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Wyoming Rocky Mountain Forest Soils: Mapping Using an ARC/INFO Geographic Information System

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ABSTRACT

In the western USA, wildland soil survey areas are often large, and the resources of money, personnel, and time required for conventional soil survey techniques are in short supply. We evaluated an alternative methodology for producing soil maps through a process of transecting, model construction, and projection onto a map base using ARC/INFO geographic information system (GIS) technology. We conducted this study in the Libby Creek watershed in Wyoming where soil distribution (Cryoboralfs, Cryoborolls, Cryaquolls, Cryaquents, Cryochrepts, and Cryorthents) is a function of geology, slope stability, and vegetation. The GIS-generated soils map was compared with existing general (Order 4) and detailed (Order 3) soils maps prepared for the U.S. Forest Service (USFS). Discrepancies noted between the GIS-generated map and USFS maps included: Cryochrepts were the dominant soil on the GIS map (44%), but comprised only 15% on the USFS detailed soils map; Cryumbrepts occupied 19% of the USFS general soils map but only 2% on the GIS-derived soils map; and no Cryumbrepts were delineated in the study area on the USFS detailed soils map. Only two of the eight Cryumbrepts sampled occurred within Cryumbrept delineations on the USFS general soils map. Of the 37 pedons sampled and classified along the five transects across Libby Creek watershed, 11 (30%) corresponded to named soils of mapping units in the USFS general soils map, and 20 (54%) coincided on the USFS detailed soils map. Results of this study suggest transecting and GIS-based mapping can be an effective technique for producing general soils maps, and can aid in placing soil boundaries for detailed soils maps.

Conventional soil survey methods require resources of money, personnel, and time, which are often in short supply. This is particularly true in the western USA where soil surveys of wildlands may encompass areas of >1 million ha. In the USA, soils are mapped through identification of a limited number of key characteristics recognized in the soil taxonomic system (Soil Survey Staff, 1996). Only in the most detailed soil surveys (Order 1) are soils mapped directly by sampling all individual pedons and the mapping unit boundaries observed in their entirety (Soil Survey Staff, 1993). In most soil surveys, soils are mapped using a model of soil occurrence, based on the five soil-forming factors (Jenny, 1941), and air photos or other remote sensing techniques. Topography, vegetation patterns, and color tones on the air photos are commonly used to help soil scientists place soil mapping unit boundaries. Thoughtful and consistent ground truthing is required to maintain the integrity of such maps.

To construct useful soils maps, soil scientists must identify and understand the spatial variability of soils within the landscape. Statistics, and more recently geostatistics, allow soil scientists to quantify mapping unit properties and concepts (Rahman, 1994; Rahman et al., 1996). Today, GIS that link graphic (spatial) data and tabular (descriptive) data offer many advantages over conventional cartographic techniques used to make soils maps (Slater et al., 1994).

The purpose of mapping soils is to partition the soil continuum into natural or artificial classes that have greater homogeneity for selected properties than the continuum as a whole (Wilding, 1985). Geomorphological position and topographic attributes such as elevation, slope, aspect, specific catchment area, plan and profile curvature, and hydrological and erosional processes occurring in landscapes influence horizonation and soil attributes (Moore et al., 1991; Odeh et al., 1991).

Water movement and lateral transport of materials are a major driving force in the processes that shape landscapes (Hall and Olson, 1991). Slope attributes: position, length, gradient and shape, all affect soil distribution and morphology (King et al., 1983). The topography of a catchment has a major impact on the hydrological, geomorphological, and biological processes active in the landscape. Digital elevation models (DEMs) are the primary data used in the analysis of catchment topography (Moore et al., 1991).

McSweeney et al. (1994) proposed development and use of three-dimensional models of the soil-landscape continuum utilizing GIS. They pointed out that such soil-landscape models can provide the basis for extrapolation on a broader scale and for more reliable interpretations of soil history and land use. Rogowski and Wolf (1994) combined the spatially interpolated distribution of measured values with soil map unit delineations within a GIS framework. The resulting maps preserved the map unit boundaries and incorporated spatial variability of attribute data into map unit delineations.

We used ARC/INFO GIS software (Environmental Systems Research Institute, 1993) for mapping and documenting the spatial variability of soils in a forested watershed (Libby Creek) in the Medicine Bow Mountains, Wyoming. The objectives of the project were to: (i) develop a model of soil occurrence based on landscape features, (ii) use ARC/INFO GIS to prepare a soils map of the Libby Creek drainage based on data collected by transecting the area, and (iii) compare the GIS-generated soils map with the USFS general and detailed soils maps produced by traditional soil survey methods.

MATERIAL AND METHODS

The study site, Libby Creek drainage area, is a 58-km^2 watershed on the east flank of the Medicine Bow Mountains

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Abbreviations: GIS, geographic information system; USFS, United States Forest Service; USGS, United States Geological Survey; UTM, Universal Transverse Mercator; DEM, digital elevation model; Su, summit; Sh, shoulder; Bs, backslope; Fs, footslope; Ts, toeslope; CV, coefficient of variation.

about 50 km west of Laramie, WY (Fig. 1). The Medicine Bow Mountains range in elevation from 2432 to 3445 m, with the Snowy Range massif extending to 3652 m. Soils in the study area are derived from Bull Lake and Pinedale age tills, which are approximately 140 000 and 25 000 yr old, respectively (Richmond and Fullerton, 1986), or Holocene deposits. The tills consist of a mixture of rock types including material from Precambrian quartzites, marbles, schists, gneiss, slates, and sandstones. Soils on the Bull Lake moraines contain more clay, a higher proportion of pedogenic clay, greater amounts of weathered stones, and greater free sesquioxides (McCahon and Munn, 1991). Soils are thicker and more strongly developed in the downslope positions, particularly on the older moraines (Swanson, 1985).

Average annual precipitation ranges from 81 cm at 2432-m elevation to 122 cm at 3445-m elevation. The soil temperature regime is cryic. Air temperature ranges from a mean monthly value of 1.7°C in January at 3445-m elevation to 16°C in July at 2432-m elevation. Extremes range from −40°C in winter to 32°C in summer. The average frost-free period is approximately 90 d (5 June–5 September) at lower elevations, but only a few frost-free days occur on some of the higher north-facing slopes (Marston and Clarendon, 1988).

Dominant vegetation types in the Libby Creek watershed are forests of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.] at the higher elevations, and of lodgepole pine (*Pinus contorta* Douglas ex Louden) at lower elevations. Openings in the forest are occupied by sagebrush (*Artemisia* spp.) and grasses. Aspen (*Populus tremuloides* Michaux) often occur on moist sites and alpine meadows occur extensively above 3652 m (Sansom and Reider, 1974).

In 1992, soils were sampled along five transects placed across the watershed to intersect drainage lines and topographic features (Fig. 2). Transects were placed at right angles to stream drainage patterns, and included as much of the complete range in elevation, slope, aspect, moisture regime, and parent material as possible. Soil pits were dug at intervals of 200 m (closer where there was an evident change in landform) along each transect from crest to crest. Thirty-seven pedons were described, and samples from each horizon were collected. Horizon identification, thickness of each horizon, boundary, and coarse fragments in each profile were recorded. At each sampling site, elevation, slope, aspect, and over- and understory vegetation were recorded. Field properties were described using the methods and horizon nomenclature of Soil Survey Staff (1993, 1996) and pedons were classified according to Soil Survey Staff (1996).

The GIS methodology used in this study consisted of the following steps: data collection, data digitization and rectification, data layer display and manipulation, qualitative assessment of the individual data layers and analysis, extraction of topographic attributes from the DEM, establishment of suitability criteria for a GIS-generated soils map, and comparison of the GIS automated map with existing USFS general (Order 4) and detailed (Order 3) soils maps. The base map for this study was the Centennial, Albany County, Wyoming, U.S. Geological Survey (USGS) 7.5 minute quadrangle topo-

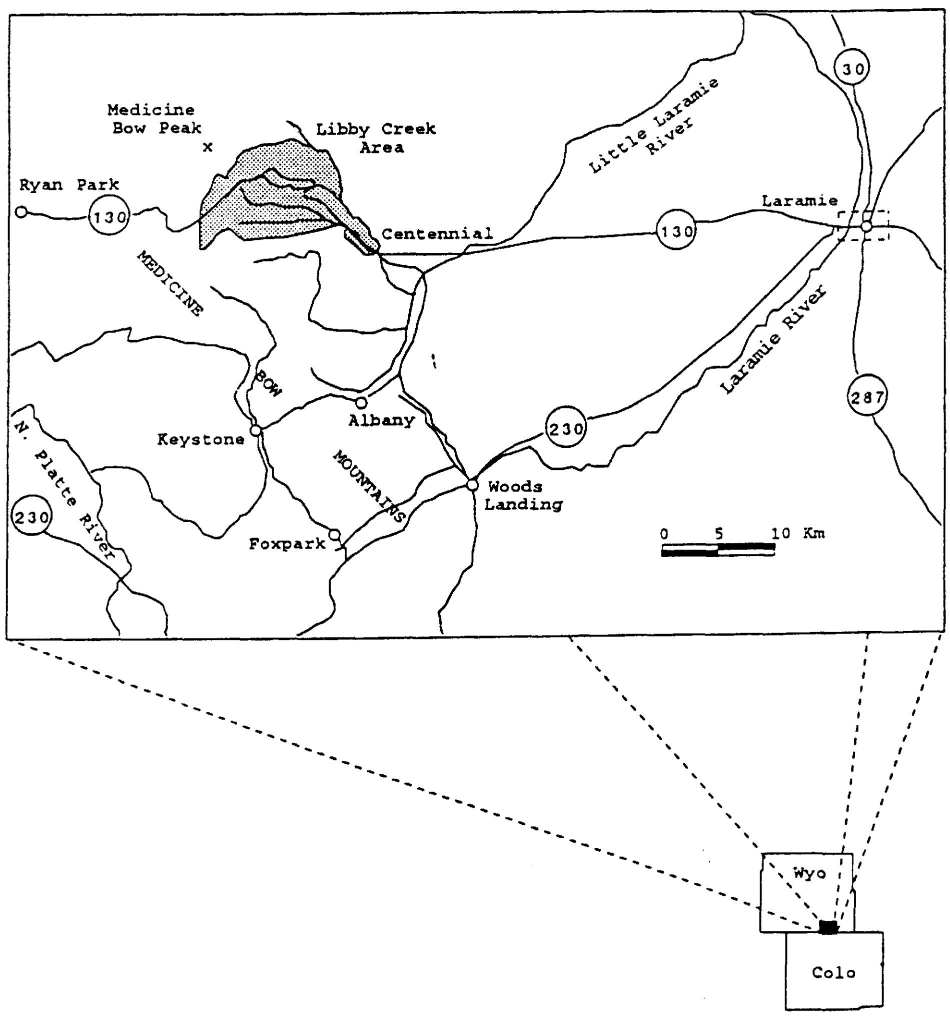


Fig. 1. Location of Libby Creek watershed in the Medicine Bow Mountains, Snowy Range, Wyoming.

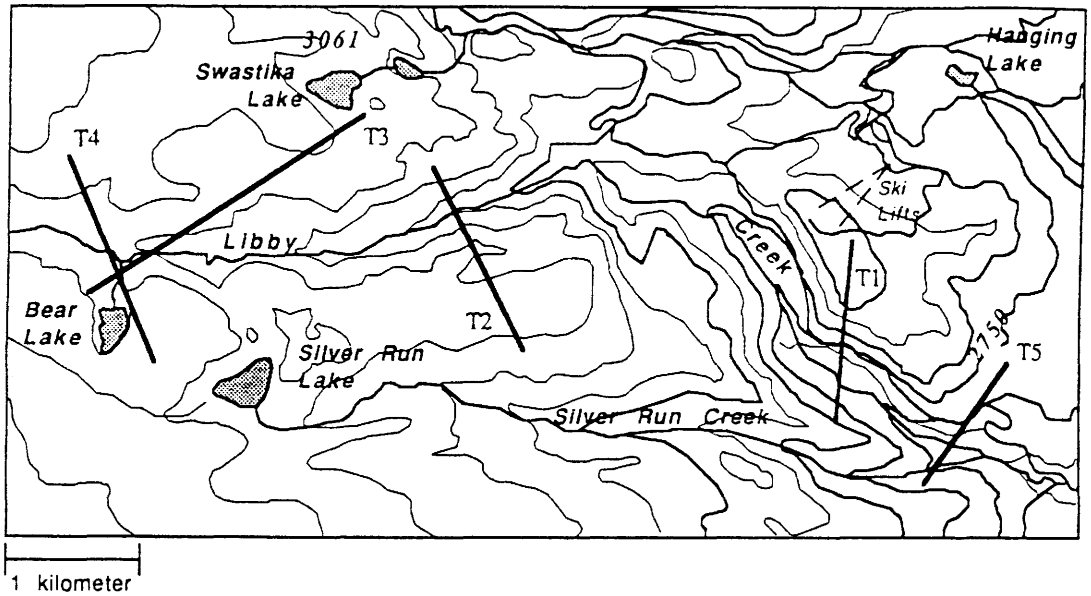


Fig. 2. Transect locations in the Libby Creek watershed. Topographic quadrangle map of Centennial, Albany County, Wyoming.

graphic map (1:24 000 scale), in polyconic projection. Streams, lakes, contours, and roads were digitized from this map, and all other data were registered to this cartographic base. Surficial geology and vegetation maps were not available for the study area. Maps of surficial geology and vegetation were produced through interpretation of aerial photographs taken on 27 Aug. 1990. The USFS soils maps were photo-reproduced at a scale of 1:24 000. This required enlargement of the general soils map (Marston and Clarendon, 1988) from its original scale of 1:126 720: the detailed soils map (Bauer and Hudnell, 1986) was originally prepared at 1:24 000. These maps were digitized and geometrically rectified to the base map using six ground control points.

Environmental Systems Research Institute's ARC/INFO ARCEDIT subsystem was used for digitizing and editing coverage features. All coverages were transformed into the Universal Transverse Mercator (UTM) coordinate system (Zone 13). A DEM of the Libby Creek drainage consisting of 24 084 cells with a 30 by 30 m resolution was obtained from the USGS. Techniques developed to extract hydrologic features from DEMs were based on neighborhood operations, in which calculations and decisions were made for a particular point based on the values of the eight neighboring cells (Jenson and Dominque, 1988). Using a linear interpolation algorithm, a macro program was designed to compute topographic attributes such as slope, aspect, elevation, flow accumulation, plan curvature (contour curvature), profile curvature (slope curvature), and flow direction from the DEMs. The flow accumulation data set models the drainage network (O'Callaghan and Mark, 1984). Each cell was assigned a value equal to the number of cells that indicated water would flow into the assigned cell. Slope profile curvature (in the direction of maximum slope) and plan curvature (transverse to profile curvature), both measures of the rate of change of slope steepness along a streamline, were expressed in degrees per 100 m. Slope profile curvature affects flow acceleration and deceleration and hence influences soil sediment aggradation and degradation. Plan curvature is a measure of the convergence or divergence of overland water flow and hence the concentration of materials in a landscape. Three-dimensional graphic displays were produced for both contours and slope of the study area. The segments of slopes included: summit (Su), the interfluve or ridge crest; shoulder (Sh), the maximum convex segment; backslope (Bs), the relatively straight, steep segment; footslope (Fs), the concave segment; and toeslope (Ts), the lower part of Fs, which is nearly flat at the base of the slope.

A slope map of the study area was constructed, partitioning the landscape into four slope classes: 0 to 10, 10 to 25, 25 to 40, and >40%. Vegetation and surficial geology maps were produced through photo-interpretation of aerial photographs. The vegetation was broadly classified into three categories: continuous forest, grassland, and open forest. Geologic parent materials were also mapped in three categories: Bull Lake glacial deposits, Pinedale glacial deposits, and rock outcrop or Holocene colluvium.

The ARC/INFO OVERLAY process was used to produce the soils map, at a scale of 1:24 000, by overlaying the surficial geology, vegetation, slope, and curvature coverages, according to the soil genesis model (criteria) described in Table 1. Four soil mapping units were created, with their components represented by the following taxonomic classes (great groups): Cryochrepts, Cryumbrepts, Cryoboralfs, and Cryaquepts/Cryaquolls.

Two existing USFS soils maps (an Order 4 general soils map and an Order 3 detailed soil survey) were compared with the ARC/INFO GIS digital map by overlaying the maps and

Table 1. Criteria established for different soil classes in constructing the soil genesis model. Map units are complexes or consociations (Rahman, 1994).

Soil map unit	Vegetation type	Slope	Criteria
Cryaquepts/Cryaquolls	Grassland	<10%	In depressions and in areas approximately 50 m from lakes and streams
Cryochrepts	Grassland and open forest	>40%	Very steep slopes on all parent materials
	Forest	>10%	Pinedale–Holocene colluvium–rock outcrop parent material
Cryumbrepts	Grassland	<40%	Nearly level to steep slopes
Cryoboralfs	Forests	<25%	Bull Lake–Pinedale parent material

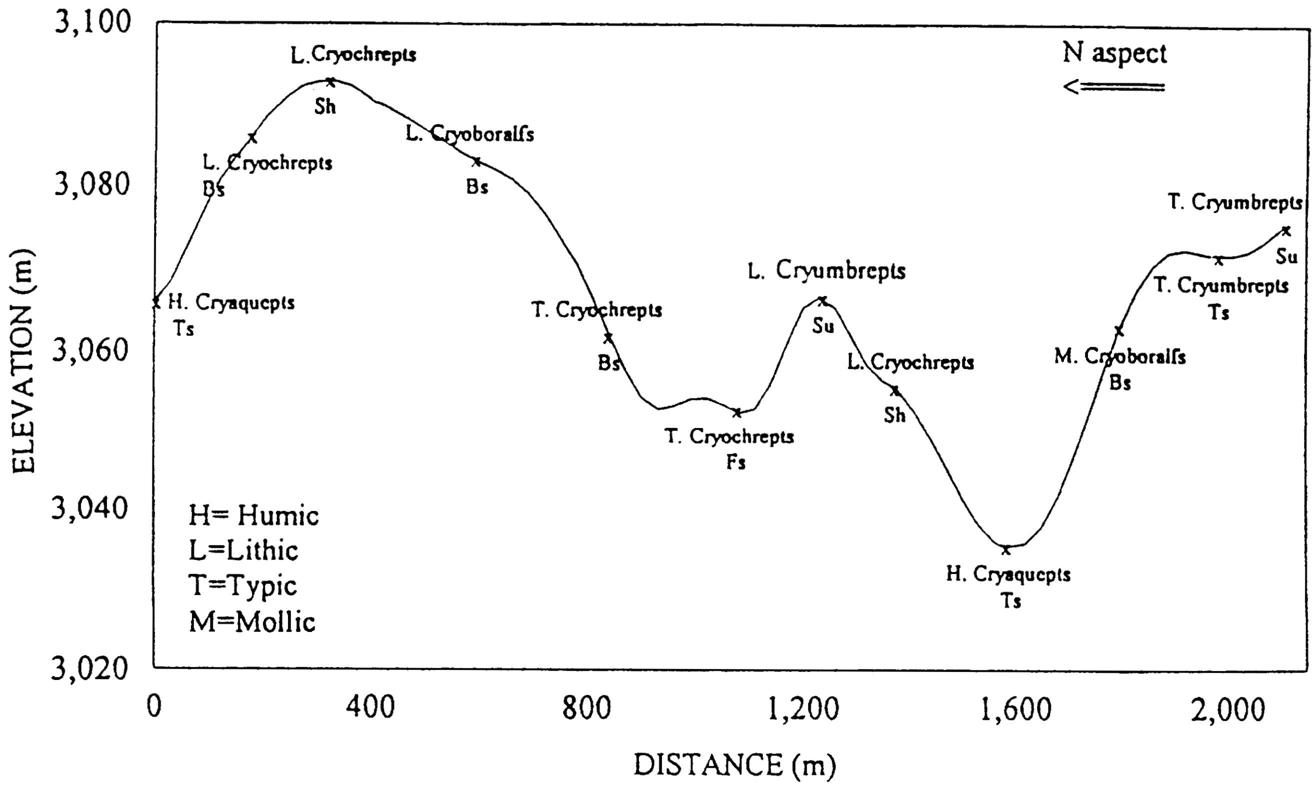


Fig. 3. Representative slope positions and suborders of transect no. 3 in Fig. 2. Slope positions correspond to: Ts = toeslope (nearly flat base of slope in the lower part of Fs); Bs = backslope (relatively straight, steep segment); Sh = shoulder (maximum convex); Fs = footslope (concave segment); Su = summit or crest (relatively flat segment).

cross tabulating the total area of each soil class. On the USFS general soils map, the soils of the study area were mapped with five units: Cryoborolls/Cryochrepts, Cryoboralfs/Cryoborolls, Cryoboralfs, Cryumbrepts, and Cryoboralfs/Cryaqualfs. For the detailed soils map, the study area was described by 17 soil mapping units. The GIS-derived soils map and the USFS soils maps were compared by visual interpretation, and the percentage of the total area occupied by each soil class was computed. After overlaying the different coverages, the area within comparable mapping units was cross tabulated.

RESULTS AND DISCUSSION

Soil occurrence in the Libby Creek watershed is related to soil age and to slope position and gradient (Fig. 3). Soils on younger, steeper slopes are less weathered than the soils on older and more stable sites (Rahman, 1994). Soils developed from Bull Lake till have thicker soil profiles and argillic (Bt) horizons, whereas the less weathered soils formed in Pinedale till or Holocene colluvium parent materials are shallow or moderately deep and generally have cambic (Bw) horizons. Grassland soils have comparatively greater surface (A) horizon development than forested soils. Forested soils have E horizons below thin A horizons, are moderately deep, and have cambic horizons. Soils vary by slope position as a result of both colluviation and pedogenic processes. There is greater accumulation of fine materials transported onto lower slope positions and possibly also greater in situ weathering of mineral grains in soils on toeslopes.

The spatial variability of soil properties related to soil classification in the study area was described by Rahman (1994) and Rahman et al. (1996). Carbon content decreased with depth in the profile while pH followed no particular trend; solum thickness and solum coarse fragments were not related to slope gradient. There was considerable variability in the depth of the A horizon followed by solum coarse fragments, organic C content, depth of the B horizon, and solum thickness, respectively (Rahman et al., 1996). Soils on concave portions of the slope are more strongly developed than soils on the convex portions.

Slope gradient at sampling sites ranges from 0 to 65% and accounts for much of the soil variation in the study area. Soils on steep slopes are Cryochrepts, and low-gradient slopes and flat surfaces have well-developed profiles such as Cryoboralfs, Cryaquolls, and Cryaquepts. Slope gradient along the transects ranks in decreasing order from Sh > Bs > Fs > Su > Ts. Corresponding soil classes are Cryochrepts on Sh positions, Cryochrepts, Cryumbrepts or Cryoboralfs on both Bs and Fs positions, Cryumbrepts or Cryoboralfs on Su positions, and Cryaquepts, Cryaquolls and Cryoboralfs on Ts positions. Soils on forested Su and Bs positions are Cryoboralfs if the parent material is Bull Lake age till. Aspect did not apparently influence soil properties in this study.

For the study sampling sites, the flow accumulation values ranged from 0 to 741 cells (Rahman et al., 1996). Concave surfaces and depressions such as Ts and Fs positions (Fig. 3) had greater flow accumulation values while steeper, flat, and convex surfaces had low flow

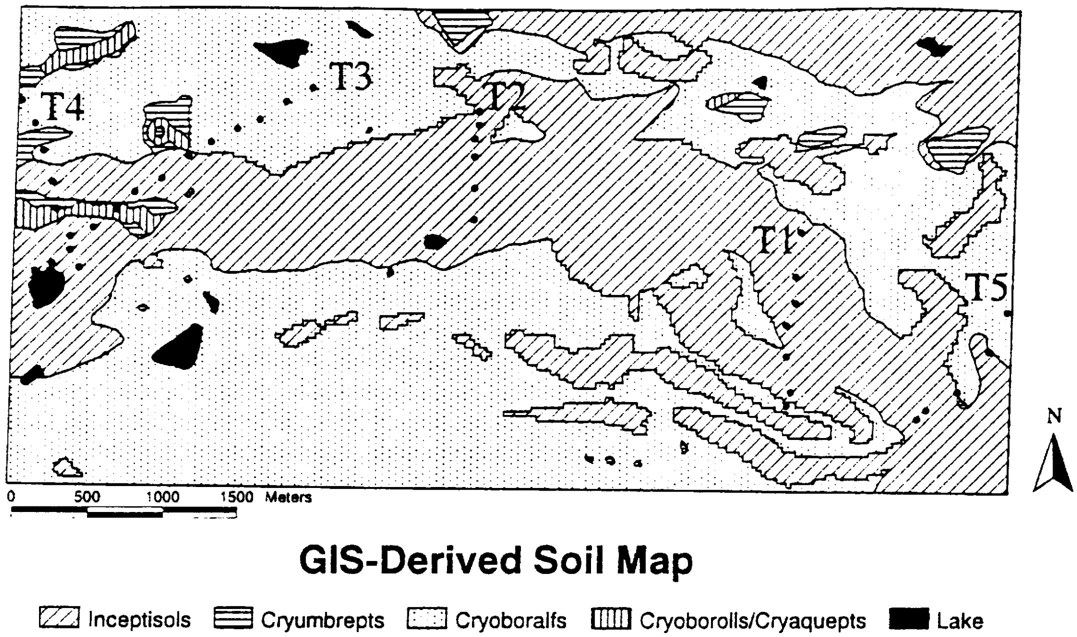


Fig. 4. GIS-derived soils map of the Libby Creek watershed study area. Map was produced according to the criteria stated in the soil genesis model (Table 1).

accumulation values. Slope curvature measurements were also highly variable topographic attributes. Higher slope curvature values were recorded at Ts and Fs segments and lower values at Sh and Su positions, reflecting the relative rates of deposition and erosion of sediments on these respective slope segments. Positive values indicate deposition or aggregation whereas negative values reflect erosion or degradation. Moore and Burch (1986) demonstrated that slope curvature was an important determinant of erosion and deposition processes at the hillslope scale.

Plan curvature measurements of the study area range between −1.56 and 1.78 (Rahman et al., 1996). It is the most variable topographic attribute recorded in this study (CV = 2000%). The Ts and Fs positions (concave slope curvature) and convergent areas (concave plan curvature) gain water by runoff. These areas are generally stable or aggrading, and have active pedogenic processes that result in the formation of deep, well-developed soil profiles. Patterns of occurrence of Cryoboralfs and Cryochrepts observed during this study support the hypothesis that the soil catena develops in response to water flow

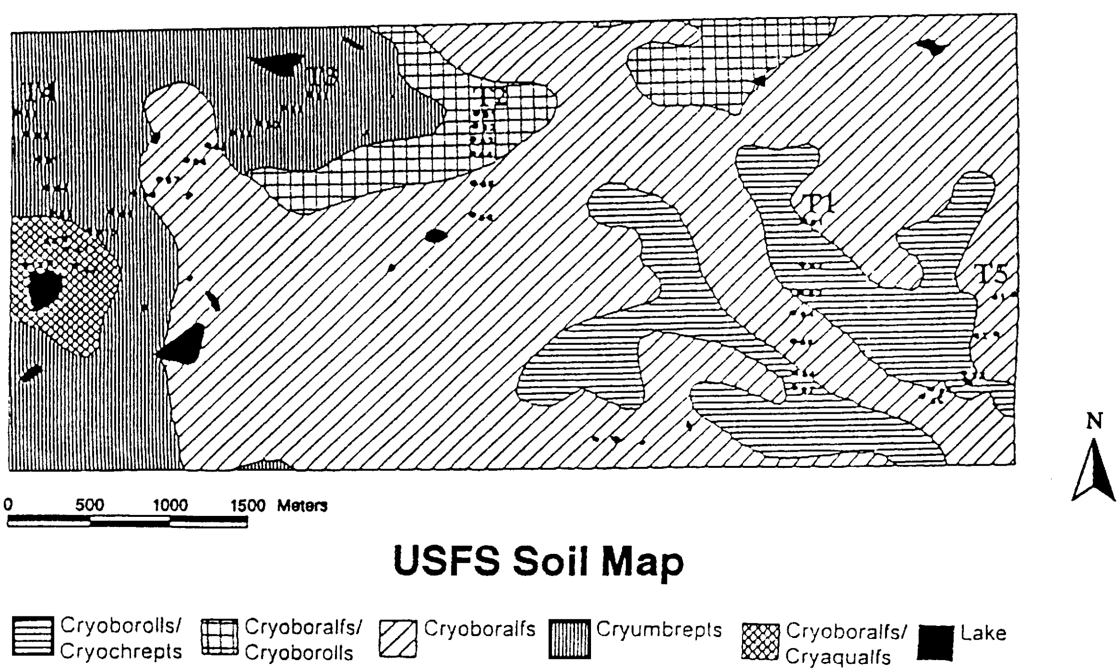


Fig. 5. USFS general soils map of the Libby Creek watershed study area. Map was produced from data taken from a U.S. Forest Service map of soils in the Snowy Range, Medicine Bow Mountains.

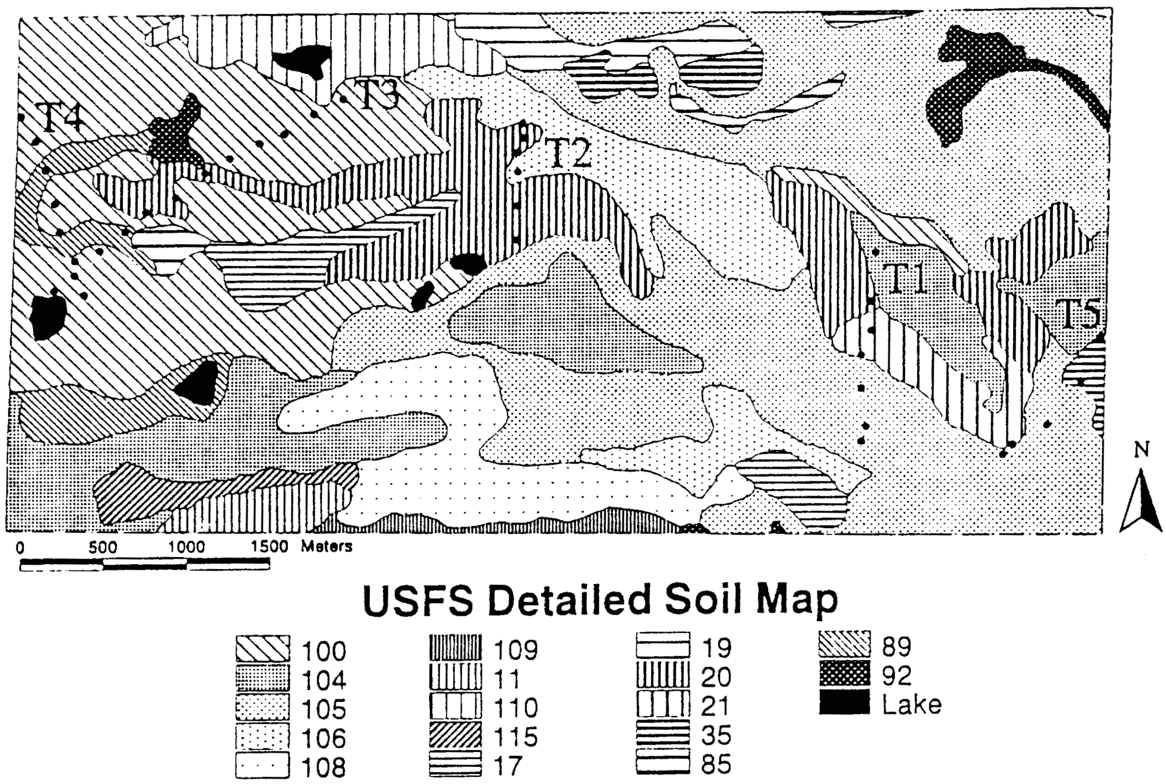
through and over the landscape. Higher slope gradient surfaces had lower flow accumulation, flow direction, and slope curvature, and higher plan curvature.

Simple correlation and regression analyses conducted elsewhere (Rahman, 1994; Rahman et al., 1996) revealed that relationships among soil properties and terrain attributes were not statistically significant. Principal components analysis indicated that flow accumulation contributed most to the total variance in soil properties, followed by aspect, elevation, and flow direction (Rahman, 1994; Rahman et al., 1996).

Comparison between the GIS-Derived and USFS Soils Maps

Approximately 51% of the total area of the GIS-derived map (Fig. 4) was classified as Cryoboralfs, compared with 57% of the USFS general soils map area (Fig. 5) and 54% of the detailed soils map (Fig. 6). There was 90% overlap of Cryoboralfs mapping units on the USFS general soils map and 71% overlap of Cryoboralfs mapping units on the detailed soils map with Cryoboralfs delineated on the GIS-derived map (Table 2). Ninety-five percent of the area mapped as Cryoborolls/Cryochrepts on the USFS general soils map was mapped as Cryochrepts on the GIS-derived map; however, Cryochrepts on the GIS-developed soils map covered 44% of the total area, compared with only 14% on the USFS general and 15% of the detailed soils maps. Almost 10 times as large an area of Cryumbrepts was mapped on the USFS general soils map (19%) as on the GIS-derived map (2%); Cryumbrepts were not delineated on the USFS detailed map. Cryumbrepts are more extensive at higher elevations adjacent to the study area (Libby Flats).

For the USFS detailed soils map, seven mapping units were delineated in the study area that had at least one component with an aquic moisture regime. The total area with at least one wet (aquic) component on the USFS detailed map was 28% of the study area; this



USFS Detailed Soils Map Legend

11	Typic Cryoboralfs-Typic Cryochrepts, 0 to 10%	100	Dystric Cryochrepts-Cryaquepts complex 2 to 25%
17	Typic Cryochrepts25 to 40%	104	Typic Cryoboralfs 0 to 10%
19	Typic Cryochrepts-Typic Cryoboralfs complex 10 to 25%	105	Typic Cryoboralfs 10 to 25%
20	Typic Cryochrepts-Rock Outcrop complex 45 to 65%	106	Typic Cryoboralfs 25 to 40%
21	Argic Cryoborolls-Lithic Cryoborolls-Rock Outcrop 40 to 60%	108	Typic Cryoboralfs-Kettleholes 0 to 25%
35	Lithic Cryoborolls-Argic Cryoborolls complex 10 to 25%	109	Typic Cryoboralfs-Aquic Cryoboralfs, 0 to 10%
85	Argic Cryaquoll-Histisol complex 0 to 10%	110	Typic Cryoboralfs-Aquic Cryoboralfs, 10 to 25%
89	Cryaquolls-Cryoborolls, 0 to 10%	115	Aquic Cryoboralfs-Typic Cryoboralfs, 0 to 10%
92	Cryoboralfs-Cryaquolls-Histisols complex 10 to 20%		

Fig. 6. USFS detailed soils map of the Libby Creek watershed study area. Map was produced from maps included in Bauer and Hudnell (1986).

Table 2. Summary of area, percentage of total area, and co-occurrence of each soil class delineated on the GIS-derived and USFS soils maps.

Soil class	GIS map		USFS general soils map			USFS detailed soils map		
	Area	Total area	Area	Total area	Areal co-occurrence between maps†	Area	Total area	Areal co-occurrence between maps
	ha	%	ha	%	%	ha	%	%
Cryoboralfs	1224	51	1351	57	90	1275	54	71
Cryoboralfs/Cryoborolls	–	–	174	7	–	–	–	–
Cryoboralfs/Cryaqualfs	–	–	52	2	–	124	5	–
Cryaquepts/Cryaquolls	22	1	–	–	47‡	–	–	–
Cryoborolls/Cryochrepts	–	–	324	14	95§	–	–	–
Cryochrepts	1056	44	–	–	–	295	14	36
Cryumbrepts	49	2	449	19	11	–	–	–
Cryaquolls/Histisols	–	–	–	–	–	20	1	–
Argic Cryoborolls/Lithic Cryoborolls	–	–	–	–	–	79	3	–
Cryaquolls/Cryoborolls	–	–	–	–	–	63	3	–
Cryoboralfs/Cryaquolls/Histisols	–	–	–	–	–	41	2	–
Cryochrepts/Cryaquepts	–	–	–	–	–	398	17	–
Cryoboralfs/Cryochrepts	–	–	–	–	–	29	1	–
Lake	24	1	24	1	100	21	1	70
Total	2376	100	2376	100	–	2376	101	–

† Comparison between maps indicates the percentage of each GIS-derived soil class in relation to the respective USFS base map soil class.
‡ Cryaquepts/Cryaquolls on GIS-derived soils map compared with Cryoboralfs/Cryaqualfs on USFS soils map.
§ Percentage of Cryoborolls/Cryochrepts on USFS soils map mapped as Cryochrepts on GIS-derived soils map.

compared with 1% of the area on the GIS-derived soils map. A Cryochrepts/Cryaquepts mapping unit accounted for 17% of the area of the detailed map. Two of the named wet soils, Argic Cryaquolls and Histisols, were not observed during our transecting of the study area. Argic Cryoborolls, delineated with Lithic Cryoborolls on 3% of the detailed soils map, were also not observed during our transecting. Lakes showed good agreement (occurred at similar locations) on all three maps.

Classifications of the 37 pedons sampled along the five transects were compared with the major soils indicated for each location on the USFS general and detailed soils maps. Only 11 of the 37 pedons (30%) matched the named soil(s) for the mapping units on the general soils map. Twenty of 37 pedons (54%) matched named soils for mapping units on the detailed soils map. The 37 pedons were not selected randomly as a basis for the test; however, the study transects were laid out without any prior knowledge of the USFS map delineations, and transecting is commonly used to check mapping unit composition (Soil Survey Staff, 1993).

Discrepancies were expected due to the different soil genesis models used to construct mapping units as well as different scales of the general soils map compared with the GIS-derived and USFS detailed soils maps. In all three soils maps, map units were named for the dominant soils (soil series for the USFS detailed soils map, great groups for the other two maps) occurring in the delineated landscape body. Soils classified as Cryumbrepts are more common at higher elevation landscapes immediately west of the study area (Libby Flats) and the unit was apparently "carried over" into the study watershed on the USFS soils maps. Similarly, Histisols are more common at slightly higher elevations. Because most soil characteristics change gradually along a landscape, the soil boundary (i.e., delineation line on a soils map) is viewed as a zone rather than a line. The width of each boundary (zone) varies and is controlled mostly by the nature of the landform as well as the origin and nature of the soil parent material. Placement of the boundary as a line on a soils map is always discretionary, whether placement is aided by air photo interpretation or GIS. This gradual change of soil characteristics from one soil unit to another across a delineation boundary is an impediment in solving problems relating to spatial variability using GIS (McSweeney et al., 1994). Overlaying different coverages obtained from different sources also adds to the discrepancies. Bailey (1988) pointed out that when maps are overlaid, errors may occur due to different scales of base maps and projections. He also warned that the use of GIS will not solve these problems, but may instead lead to unfounded conclusions about the quality of the results.

The GIS-derived map was based on intensive characterization of sampling sites within the Libby Creek watershed, while the USFS general soils map was broadly characterized to represent a large area. However, comparison of the two maps is appropriate since GIS-based soils maps have been used for broad resource inventory. For example, the recently completed GIS-based map of Yellowstone National Park was correlated as an Order 4 Soil Survey by the National Resource Conservation Service (Shovic et al., 1996). Geographic information systems technology has the advantage of using objective interpretations of spatial data to aid delineation of soil mapping units, and is time efficient and cost effective. Use of transecting and GIS-based mapping does appear to be an effective tool for producing general soils maps of wildland areas, as demonstrated here for the Libby Creek watershed. The use of GIS should also facilitate production of detailed soil surveys, particularly as an aid in the placement of soil mapping unit boundaries. An independent test of the GIS-derived mapping units in comparison to the USFS detailed map would be required to identify the "better" map. However, our objectives were to compare a GIS-derived map to a soils map produced through conventional soil survey techniques. We suggest that use of GIS will aid in the efficient production of more accurate soils maps of wildlands, and may be particularly suitable as a tool to produce a general soils map for an area at the start of detailed mapping.

SUMMARY AND CONCLUSIONS

The detailed examination of soil-landscape relationships undertaken in this study suggest that soil properties were influenced by age, parent material, and slope gradient and shape. Different segments of slopes possessed soil characteristics that appeared to be related to the morphological nature of the components (i.e., slope gradient, slope segment, slope curvature). Well-developed soils occur on less steep slopes or flat and concave surfaces, whereas weakly and moderately developed soils are found on steep and convex surfaces. Soils on the older (Bull Lake) parent material are more developed than the soils at corresponding slope positions or sites with slope curvature on the younger (Pinedale or Holocene colluvium) parent material.

A soils map of the Libby Creek watershed was produced using ARC/INFO GIS according to a soil genesis model. This model was constructed by characterizing soils developed at various segments of the slope and on different-aged parent materials. A comparison of the GIS-derived map with USFS soils maps demonstrated discrepancies between them. The discrepancies were attributed to the use of different soil genesis models to construct and delineate mapping units, and to the different sampling intensities used in development and field verification of the maps. Transecting and GIS-based mapping proved effective in generating a map of the soils in the Libby Creek watershed.

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