LARS Information Note 032774

MACHINE-AIDED ANALYSIS OF LAND USE-LANDFORM RELATIONS FROM ERTS-1 MSS IMAGERY, SAND HILLS REGION, NEBRASKA

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Abstract

Machine-aided analysis of ERTS-1 MSS data obtained over the Sand Hills of Nebraska indicates that reasonably accurate soils maps can be produced automatically. An interpretation of spectral class spatial distribution and statistical character allows confident assignment of familiar soil and cover type names to computer classes. Resultant computer classification maps are displayed on a television screen or printer image. Correlation between computer maps and the USDA soils map of the same area is high. Geographic distribution of classes of interest can be accentuated by automatic methods. Percentages of cover type for any classified area also can be obtained. Interpretation of machine maps yields information concerning land use, physiographic, soil, and hydrologic patterns of the region.

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Introduction

The results described in this paper are an outgrowth of geomorphological studies of the Western states conducted during the past two years at LARS-Purdue.[1,2,3] In attempting to classify landforms through computer-aided spectral signature analysis performed on ERTS-1 MSS data, it was soon realized that vegetation, soil, and hydrologic patterns are paramount in determining the spectral characteristics of the Earth's surface forms. To effectively implement machine-aided landform classification, it is necessary to develop an understanding of spectral relationships among these surficial variables. A portion of the Sand Hills region of Nebraska was chosen for study because it has a relatively simple indigenous ecosystem, with surface variables that are amenable to automatic data processing. The interdependence of soils and vegetation, and their genetic relationship to groundwater make the Sand Hills a prime area for a case study in machine-aided spectral analysis. The human portion of the ecosystem is intertwined with the physical variables; thus, land use studies are another, albeit peripheral, aspect of this report.

Description of the Region

The Nebraska Sand Hills are one of the most varied and extensive prairielands in North America, and undoubtedly represent the greatest single areal accumulation of aeolian materials on the continent. Hayden[4] in 1871 estimated the total area as 20,000 mi^2, a figure which recurs in modern literature. The region is encompassed in the area bounded by the Niobrara River on the north and the Platte River on the south. The Sand Hills are composed of quartzose sand commingled with loess derived from continental glacial deposits of northeastern Nebraska, as described by Thornbury[5] and Condra.[6] The hills extend eastward from the 103rd Meridian to near the 99th Meridian; farther east and southeast they pass into loessial hills which are derived in part from finer clay and silt deflated leeward from the Sand Hills. McPherson County, the principal locale of our study, is located in the south-central part of the region described (Fig. 1).

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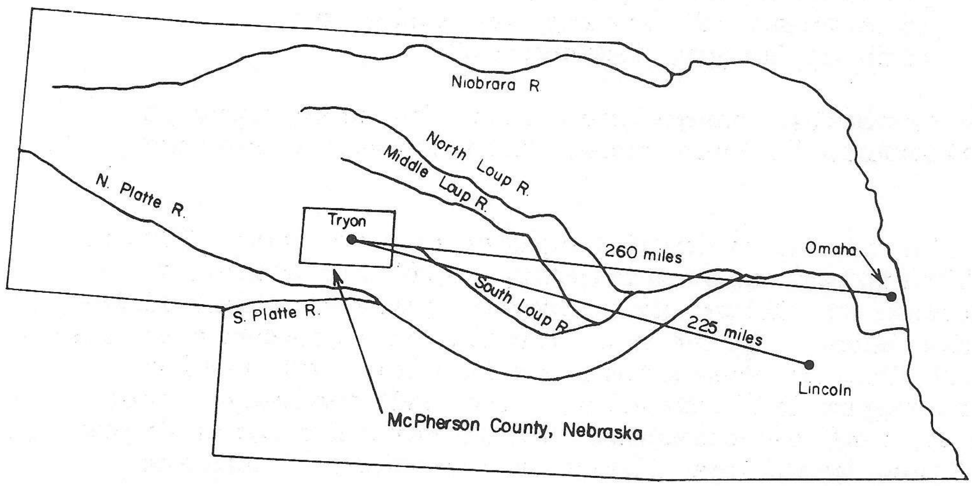

Fig. 1 Location map of McPherson County, Nebraska.

The geology is relatively simple; 20 to 400 ft of Quaternary and Tertiary sands rest on the Ogalalla Formation and older Tertiary rocks. The size and height of dune complexes varies within the region, but in McPherson County they range upwards to 15 mi long, 1 mi wide, and 90 to 300 ft high. Sniegocki[7] has described an air view of this region of sand dunes and intervening sand-floored valleys as resembling the surface of a billowy sea. The dunes are generally asymmetric, with steeper sides on the north and east, a response to prevailing westerly winds. The tops and sides of dunes have commonly been hollowed out by wind action, creating crater-like features called "blowouts." Interspersed in hollows between dunes are basins containing ephemeral groundwater lakes and marshes, though these are scarcer in McPherson County than elsewhere farther west. Blowouts show all stages of gradation from almost constant movement to total stabilization.[8] The gradation is clearly evident in terms of depth and outline of blowouts, and abundance of encroaching vegetation. Temporal change in stabilization by good range management, and perhaps changing climate, is evident from Aughey:[9]

> "Formerly these "barren holes" were abundant...now the body of them are grown over with grass, and new ones in process of forming are only met with at longer intervals."

It is probable, therefore, that the frequency of new blowouts is less today than it was a century ago.

The annual rainfall equivalent is about 20 in, or climatologically subhumid. Soil moisture is available to climax and invader grasses which blanket the area. McPherson County, as elsewhere in the Sand Hills, is characterized by high evaporation rates, rapid infiltration, internal drainage, and lack of surface streams. North Fork Birdwood Creek and Squaw Creek are the only significant surface streams in the county. Annual recharge to subsurface aquifers is estimated at 5 in/yr and loss by lateral seepage to subirrigated hay meadows as 3 in/yr. The remaining moisture is probably lost to evapotranspiration. The piezometric surface rises westward across the county, coincident with an increasing gradient. However, eastward slope on the water table is greater than surface declension; thus, the groundwater surface is more than 100 ft deep in the east, but as shallow as 15 ft at the western side of the county. Physiographically, this change is evidenced by the appearance of permanent lakes in the west where the water table intersects the land surface in depressions, whereas there is no surface water in the eastern two-thirds of the county.

Native grass is the predominant vegetation, and about 97% of the county is in rangeland or native hay pasture. The great variation of grasses includes elements of tall, short, and bunch grass prairie. The grasses grow luxuriantly in the valleys, but on the higher sand hills are thin and are interspersed with small, woody plants, weeds, and prickly pear cactus. Previously tilled land tends to coverage with ragweed and tumblegrass. Trees, introduced by homesteaders, thrive along the few streams, the semi-permanent lakes, and subirrigated hay meadows, and are mostly cottonwood, boxelder, willow, and hackberry.

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Windblown, fine-grained sand of the Valentine soil series occupies 93% of McPherson County, under a cover of mid-high to tall range grasses. In low areas, the fluctuating water table and coincident luxurious growth of reeds, rushes, and water affine trees have contributed to more extensive soil development in the A-horizon. Gannett, Elsmere, and Dunday soil series are abundant in such depressions and adjacent to surface streams. These soils are better suited for growth of native grasses capable of being cut for hay. However, care must be taken in the spring and immediately following summer rains to avoid excessive soil damage during cutting, owing to the susceptibility of these fragile soils to disruption by farm equipment. Breakdown of soil structure promotes deflation and resultant blowout development.

Areas of Valentine soils are best utilized for grazing, with range conditions varying from poor to good. Areas on the Gannett-Dunday-Elsmere series, formerly cultivated, are now returning to range. Blowout land, normally in plots 2 to 5 acres in extent, occupies only 0.3% areally, and lakes occupy about 0.1%.

The Sand Hills represent an interesting story of changes in vegetation and land use within historic times. Jackson[10] cites the reports of early visitors to the region. One description, in 1797, defines the region as an area of shifting sands devoid of trees, soil, or water. A representative of the Chadron Land Office, is 1855, wrote that no grasses grow among the hills, but that lakes were hidden amid the labyrinth of dunes. However, in 1871 Hayden[4] was able to state:

> ..."this region is by no means the utterly barren waste that it is sometimes represented to be. It has been a favorite range for buffalo, and still is for antelope and deer; and, judging from their condition, the conclusion would be natural that this region could be used for stock raising."

During the 1870's, a few cattle from herds trail-driven from Texas to railheads on the Platte River escaped, wandered into the sand hills, and reproduced. This led to movement of cattlemen into the dune country. After passage of the Kincaid Homestead Act in 1904, prairie homesteaders entered the region in numbers and attempted to raise corn or other grain crops. However, poor soils, undependable surface water supply, and erosion by deflation caused by tillage doomed extensive row cropping. The drought of the early 1930's completed extinction of any large-scale organized farming, and the area has subsequently reverted chiefly to grassland range for feeder cattle. The scars of farming remain, however, as "go-back land" tucked in the recesses of the "choppies" or sand hills.

Analytical Procedure

It is necessary to automatically generate spectral statistics for a range of classes representative of the total range of surface reflective characteristics to classify an area by techniques developed for the LARS-Purdue IBM 360-67 computer. The following procedure was used to implement computer classification and mapping of the Sand Hills region.

Four sets of training fields (groups of approximately 100 adjacent data elements) were selected from the 4 most spectrally contrasting areas on single channel non-classified computer grey scale printouts of the region (ERTS-1 Scene I.D. 1313-16563, CCT number 73039300, 1 June 1973). Data from each of these 4 training groups were separated statistically into 5 spectral classes by a non-supervised algorithm.[3,11] Values for the mean relative reflectivity (scale 0 = black to 256 = white) of each class were obtained for each ERTS-1 channel from the LARSYS processor, CLUSTER.

These values were plotted as a function of ERTS-1 wavelength bands to obtain spectral plots for each of the 5 spectral classes in each major training group. These plots provide a means to visually inspect spectral signatures of classified surface phenomena. In this manner the spectral classes for all training groups were compared. In each case, the plots of the least reflective class and/or classes from the brighter training groups coincided with those of the most reflective class and/or classes of the next darker training groups. Overlapping classes were combined, eliminating several non-supervised classes from consideration as distinct spectral types. From the initial set of 20 non-supervised classes, 14 were chosen for further analysis. These 14 classes contained the complete range of spectral variance within the region (Fig. 2).

Printer images were then generated to show the spatial distribution of the non-supervised classes within each 100 data element training field. Training fields of 1 to 10 data elements were relocated within the initial, larger training fields. The new training fields were selected as representative of the 14 chosen spectral classes, and processed by a supervised algorithm.[3,11] This processor, STATISTICS, generated classification statistics for the 14 classes of interest.

To interpret these statistics in a meaningful manner, classes represented by the statistics must be correlated with familiar surface cover types such as soils, vegetation, lithologies, hydrologic features, etc. To achieve this correlation, an area in McPherson County of about 44,000 acres (200 x 200 data points) was automatically classified, based on the supervised statistics. Each spectral class was then displayed on a printer image by a particular alphanumeric symbol, allowing inspection of the spatial distribution of each class. This distribution was then compared with soils distribution shown on the USDA soils map.[8] Significant geographic correlation among certain spectral classes was noted. Sets of similarly distributed spectral classes, if considered as units, were found to follow closely the patterns represented on the soils map. Based on this pattern similarity, soil names were assigned to the spectral classes. Land use and vegetation type names derive from soil type. Because the Valentine soil series is represented by 6 spectral classes, land use and vegetation categories within these classes must be inferred from other information. Figure 2 shows that classes C, D, E, F, G, and H decrease in reflectance from class C to class H. The more highly reflective classes, D and C, grade into classes representative of blowouts (as determined by spatial comparison as outlined above). From these spectral characteristics it was inferred that the more highly reflective classes represented areas with a less dense vegetal cover, grading

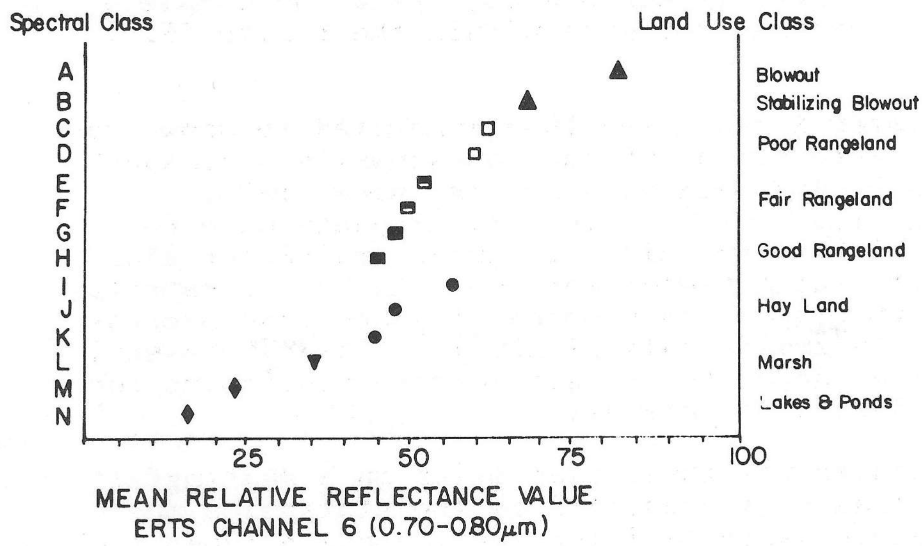

Fig. 2 Coincident spectral plot showing relationships among 14 spectral classes used in this study. Relative reflectance in ERTS-1 channel 6 is plotted for each class.

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eventually into blowouts with no cover. These less densely covered classes were named "poor rangeland." The spectrally less reflective classes were accordingly called "fair" and "good" rangeland to indicate the inferred increase in grass cover. A subsequent revision of the classification statistics was performed to include a class interpreted as cropland on Gannett and Elsmere soils in the classification scheme. Thus, a combination of geographic relationships and spectral characteristics was used to infer the surface type represented by the spectral class.

Results

The machine-aided analytic procedure outlined provides a means to rapidly reduce large amounts of data to forms more compatible with human pattern recognition capabilities. The statistical computations and refinements of the project required about one hour of central processing time. Classification results can be automatically displayed on printer images, television screens, graphical images, or tabular matrices through the LARS computer program system (LARSYS). However, at this point the capabilities of the machine come to a halt. The machine cannot interpret its own maps, graphs, or tables. As discussed under analytical procedure, naming of spectral classes is a uniquely human task based on inference, induction, and a certain degree of intuition. Because these mental processes inevitably bias the experimental framework, the objectivity of computer-assisted mapping techniques is not to be accepted as complete. This is not to say that the experimental results are invalid or inaccurate, but merely to point to the indispensible necessity of human interpretation in any mapping project, computer-assisted or otherwise.

Figure 3 is a machine-generated spectral class map of the western half of McPherson County, eastern Arthur County, and southern Hooker County (see Fig. 17 for a location index of all computer maps discussed in the text; outline A of Fig. 17 locates the area represented in Fig. 3). The photograph is a Polaroid black and white print of the Sand Hills classification results as displayed on the photocopy unit of the LARS digital display television screen. The spectral classes have been grouped to accentuate land use and soils patterns. Each group of spectral classes was assigned a particular grey level for photography.

The lightest grey tone areas represent poor, sparsely vegetated rangeland dominated by invader and increaser grasses and shrubs. The next two darker greytones represent improving rangeland conditions. Optimum rangeland is displayed as medium-greytone. The forage is composed predominantly of decreaser grasses such as big and little bluestem, indiangrass, etc. All classes of rangeland are developed primarily on entisols of the Valentine series. A light grey swath separating two medium-greytone areas traverses the figure from northwest to southeast. This band of poor to fair rangeland conforms to the top of a broad "whaleback" or seif dune structure. Similar, large seif dunes within the Sand Hills region are oriented in the same direction, indicating a northwesterly wind direction during dune formation. The medium-greytone bands bordering the seif dunes on the northeast and

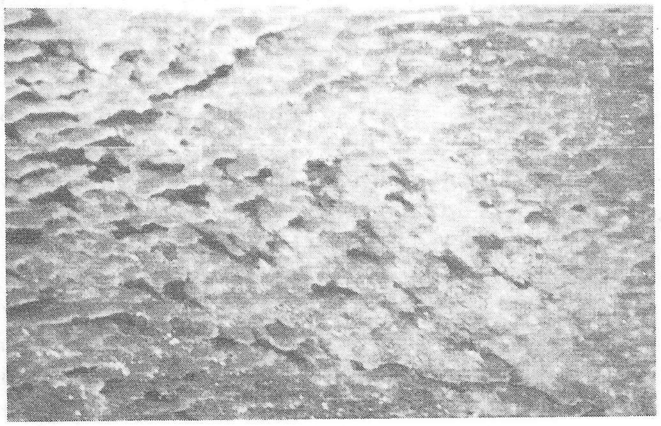

Fig. 3 Spectral class computer map of Sand Hills region obtained from digital display television screen. Greyscale coding is discussed in text. See outline A, Fig. 17, for geographic location.

southwest are located along wide swales between adjacent dunes. The best rangeland is in these broad, interdunal swales or valleys (Figs. 4 and 5).

The darkest grey splotches distributed throughout the western portion of the spectral class map (Fig. 3) represent lowlands in irregularly shaped depressions and along the valleys of Birdwood and Squaw creeks. These areas are the best lands in the region for cutting of native hay. Here, the water table is near the surface and provides better growing conditions for native grasses suitable for harvesting. Proximity of the water table to the surface is genetically related to development of the Elsmere, Dunday, and Gannett alfisols that predominate in these depressions (Fig. 6). Where water table intersects the surface lakes, ponds, and marshes occur (Fig. 7). These are displayed as black on Fig. 3. Wetlands comprise only a small percentage of the dark grey depressional areas. For this reason, water covered areas are difficult to locate on Fig. 3.

By representing each datum point with 4 picture elements, an enlarged portion of Fig. 3 can be photographed directly from the digital display unit. Fig. 8 is such a data enhanced image; the spectral class grey scale symbols are the same as in Fig. 3. This method of enlargement facilitates perception of

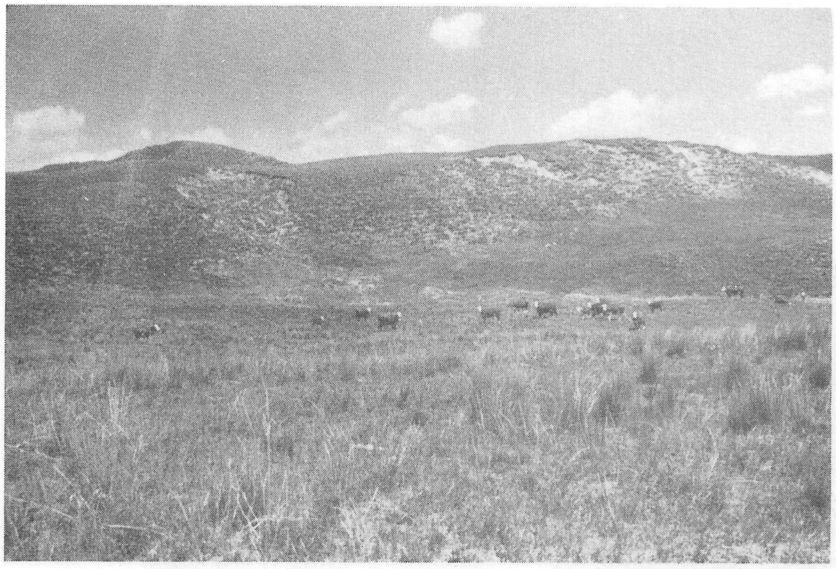

Fig. 4 Rangeland in the Sand Hills. Note the lush grasses in the foreground and the sparser grasslands on the seif dune in the background. A small parabolic dune is superposed on the larger dune structure in the upper left of the picture.

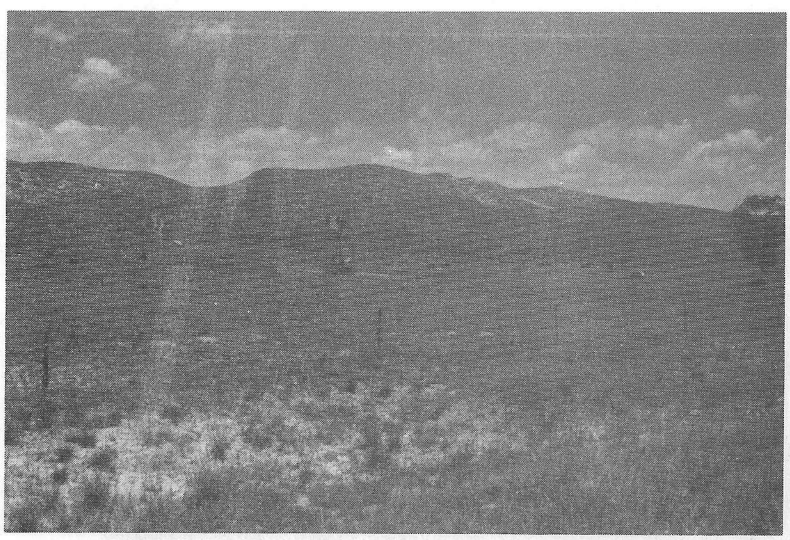

Fig. 5 Good rangeland in the swales or valleys, and poor to fair rangeland on the seif dunes. Windmill driven pumps draw water to the surface for the cattle.

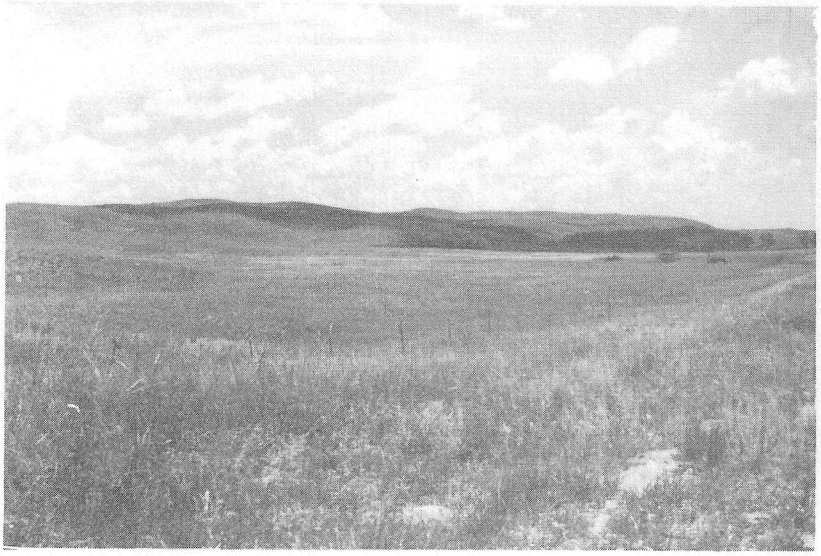

Fig. 6 Lowland suitable for hay cutting. Note change in vegetation just beyond the fence where the slope ends and the basin begins. A few trees are in the background at the far end of the lowland.

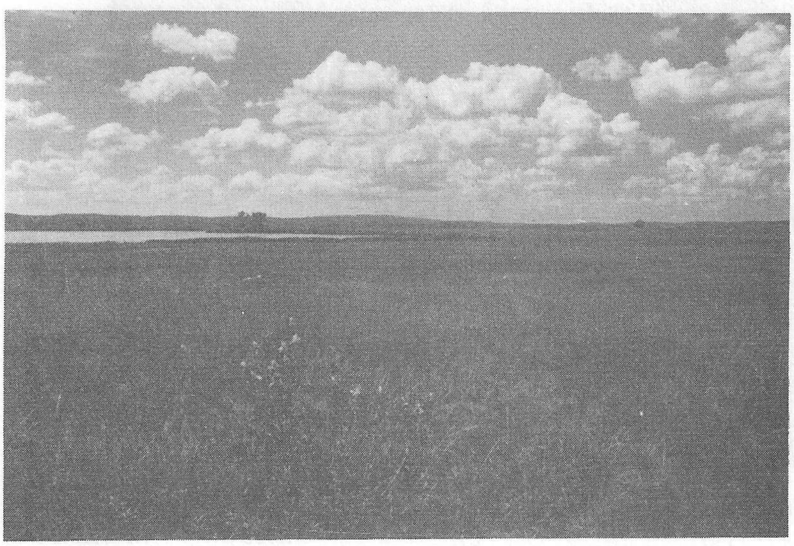

Fig. 7 Arthur Lake, a typical Sand Hills lake, in eastern Arthur County. Note the lush vegetation in the foreground and the ring of reeds and rushes encircling the lake.

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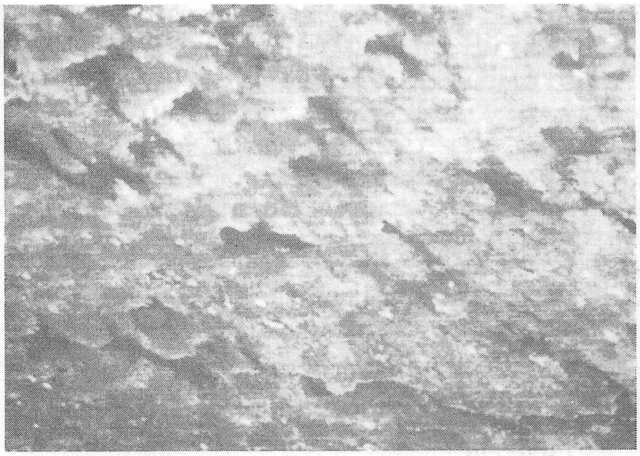

Fig. 8 Computer enlargement of Fig. 3. See outline B, Fig. 17, for geographic location.

small units of greytone impossible to see on the smaller scale map. A further enlargement, whereby each datum point is represented by 16 picture elements is shown in Fig. 9. This photograph portrays the area around Schick Lake, 15 miles west of Tryon, the county seat of McPherson County. The lake is clearly visible at the eastern end of the dumbbell-shaped dark grey lowland region in the center of the picture.

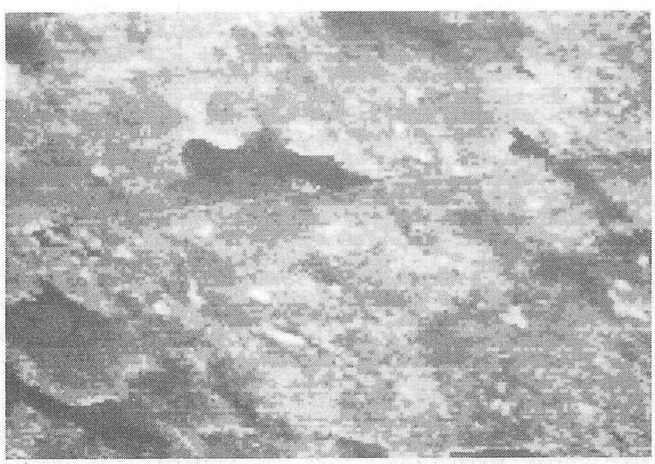

Fig. 9 Further computer enlargement showing detail of Schick Lake region. See outline C, Fig. 17, for location.

A further level of image enlargment is available to users of the LARSYS computer programs, but to obtain it the medium of display must be changed. Figure 10 is a photographically reduced printer image of approximately the same area as Fig. 9. Each alphanumeric symbol on the printout represents a certain group of spectral classes, which in turn are interpreted as a particular soil type. Blank areas are blowouts, which range in size from a single datum point (1 acre) to as many as 10 data points (11 acres). Soils of the Valentine series (dots) cover 83.2% of the surface represented on Fig. 10. Asterisks represent the Elsmere and Dunday soil series formed in the depressions. Other lowland classes are the Gannett soils displayed by "G's", marshes by "M's", and lakes by "W's". A roughly circular area of crosses in the lower left portion of the figure is interpreted as cropland irrigated by a center-stand irrigation system. The identity of the crop type is unknown. The scale of the printer map before photographic reduction is approximately 1:24,000. Geographic distortions are inherent in the data, but can be removed by techniques developed at LARS-Purdue and elsewhere.[12]

To facilitate interpretation of this computer printout map, an overlay outlining the major symbol groups was constructed, and is shown in Fig. 11. Township and range lines, one highway, and two lake names have been added to accentuate the map's geographic character. For comparison of this map to a previously published map of the same area see Fig. 12. This "ground-truth" map was taken from the McPherson County Soils Survey, sheets 7,8,13,14,19 and 20.[8] Note the stiking similarity between the two maps. Blowouts, lakes, and soil groups are in the same geographic locations; they are the same shapes; and they are approximately the same sizes. The computer map indicates more blowouts and larger extents of Elsmere and Dunday soils. The distribution of "anomalous" Elsmere and Dunday soils on the computer map is localized along shallow topographic troughs between the northwesterly trending longitudinal dunes. These troughs are regions where conditions are favorable for formation of Elsmere and Dunday soils. Therefore, it is not unreasonable to expect these soils to exist at the locations indicated on the computer map. The authors believe that

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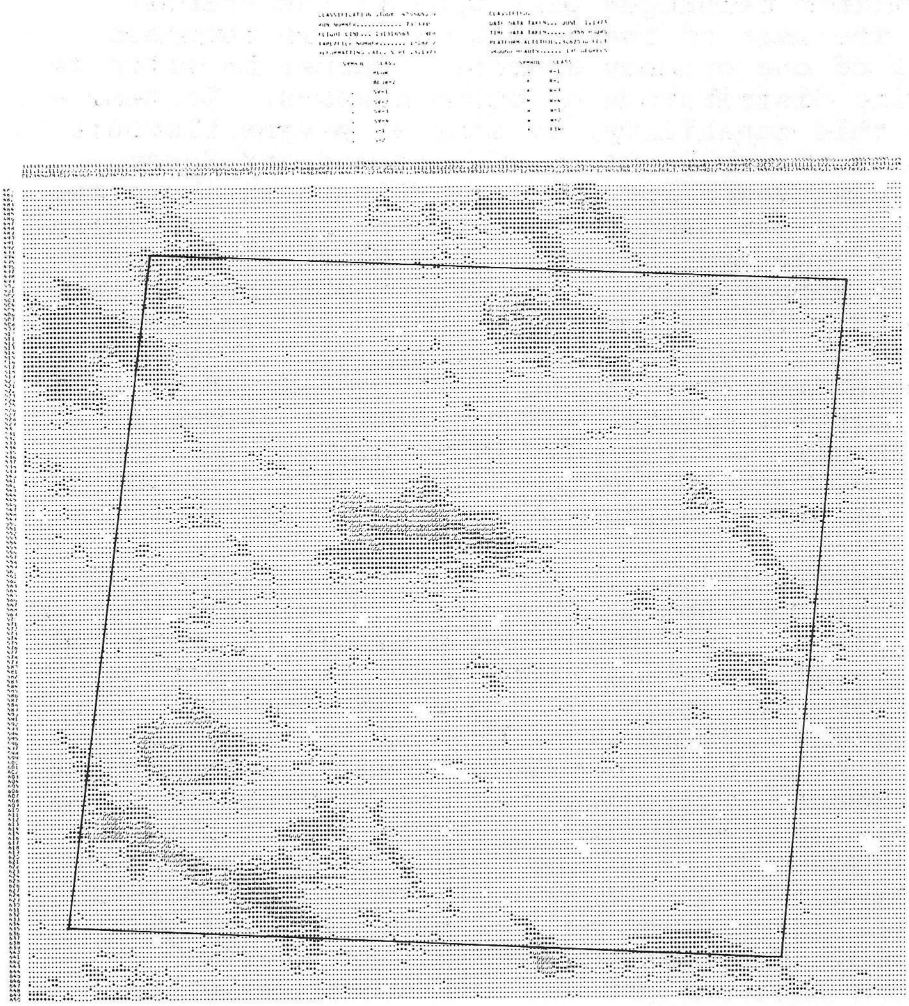

Fig. 10 Computer printout spectral class map of approximately the same area as Fig. 9. Blank = spectral classes A and B; · = classes C,D,E,F,G, and H; G = class I; * = classes J and K; M = class L; W = classes M and N.

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the method of mapping described in this report, with judicious interpretation, offers a capability to upgrade many surface cover type or soils maps constructed by conventional techniques. This does not imply that all surface mapping units nor all geographic areas are equally adaptable to such machine-aided analysis.

Another technique developed at LARS-Purdue allows the user of the LARSYS system to suppress display of one or many spectral classes in order to emphasize distribution of other classes. To demonstrate this capability, an area of severe blowouts northeast of the junction of Birdwood and Squaw creeks was chosen for display. Figure 13 shows two pictures of the same area. Figure 13A is displayed with the same grey scale code as Figs. 3, 8, and 9. Blowouts appear white. The larger ones can be seen, but their outlines are indistinct, and many small blowouts are impossible to distinguish. Figure 13B suppresses the contrasting greytones of all classes except blowout (white). River bottoms appear as black to aid in geographic orientation. On the blowout accentuated image, blowout locations and sizes are easily discernible.

Blowouts (Figs. 14 and 15) are an economic detriment in the Sand Hills region. Commonly, as seen in Fig. 14 with the white-faced culprits caught red-handed, cattle walking along fence lines disturb the grass cover and initiate blowout development. The tires in the foreground of Fig. 15 are not the beginnings of a trash heap but, hopefully, the ending of a blowout. Field observations indicate that old tires are used commonly to line incipient blowouts in an attempt to stabilize moving sand. Timely and accurate location of constantly changing blowouts can significantly reduce the erosional loss of rangeland. Thus, maps obtained from analysis of satellite data can provide both needed timeliness and accuracy.

Two other class accentuation images are shown in Fig. 16. Both photos are of the same area covering parts of western McPherson County and eastern Arthur County (see Fig. 17, outline E). This area is a lake district of the Sand Hills, and is marked by many wet lowlands comprised of marshes, ponds, and productive hay areas. Figure 16A displays the depressionnal areas as black and white in a medium-greytone matrix. Black areas are lowlands suitable for hay cutting. These haylands surround or border on the west the marshes, lakes, and ponds, as shown in white. To further accentuate the character of these water-covered areas, Fig. 16B separates for

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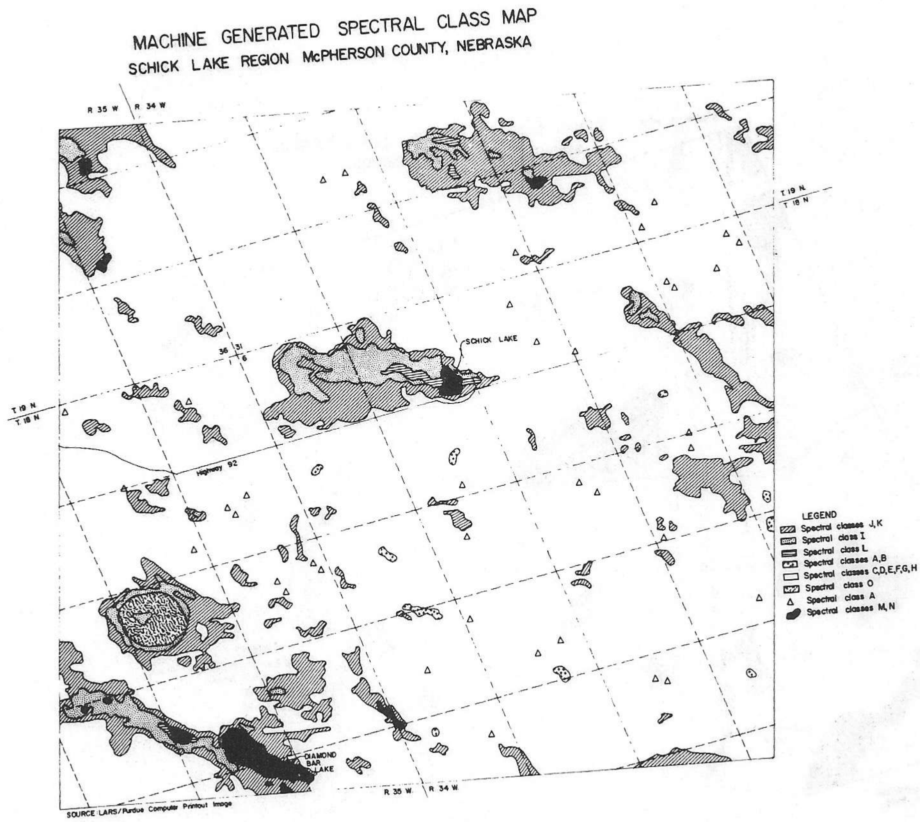

Fig. 11 Overlay of spectral class map, traced directly from Fig. 10.

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display 3 classes of wetlands. White represents permanent lakes. Light grey portrays areas of shallow, seasonal lakes, filled at this time of year, 1 June 1973, by late spring and early summer rains. These seasonal rains raise the water table and produce numerous ephemeral lakes and ponds. Black areas of Fig. 16B are marshes, many also seasonal. These wetlands offer recreational activities such as fishing, duck hunting, and swimming, and as such are economically important in our era of leisure dominated lifestyles.

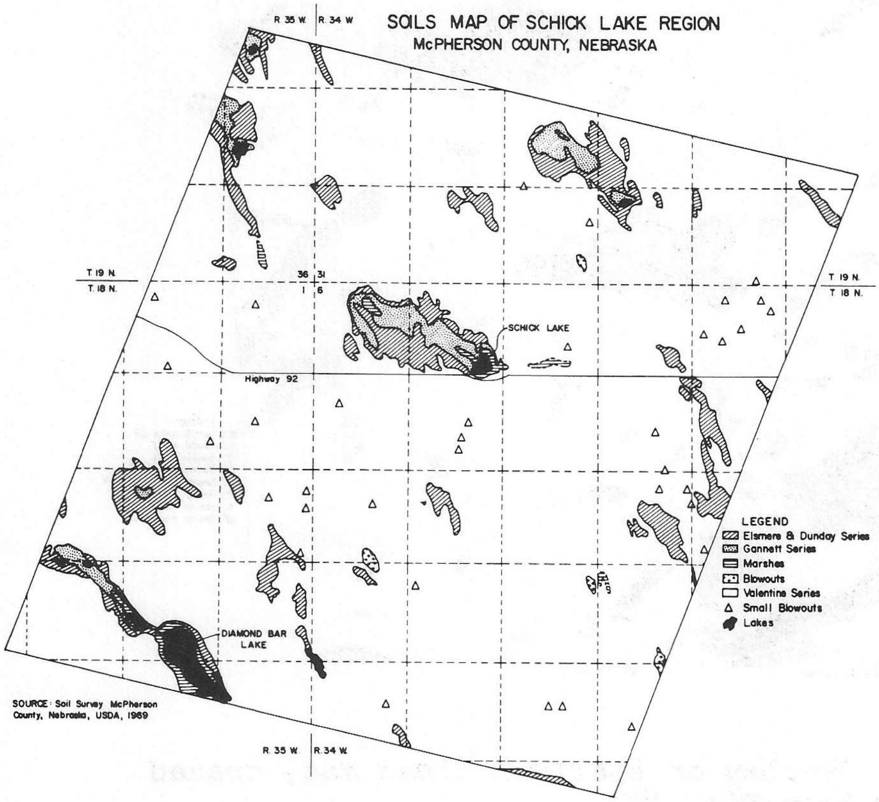

Fig. 12 USDA soils map of Schick Lake area, traced directly from portions of sheets 7,8,13,14,19, and 20 of Sherfey's[8] report.

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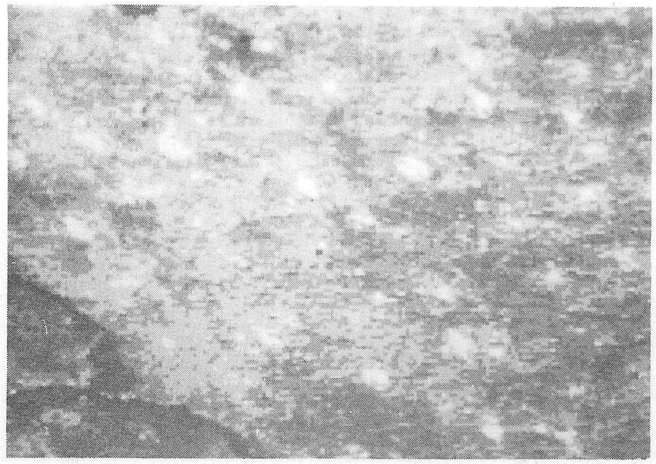
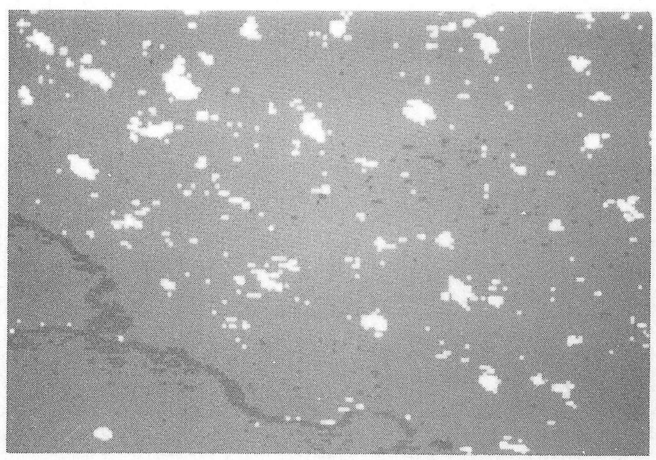


A



B

Fig. 13 Computer digital display map of severe blowout area in McPherson County (outline D, Fig. 17). Figure 13A displays all classes with same greytones as Figs. 3,8, and 9. Figure 13B suppresses most classes for emphasis of blowouts (white).

Fig. 14 Beginnings of a blowout. Blowout development is commonly initiated along cattle trails adjacent to fence lines.

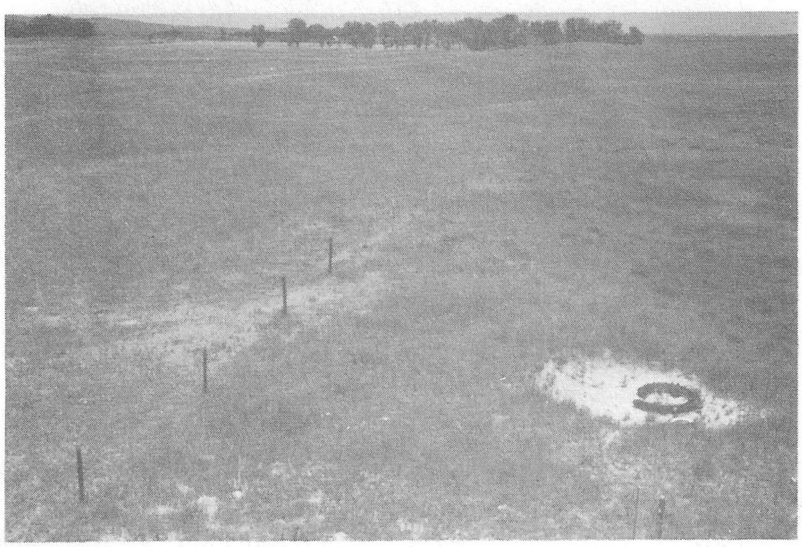


Fig. 15 Small, incipient blowout with worn out tires placed along the edge to retard wind erosion.

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A

B

Fig. 16 Spectral class accentuation map of the lake area (outline E, Fig. 17). In Fig. 16A, white = wetlands; black = lowlands. Figure 16B furthur accentuates wetland classes. White = permanent lakes; light grey = temporary lakes; black = marshes.

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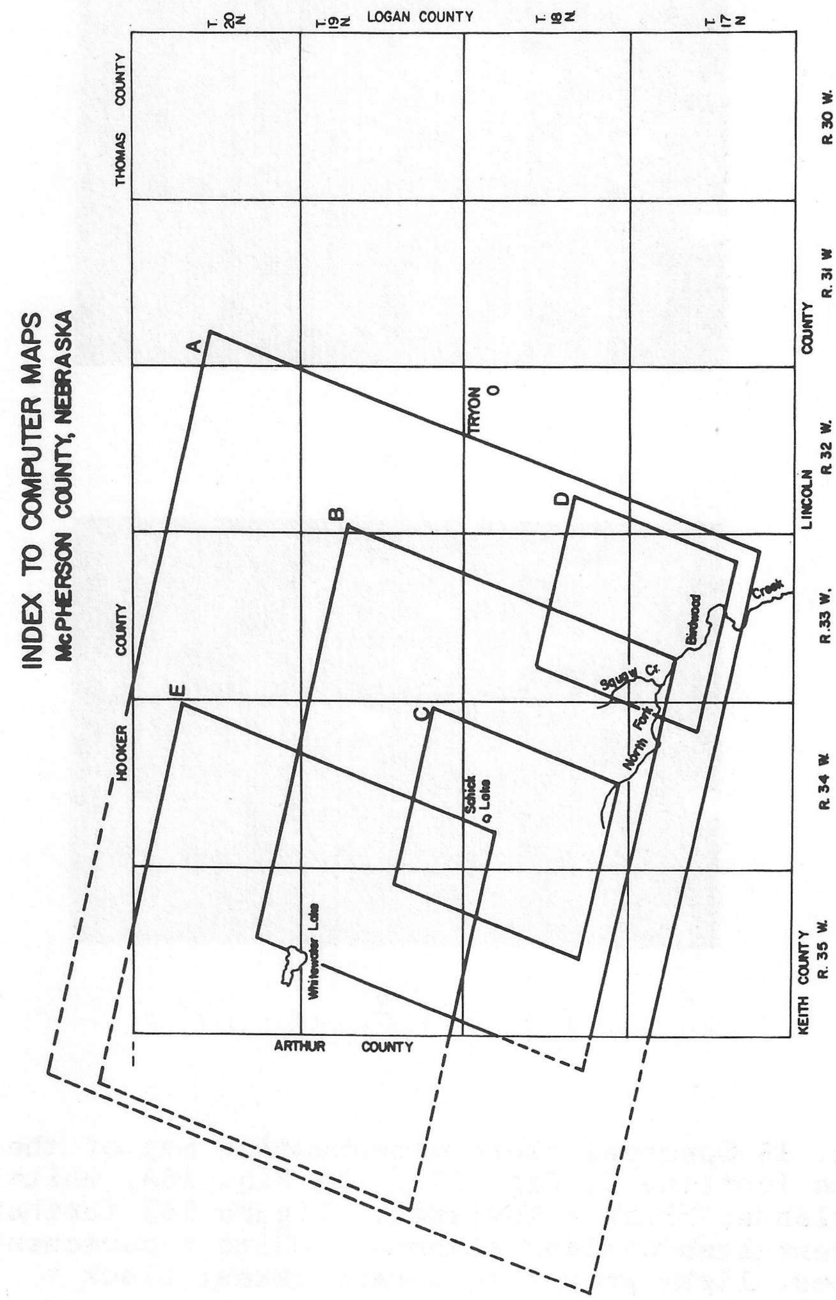

Fig. 17 Location index map for all computer maps discussed in text, and referenced in Figs. 3,8,9,13, and 16.

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