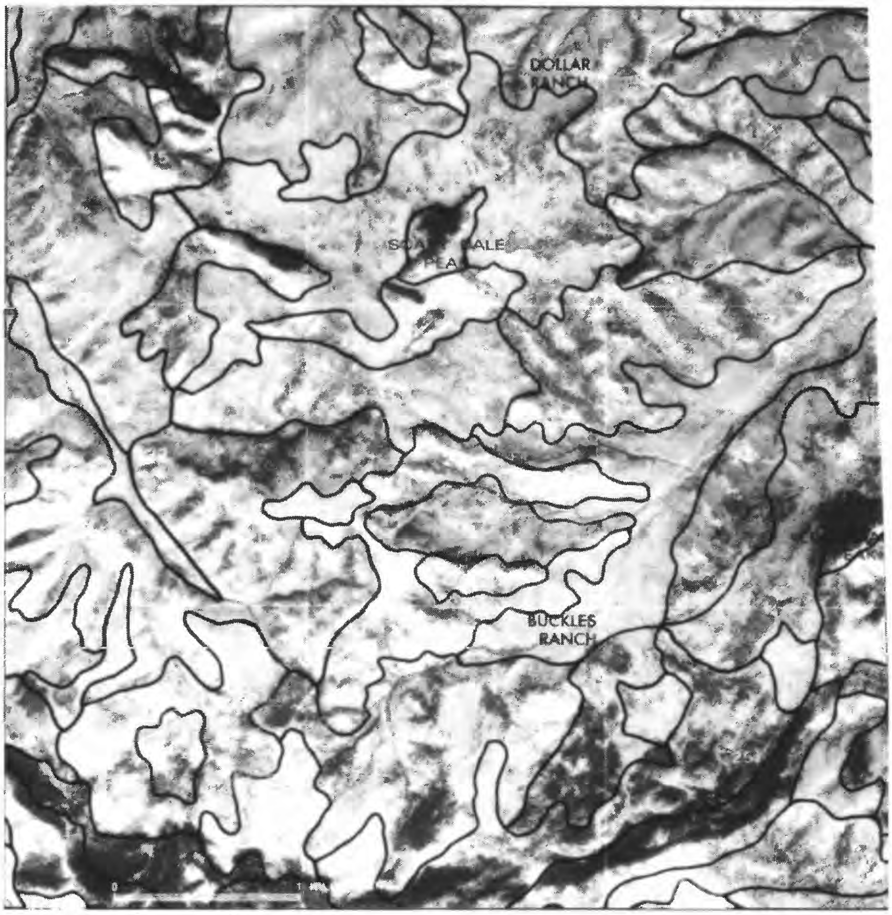

Figure 8. — Soil survey pre-map based on slope, aspect, and elevation information maps, together with other resource data available to soil scientists.

of soil and vegetation. In areas where aspect and elevation influence the kind of soils and their use, those maps can be used in the pre-map stage to make further delineations, or they can be used when the final soil map is made *(fig. 9)*.

Considerations for Making And Using Slope Maps Derived From DEM Maps

- The digital slope-class map will not perfectly conform to the slope-class polygons as interpreted by a soil scientist. On steep slopes, the slopes tend to be underestimated, and landforms containing complex slopes such as highly dissected terranes, drainages, and saddles will require manual interpretation. However, after these maps have been adjusted to the topographic map and the orthophotoquad, they have proved to be accurate and adequate for use in making order-3 soil surveys. As the digital processing methodology evolves and data quality improves, less adjustment to the topographic map will be necessary, even though some adjustment will always be required.
- Slope classes derived from DEM data are not reliable on slopes of less than 5 percent. These slopes must be separated by manually interpreting the topographic maps, or by inference, using the orthophotoquad or other photographs.
- Experience indicates that a 4-hectare (10-acre) filtering of the slope data provides the most useful slope-class maps for soil surveys. The unfiltered maps contain too much detail, and filtering of

Figure 9. — Clear overlay with slope-polygon boundaries after adjustment to the topographic map and the orthophotoquad on aspect-class map. Legend: Slope classes: (B) 0-15%, (B-C) 0-40%, (C) 16-40%, (C-D) 16+%, (D) 41+%. Aspect classes: white, north; light gray, east; medium gray, south; dark gray, west.

more than 4 hectare leaves out too much detail, resulting in slope-class maps that are even more difficult to fit to the landscape. However, some people prefer using unfiltered slope-class maps.

- It is important to select slope classes that fit desired breaks in the landscape, which should coincide with the soil legend, and that reflect differences in management, soils, and vegetation.
- Colored, unfiltered slope-class maps derived from DEM data can be used directly as overlays on other maps, or on the completed soil map to obtain quantitative estimates of the range in slope classes, the areal extent of each slope class, and the complexity or uniformity of slopes within an area. These maps will show the existence of the different slope classes within an area, but the boundaries and extent of these slope classes commonly do not fit the landscape. Thus, it is important to adjust the DEM slope-class map to the topographic map and the orthophotoquad.
- A light-table is generally needed when using the colored, unfiltered slope-class maps.
- Selecting too many slope classes for an area is often better than selecting too few, because if more detail is needed for some map units, adequate slope classes are available. For the map units that are broad and general, the slope classes can be combined. More slope classes provide greater flexibility in use of the slope-class maps.
- On the average, it takes a person about 1 day to make an accurate slope-class map of a 7.5-minute quadrangle by overlaying the computer-generated map on the topographic map and the orthophoto-quad. The time required depends on the complexity of the area and the number of classes to be delineated.
- DEM derived slope-class maps commonly show a lot of "noise" (cells of different slope classes) on terrain where the slopes are short, irregular, and generally less than 25 percent. Some extra time is required in these areas to map a complex of slope classes.

Aspect-Class Maps

Aspect is an important feature to recognize in some landscape and climatic areas. It is especially important in mountainous country where the microclimate changes with elevation and aspect. Commonly northern and eastern exposures on slopes over 15 percent are cooler and more moist than southern and western exposures, resulting in different kinds of vegetation and growth rates. As a result, it is not uncommon to relate these conditions to different kinds of soil and management practices.

Aspect-class maps are found to be useful in the higher, more rugged terrain where aspect has an influence on the soil temperature and moisture regimes and the kinds and amounts of vegetation. Aspect-class maps are not generally too useful in arid and gently rolling areas where aspect has little influence on soil temperature and moisture.

The aspect class map is overlayed by the slope map after adjustment to orthophoto and/or the premap to provide additional information.

Critical Elevation Contours

For the more rolling, steep terrain at higher elevations, there are close inter-relations among elevation, precipitation, and temperature, which in turn influence the kind of soil and vegetation found in the area. Also, in many areas, specific landforms, such as terrace remnants with their associated soils, occur consistently at a given elevation. Where these relationships occur, the elevation contours are overlayed on the orthophotoquad and/or the premap to provide additional information about the area and where to expect these features to influence the kind of soil to be mapped.

Spectral-Class Maps

Landsat imagery can be used with DEM data in making soil surveys. This is done by registering the Landsat map data to the quadrangle map at the scale of 1:24,000.

When the spectral data are plotted as maps for each quadrangle area, ellipse plots are provided to the soil scientists to facilitate the recognition and labeling of the spectral classes that occur within each soil delineation in terms of overall brightness and greenness. The ellipses plot one standard deviation drawn about the mean for each spectral class from the brightness-versus-greenness data. High brightness values indicate bare areas, rocks, and eroded areas, which are highly reflective. High greenness values indicate vegetation and areas of high green biomass.

The probability ellipses offer several advantages when used in the field: (a) they provide a quick estimate of the mean brightness and greenness values for each class and how these values are distributed among the classes, (b) they provide an estimate of spatial variability for each spectral class, and (c) they illustrate which spatial classes are most likely to be either an association or a complex of surface patterns.

Spectral-class maps are used mainly during the field verification phase to identify spatial and spectral variability within the pre-map delineations. Spectral classes provide useful information in areas having 20 percent or more vegetative cover; however, the interpretations vary from map to map for the various spectral classes. Due to the added cost of the spectral data and the lack of reliability of the interpretations over broad areas, the use of this product for the average soil survey must be thoroughly evaluated. The spectral-class maps and accompanying tabular summaries are available from EDC and can be ordered in ways similar to DEM products.

Tabular Summaries

Two tables providing statistical information for each filtered slope-class polygon for a 7.5-minute quadrangle are available from EDC when filtered slope maps are generated from the DEM data. The tables describe the slope-class polygon before any manual adjustment. The tables are available from EDC as either paper copy or on a 5¼" floppy disc in a Microrim Rbase format. *Figure 10a* contains an example of a standard table index map for the Soapy Dale Peak, Wyoming, 7.5-minute quadrangle subset. Statistical data are given for slope, aspect, and elevation for each polygon on the map *(fig. 10b)*. The columns of the two tables are defined as follows. The abbreviation in parentheses is the name of the column within the Rbase data base.

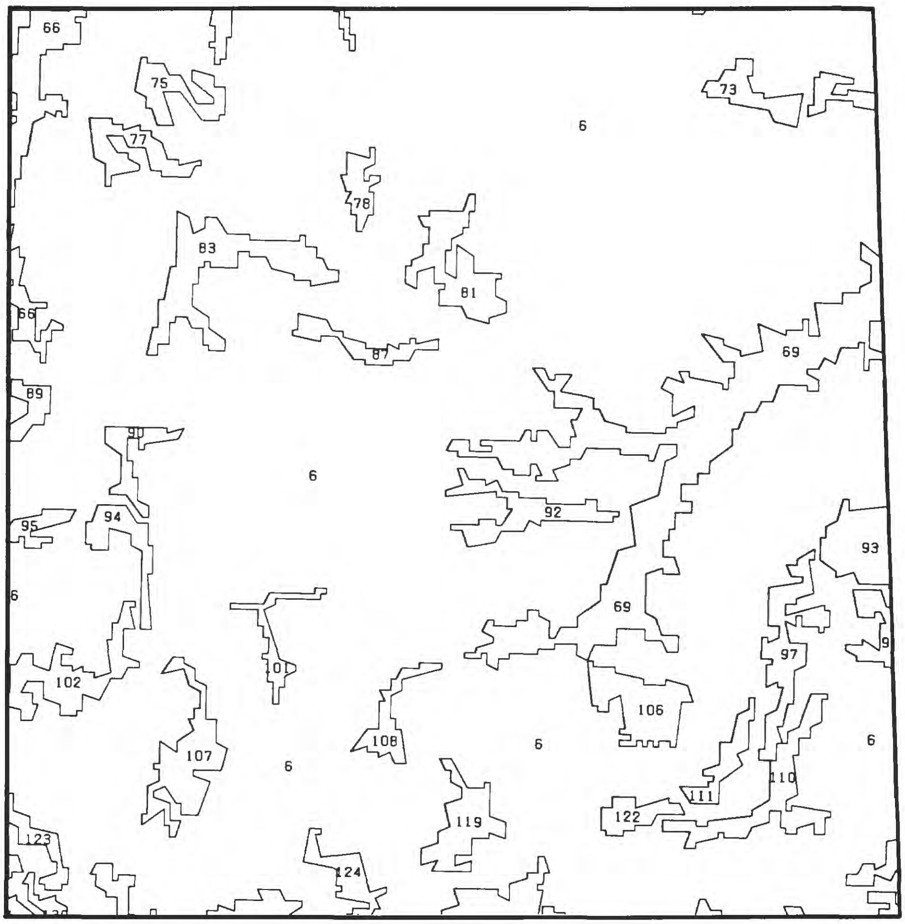

Figure 10a. — Index map for the Soapy Dale Peak quadrangle, Wyoming, tabular summary using the region number (subset of figure 4).

SOAPY DALE PEAK, WYOMING
DESCRIPTIVE STATISTICS FOR SLOPE AND ELEVATION

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REGION	SLOPE (percent)					ELEVATION (meters)				
NUMBER	MEAN	SD	MINIMUM	MAXIMUM	MODE	MEAN	SD	MINIMUM	MAXIMUM	MODE
6	26.04	9.57	0	107	22	2221.87	136.37	1916	2715	2127
66	9.84	3.84	1	20	11	2083.94	19.98	2050	2132	2064
69	9.52	3.77	0	22	11	2065.11	54.30	1954	2194	2089
73	10.92	4.05	1	19	12	2140.01	9.28	2119	2156	2152
75	45.87	7.52	12	60	47	2167.95	25.50	2106	2221	2172
77	48.83	7.04	23	69	41	2174.96	29.06	2116	2234	2139
78	11.85	2.97	5	16	15	2215.38	10.16	2191	2234	2214
81	53.88	10.16	28	78	52	2327.35	34.99	2246	2394	2314
83	50.50	14.65	1	81	48	2288.60	42.64	2195	2380	2288
87	49.04	5.92	41	61	47	2308.51	17.70	2271	2347	2300
89	47.36	3.85	41	57	45	2174.43	16.43	2136	2206	2164
90	9.06	3.92	1	15	11	2144.48	7.81	2132	2159	2140
92	10.66	2.96	2	15	12	2128.95	20.05	2095	2165	2108
93	51.79	12.60	10	79	51	2268.26	34.22	2189	2350	2273
94	44.14	8.08	19	57	45	2180.80	14.96	2152	2212	2177
95	45.55	7.88	21	59	44	2200.70	14.43	2174	2227	2187
97	9.90	3.94	1	20	11	2242.02	11.11	2221	2266	2230
101	10.76	2.92	5	15	12	2198.13	13.31	2173	2224	2193
102	11.76	2.76	3	18	15	2247.05	15.65	2216	2278	2243
106	11.96	4.36	1	26	14	2167.93	17.80	2126	2193	2185
107	11.17	3.01	2	18	11	2230.31	22.53	2181	2275	2240
108	10.94	3.30	4	18	11	2172.21	14.09	2145	2195	2183
110	49.05	9.67	18	73	44	2306.35	27.67	2257	2367	2305
111	9.28	3.72	1	15	7	2233.92	5.06	2222	2248	2232
119	12.04	3.60	4	22	15	2259.25	13.10	2234	2287	2248
122	8.51	3.75	2	16	6	2243.85	4.80	2233	2251	2243
123	44.56	5.21	26	53	41	2350.91	12.86	2318	2374	2329
124	11.63	3.00	2	17	11	2286.88	10.82	2258	2309	2290

SOAPY DALE PEAK, WYOMING
CLASS STATISTICS FOR SLOPE AND ASPECT

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REGION	TOTAL	SLOPE (class)					ASPECT (class)			
NUMBER	HECTARES	ASSIGNED	DOMINANT	PERCENT	SECONDARY	PERCENT	DOMINANT	PERCENT	SECONDARY	PERCENT
6	10055	3	3	82	2	11	1	26	2	24
66	32	2	2	81	1	15	10	96	1	2
69	193	2	2	82	1	17	10	98	1	1
73	7	2	2	79	1	13	10	92	1	8
75	8	4	4	89	3	10	4	53	1	43
77	8	4	4	99	3	1	1	55	4	43
78	5	2	2	94	1	4	10	98	4	2
81	15	4	4	97	3	3	2	28	4	26
83	23	4	4	87	3	10	4	51	1	34
87	6	4	4	100			3	94	4	4
89	5	4	4	100			2	53	3	25
90	6	2	2	77	1	23	10	100		
92	11	2	2	94	1	6	10	100		
93	18	4	4	89	3	10	1	34	3	27
94	8	4	4	85	3	15	2	52	4	26
95	4	4	4	87	3	13	3	72	1	17
97	15	2	2	82	1	16	10	98	3	1
101	5	2	2	98	1	2	10	100		
102	15	2	2	96	1	3	10	99	1	1
106	14	2	2	84	3	11	10	89	1	6
107	15	2	2	92	1	5	10	98	1	2
108	6	2	2	90	1	6	10	96	1	3
110	15	4	4	91	3	9	4	52	1	31
111	6	2	2	84	1	16	10	100		
119	11	2	2	84	3	10	10	90	2	10
122	5	2	2	76	1	22	10	98	1	2
123	5	4	4	93	3	7	4	56	3	31
124	7	2	2	94	1	5	10	99	2	1

Figure 10b. — Tabular summary for subset of Soapy Dale Peak quadrangle, Wyoming.

Descriptive Statistics:

Region Number	- A unique polygon identification number that is indexed to the vector filtered slope polygon map (REGNUM).
Mean Slope	- (MEANSLP)
Standard Deviation of Slope	- (SDSLP)
Minimum Slope	- (MINSLP)
Maximum Slope	- (MAXSLP)
Mode Slope	- (MODESLP)
Mean Elevation	- (MEANELE)
Standard Deviation of Elevation	- (SDELE)
Minimum Elevation	- (MINELE)
Macimum Elevation	- (MAXELE)
Mode Elevation	- (MODEELE)

Class Statistics:

Region Number	- (REGNUM)
Total Hectares	- (HECTARES)
Assigned Slope	- Slope class associated with filtered polygon that should, in all but extreme cases, be the same as the dominant slope (CLASS).
Dominant Slope	- The most frequently occurring slope class in polygon (DOMSLP).
Percent Dominant	- The percentage of the polygon occupied by the dominant slope class (DOMSLPHA).
Secondary Slope	- The second most frequently occurring slope class in polygon (SECSLP).
Percent Secondary	- The percentage of the polygon occupied by the secondary slope class (SECSLPHA).
Dominant Aspect	- The most frequently occurring aspect class in polygon (DOMASP).
Percent Dominant	- The percentage of the polygon occupied by the dominant Aspect class (DOMASPHA).
Secondary Aspect	- The second most frequently occurring aspect class in polygon (SECASP).
Percent Secondary	- The percentage of the polygon occupied by the secondary Aspect class (SECAPHA).

The data in tabular summaries can be helpful to soil scientists in describing soil mapping units and interpreting soils, determining the composition of mapping units, locating sample sites, determining the acreage of individual mapping units, and in preparing the final soil survey manuscripts. The extent and occurrence of soil map unit components can also be more accurately identified and described from the information provided by the summaries.

Tabular summaries like those in figure 10b are a standard product accompanying USGS-generated filtered slope maps. Where digitizing of the adjusted pre-map or final soil map is not practical, tabular summaries like figure 9 are still useful for estimating the slope, aspect, and elevation within the polygon shown on the map. These data can provide general statistics for the area; however, as the slope-class lines are adjusted to fit the landscape, the data become less specific for individual delineations.

Tabular summaries are available in hard copy or electronic medium from EDC. Obtaining the summaries in electronic medium enables direct entry of the data in microcomputer database management systems where the data can be manipulated and retrieved. It also enables the addition of other polygon attributes such as map unit symbol, geology, landform, soil classification, vegetation and other resource information.

The database can be queried for such information as: "Find all soil delineations in the survey area that are located between 1,067m and 1,379m elevation, on western exposures, and on slopes that are over 30 percent." Another query would enable all delineations that have the same mapping unit symbol to be found, and the shared properties of these delineations listed. This aids uniform mapping unit design, and can also increase consistency in the mapping process.

A further step, though not within the capability of most field soil scientists, is for entry of the DEM data into a geographic information system (GIS). The soil delineations on the final soil map can be digitized and analyzed with the DEM data to provide statistical data similar to that discussed above but for the actual map unit.

Using raster image-processing techniques *(Swain, 1978)*, information from all data categories could then be viewed on a computer screen and analyzed for each soil delineation. When a specific subset of soil delineations is desired, the spatial database could be used to produce a map showing the distribution of those delineations.

FIELD EXPERIENCE IN USING DEM-DERIVED MAPS

In association with this project, soil scientists from the Soil Conservation Service, Bureau of Land Management, and the Forest Service, have used and evaluated DEM-derived products as part of their soil survey efforts in various States since 1982. Although individual experiences differ considerably there is an agreement on the following:

— Slope and aspect maps derived from the DEM-derived products are generally adequate for the needs of an order-3 soil survey. Slope-class maps for areas that were nearly level (for example, less than 4 percent) were not accurate or contained excessive errors.

— Major benefits expected from the use of DEM-derived products are the improved quality of soil maps, soil descriptions, and interpretations. The tabular data associated with soil surveys executed with the use of the DEM-derived products will greatly enhance the soil scientists' ability to provide accurate and versatile interpretations from a soil survey.

— Soil scientists have greater confidence in their soil delineations when they use the DEM-derived products, especially where terrain and vegetation reduce visibility and access.

— The use of DEM-derived products increases the efficiency of the fieldwork by enabling the soil scientist to perform a more complete interpretation, and thus generate better pre-maps in the office. Therefore, the soil mapping will procede at a faster rate allowing more acreage to be mapped.

— Used with orthophotoquads, DEM-derived products will facilitate the eventual digitizing of soil surveys, and the incorporation of soil survey information into a data base.

— Soil scientists who customarily make pre-maps before detailed fieldwork are more receptive to the use of DEM-derived products than those that do not and those that pre-map only "in their heads" by visualizing delineations after photointerpretation.

— Soil scientists generally dislike the time it takes to adjust the original computer-generated slope-class plot to the topographic map to produce a usable slope map. The slope maps, however, frequently result in delineations of significant soil units that would be missed otherwise.

<u>Idaho</u>

Thirty-four of 315 soil pre-map delineations on the Johnson Creek quadrangle in southeastern Idaho were chosen at random and visited to evaluate the quality of the pre-map for soil survey. After the field visits, the soil scientists concluded that 95 percent of the landform designations were correct, 97 percent of the slope designations were correct, and 88 percent of the soil pre-map delineations corresponded with actual soil boundaries. Similar evaluations of soil pre-maps were also conducted in Wyoming and in Nevada, with comparable results.

A soil scientist in southern Idaho compared a soil pre-map, prepared with DEM-derived slope and aspect maps, to an area that he had previously mapped without these products. After a thorough comparison and some fieldwork, he decided that some adjustments were needed on the conventional soil map to account for terrain features that had been missed, but were important to the soil survey.

Soil scientists in northern Idaho offered the following suggestions:

— The tabular data, when itemized by soil pre-mapping unit, are very helpful for the evaluation of mapping units. They are also useful for writing soil-map unit descriptions.

— Aspect-class maps and elevation-class maps are an important aid in northern latitudes where temperature and moisture regimes are often closely associated with those parameters. Aspect and elevation also helped in defining soil boundaries associated with specific vegetation communities such as hemlock, grand fir, and douglas fir.

— DEM-derived slope maps add confidence and help refine boundaries that are first located using a stereoscope and aerial photographs. They also help pinpoint areas of inclusions.

— Tabular data, itemized from pre-map delineations, help identify the inclusions. The corresponding maps then aid in locating the inclusions in the field. The tabular data are an excellent tool when setting up new map units; they provide information on acreage, average slope, elevation range, and a percentage of aspect-related components.

— DEM-derived maps, in general, are excellent tools to determine representative areas to sample in the field.

— The placement of soil delineations was more accurate using a stereoscope and aerial photos.

These lines could follow a ridge, an escarpment, bottom land boundary, or a vegetation pattern more accurately than any of the DEM-derived products tested by itself.

Nevada

An order-3 soil survey was completed in 28, 7.5-minute quadrangles in south-central Nevada, using DEM-derived products. The conclusions drawn from this 2-year effort generally reflect those already mentioned, since they were the ground work for the methodology. Spectral maps derived from satellite imagery were not useful for this area, where surface patterns bear little resemblance to final soil mapping unit delineations.

The procedure used to incorporate the DEM-derived products into the process of making an order-3 soil survey was very well received, particularly as a training tool and as a way of obtaining accurate information about remote areas of difficult access.

Soil scientists in Nevada suggested that the first step in making a pre-map should be the delineation of natural landforms with some preliminary field time, and then overlay the slope, aspect, and other resource maps while making the final soil map. Soil scientists in Washington made a similar suggestion.

Soil scientists in the southwest U.S. (Arizona, New Mexico, Nevada) found that in hot arid areas with sparse vegetation, the relationships of slope to soil and vegetation are less pronounced, and thus less useful for soil mapping, than in cooler, more moist areas.

Oregon

A soil scientist in Oregon used the 1:250,000 arc-second DEM data, expanded to a 1:24,000 scale. It was not found to be satisfactory for order-3 soil survey work. The slope-class map adjusted to the topographic map lacked detail, and was not accurate enough. Similar findings were reported by Horvath and others (1983) for an area in north-central Wyoming. These less detailed digital products, however, can be a useful tool for making less detailed soil maps at smaller scales, and to help visualize general patterns and relationships of soil types.

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