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Land-Use Classification Utilizing Infrared Scanning Imagery

A test of thermal infrared scanning imagery of Oak Creek Lake, West Texas, indicated that a U. S. Geological Survey land-use classification system is adequate.

Abstract: In USGC Circular 671 (1972), Anderson et al. *proposed a land-use classification system to be employed with remotely sensed aerial imagery. The system is tested here in a land-use study of a West Texas city reservoir. In the process, capabilities and utility of 8-to-14 micrometre infrared linescan imagery are examined.*

It is determined that the enhanced resolution capabilities of low-altitude infrared linescan for some targets render some of the Circular 671 categories too broad for large-scale imagery interpretation. Nonetheless, the special properties of low-altitude thermal infrared imagery in combination with the Circular 671 classification system form a research tool of great versatility in performance of thematic land-use surveys.

Introduction

This paper is the result of a study in imagery utilization. In the exercise, a strip of infrared scanner imagery was examined in an attempt to determine land use in the region covered by the imagery. In the course of the research, ancillary data were applied to the analysis. Finally, a visit was made to the area in order to verify assumptions derived from imagery interpretation.

This exercise served to examine two main concepts: the utility of the imagery for empirical, thematic land-use analysis, and the utility of the USGS Circular 671 (Anderson *et al.*, 1972) land-use classification system for infrared imagery analysis.

The study area consisted of the land immediately surrounding an artifical water impoundment in west-central Texas. It is located in a non-urban region of relatively sparse population and low precipitation (see Figure 1 and 2). Table 1 gives climatological data for the nearest large city, Abilene, which is located 68 kilometres to the northeast.

Methods and Techniques

The imagery utilized consisted of a strip of recording film containing the output of a thermal infrared scanner. The scanner was an AN/AAS-18 linescan infrared detecting set. Its sensing range extends from 8 to 14 micrometres. More specific information on the sensor was not available. However, based on other available data, it seems likely that the AN/AAS-18 is a photoconductive quantum detector utilizing mercury doped germanium (GeHg) as a detector crystal material.

The image produced by this sensor is a continuous strip of differentially toned light lines which combine to form a photograph-like image (see Figures 3(a) and 3(b)). The final result is recorded on black-and-white instrumentation film, in this case GAF Type 2005. However, there are certain basic differences between this scanning imagery and standard infrared-sensitive photographic films.

The most essential difference lies in the areas of spectral sensitivity. Nearly all

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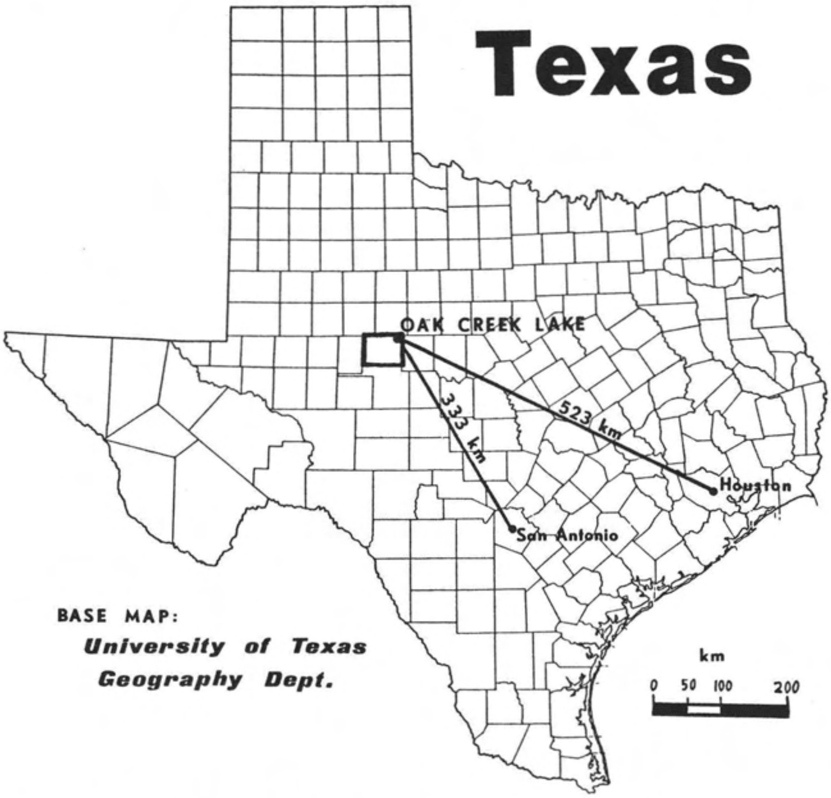


FIG. 1. Map showing location of study area within Texas.

black-and-white infrared films record in a relatively small portion of the infrared spectrum in addition to recording most of the wavelengths of the visible light spectrum. (Generally, sensitivity ranges include the near or reflected infrared (0.72 to 1.4 mi-

TABLE 1. CLIMATOLOGICAL DATA FOR ABILENE, TEXAS
32° 36′ N, 99° 42′ W Altitude 545.3 m

Month	Average Daily Mean Temperatures (°C)		Average Total Precipitation (mm)	
	1931–1960	1931–1974	1931–1960	1931–1974
January	7.0	6.7	22	25
February	9.1	8.9	28	27
March	12.8	13.0	26	27
April	17.9	18.2	58	58
May	22.1	22.3	110	99
June	26.8	26.7	68	71
July	28.4	28.5	58	58
August	28.3	28.2	37	53
September	24.4	24.2	53	68
October	19.0	19.0	72	65
November	11.7	12.0	28	32
December	7.8	7.8	32	28
Annual Mean/Mean Annual	17.9	18.3	592	614

Data 1931–1960 from Court, 1974.
Data 1961–1974 from U.S. Weather Bureau, *Monthly Climatological Data for Texas*
Data analysis by Robert E. Brown.

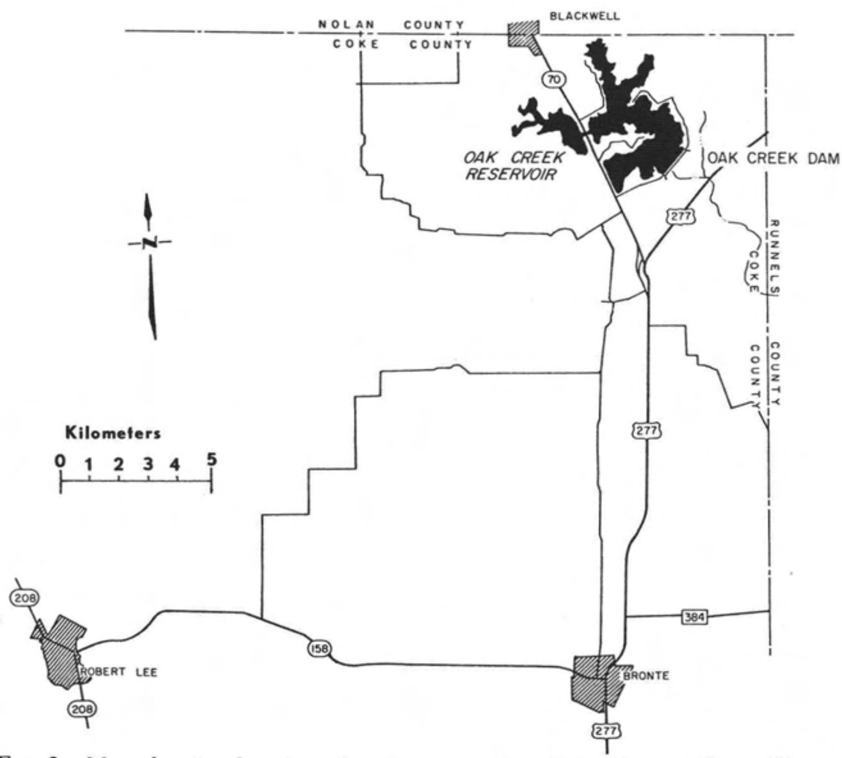


FIG. 2. Map showing location of study area within Coke County (Texas Water Development Board).

crometres.) Limitation of wavelengths recorded is accomplished through use of optical filters.

Scanners can be designed to be sensitive to almost any portion of the electromagnetic spectrum. Moreover, they can be designed to be sensitive only to infrared: no visible light energy need be recorded unless a researcher desires it to appear on the imagery. Common quantum detector ranges are

- 0.5 to 1.0 μm (Silicon crystal)
- 1.5 to 4.0 μm (Indium Arsenide crystal)
- 1.0 to 5.5 μm (Indium Antimonide crystal)
- 2.0 to 15.0 μm (Mercury-doped Germanium crystal)
- 2.0 to 30.0 μm (Copper-doped Germanium crystal).

—*Advanced Imagery Interpretation Notes,* 1969

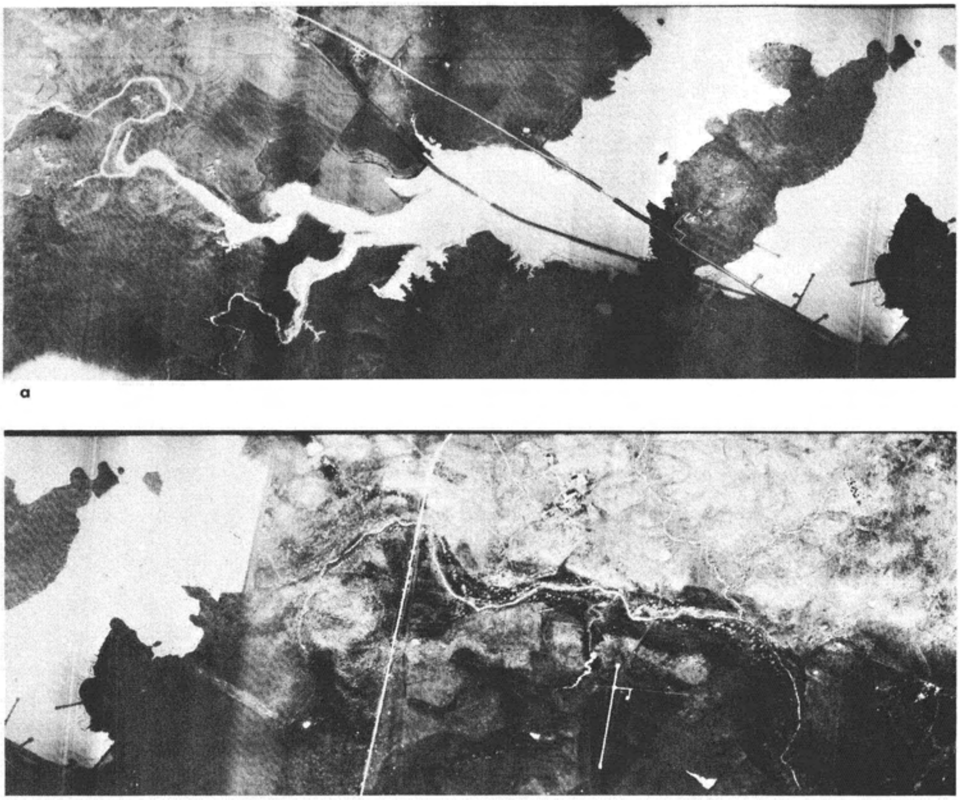
One other major difference exists between conventional aerial photography employing infrared film and infrared scanning imagery. An airborne scanner normally reads 60° either side of the geometric plane of the nadir line. For the AN/AAS-18 scanner involved in this mission, these scanning parameters yielded an effective focal length of 29.21 mm. As a consequence, in relation to scale, a scanner image has some scale elements of both vertical and oblique photographs. Longitudinal scale (distances measured parallel to the direction of flight) remains constant. However, lateral scale (distances measured perpendicular to the direction of flight) varies from the nadir line to the edge of the image (see Taylor and Stingelin, 1969).

The imagery used in this study was recorded in the early evening hours of 11 November 1974 (0106 GMT, XI/12/1974) from an altitude of 754 m above the water surface of the reservoir. Assuming a standard 60° scan angle (nadir-to-edge) and using basic trigonometry, it was determined that lateral coverage was 1306 metres either side of the nadir line, for a total lateral ground coverage (edge-to-edge) of 2612 metres.

$$\text{Lateral coverage edge-to-nadir} = H \tan \phi \quad (1)$$

where H is the height above ground and ϕ is the scan angle, edge-to-nadir.

Scanning was accomplished during post-



a

b

FIG. 3. Prints of imagery showing the study area.

twilight darkness (1906 local time). Analysis was performed in accordance with the USGS Circular 671 classification system (Anderson *et al.,* 1972).

In any land-use assessment, the question of classification of data inevitably arises. When use of remotely sensed imagery is involved, the structure of the classification scheme then becomes a function of the level of generalization necessitated by the resolution of the imagery. The researchers believe that the system described in Geological Survey Circular 671 (Anderson *et al.,* 1972) offers a more-than-adequate framework for classifying data gathered for this project. Conceived for use mainly with ERTS/LANDSAT satellite imagery, it subdivides nine broad regional categories. The major categories are based largely on vegetational differences.

The scale of the imagery was determined by measurement of the distance between two points on the imagery, provided the line between them ran parallel to the line of flight. The corresponding distance on the 1:24,000 topographic sheet of the area was then measured. The ratio of the two distances was then divided into the scale reciprocal of the topo sheet.

$$\text{imagery distance/map distance} = 1{:}x / 1{:}24{,}000 \quad (2)$$

$$I/M = 24{,}000/x \quad (3)$$

This mensuration process was employed to determine the longitudinal scale of the imagery. The longitudinal scale was ascertained to be approximately 1:25,840.

MATERIAL STUDIED

Aside from the imagery itself, sources consulted in regard to the study area included small-scale 1:500,000 aeronautical charts and 1:24,000 USGS topographic maps. Also consulted were the Texas Water Development Board's *Engineering Data on Dams and Reservoirs in Texas, Part III* (1971) and the US Soil Conservation Service's *Soil Survey of Coke County, Texas* (Barnhill, 1974).

AREA DESCRIPTION

The study area incorporates the land immediately surrounding Oak Creek Lake, an artificial water impoundment on a tributary of the Texas Colorado River. The surveyed area is located in Coke County, in west-central Texas, 333 kilometres northwest of San Antonio and 333 kilometres southwest of Dallas. Its geographical coordinates are: 32° 2′ 30″ N and 100° 16′ 30″ W (see Figures 1, 2, 3(a), and 3(b)).

Oak Creek Lake was created in 1953, primarily as a municipal water reservoir for the city of Sweetwater, 48 km to the north. However, other uses are also made of the reservoir. Its shores are rimmed with weekend and summer vacation homes. Petroleum extraction facilities operate in certain parts of the reservoir. A marina and motel complex is situated on the shore. Additional tourist service facilities are located 1.5 km north of the marina along Texas Highway 70.

Results

Headings refer to the land-classification categories postulated in USGS Circular 671.

01-01 RESIDENTIAL

The imagery recorded large numbers of dark (cool) structures situated near the shores of Oak Creek Lake. Given available ancillary information and the apparent lack of extensive peripheral automobile parking facilities, the structures can be identified as residences (Figure 4). Ground-truth observation confirmed the identification.

It would be legitimate to inquire concerning the reason why these habitations should register as cooler than the surrounding land. The answer relates to both house construction and to time of imaging.

The empirical evidence—location of reservoir, lack of nearby industry, etc.—strongly suggests that these structures are vacation homes owned by residents of other cities. Summer-season vacation homes are usually constructed of different materials and are insulated to a lesser degree than are homes intended for year-round occupation in most of North America. Consequently, such structures generate little heat when not occupied and will emit less infrared energy than the surrounding land, which bears insulating layers of dormant sod.

Two important interpretive factors may be noted in regard to the date and time of imaging. First, the late autumn date of the mission indicates that the observation was made long after the end of the normal tourist season in central Texas. Secondly, 11 November 1974 was a Monday; most weekend vacationers would have closed their vacation homes at Oak Creek and returned to their permanent residences. Consequently, most heat-generating mechanisms within these structures would be either not in use or would be absent at the time of imaging.

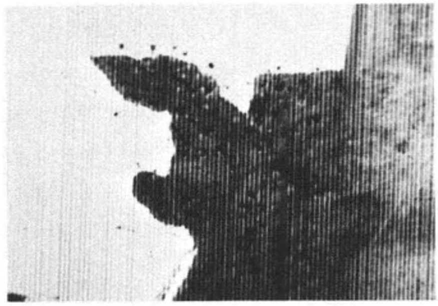


Fig. 4. Imagery enlargement showing lakeside houses and private boat docks.

The above two factors also would apply to most commercial buildings. Given such circumstances—a Monday evening in late autumn—the probability is low that any retail or food-service establishments in the study area were occupied at the time of imagery generation. As a result, these structures would register cool on the imagery, as did the unoccupied residences.

01-02 COMMERCIAL AND SERVICES

There are two main clusters of these types of buildings visible in the imagery or shown on the maps. Both were noted on the ground-truth observations. Beside Texas Highway 70, 1.5 km north of the shore, lies a complex which includes a motel, restaurant, grocery store, and gasoline station. Near the reservoir, where Highway 70 intersects the northern shore, is another complex, a fishing resort, which includes food services, equipment sales, marina facilities, boat-launching ramps, and overnight lodging.

"Oak Creek Village" Complex. This can be seen on the imagery as a cluster of eight buildings beside Highway 70, 1.5 km north of the shore (see Figures 1 and 5). Several factors suggest that the signatures represent non-residential structures:

> The structures in the complex are differently sized. Post-World War II houses in North America have generally tended to be uniformly sized within their respective price brackets, and similarly-priced houses have tended to be built in relative proximity to each other. Therefore, it is unlikely that the signatures on the imagery represent residences.
>
> Moreover, it may be noted that the signa-

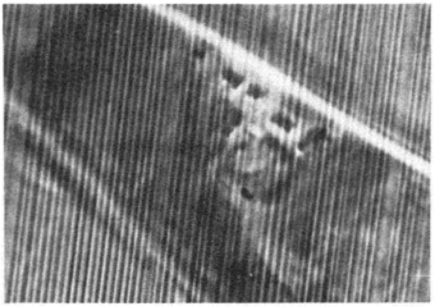


FIG. 5. Imagery enlargement showing Oak Creek Village tourist-service complex.

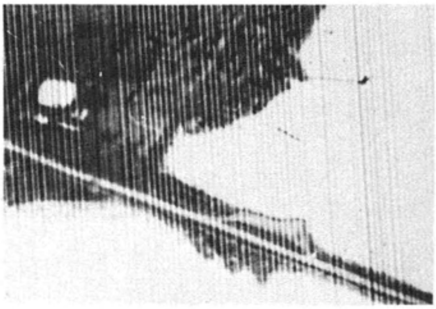


FIG. 6. Imagery enlargement showing marina complex and boat ramp on causeway.

ture on the imagery indicates warmer (lighter-toned) ground between the buildings in the complex. This warmer material was discovered to be asphalt surfacing. Residential structures are normally bordered by grass or other vegetative landscaping rather than asphalt surfacing.

Absolute data on differences in absorption and radiation rates between asphalt and vegetated soils of the study area were unavailable. However, asphalt with its crushed-rock subbase probably has a larger thermal capacity than vegetated soil. If so, asphalt in the course of a day would absorb more incoming solar energy and would thus radiate at a higher radiometric temperature immediately after sunset.

Lakeside Fishing Resort. This signature presented more of a problem. There are no telltale asphalt patches to indicate high-density automobile parking facilities. Most structures that can be seen are of roughly the same size (see Figure 6).

However, it may be noted that there are three boat-handling facilities in close proximity to each other—two long boat piers and an asphalt patch on the nearby bridge causeway. That patch was discovered to be a public boat-launching ramp during ground-truth validation. It could be surmised from that information that a boat-servicing facility probably existed at that location. Deductions were confirmed during ground-truth survey.

01-04 EXTRACTIVE

Along the southwestern shore of the reservoir can be seen five pierlike structures. Piers of such length and width would normally service large ships. Such a use would be highly improbable on a reservoir formed by the damming of a non-navigible stream. Therefore, they probably are not piers.

It was ascertained that the structures were in reality rockfill causeways terminated by "grasshopper-type" petroleum pumps. Each causeway terminus accommodated one pump at the wellhead (see Figures 3(a) and 7).

01-05 TRANSPORTATION, COMMUNICATIONS, AND UTILITIES

Two highways can be readily discerned on the imagery. Research and personal observation showed them to be U.S. Highway 277 (on the east, Figure 3(b) and Texas Highway 70 (on the west, Figure 3(a). Both are of standard macadam-and-crushed-stone-base construction. Their high visibility on the imagery is due to several factors. Most pavement types exhibit good emissivity and maintain direct thermal contact with the

FIG. 7. Imagery enlargement showing trace of heated effluent.

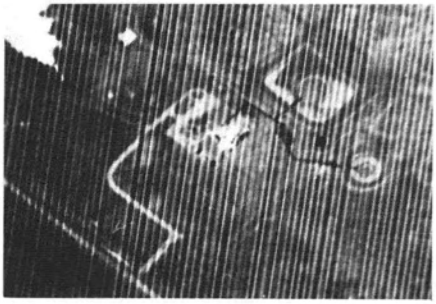


FIG. 8. Imagery enlargement showing power plant.

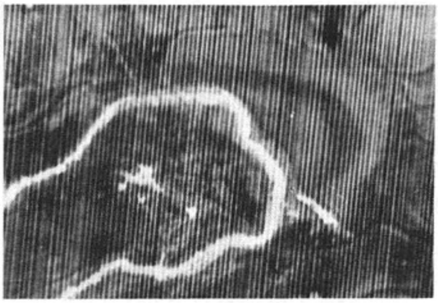


FIG. 9. Imagery enlargement showing meander scar.

earth. Moreover, the pavement, having a greater thermal capacity, radiates at a higher radiometric temperature than the surrounding soil during early evening hours. This difference becomes less pronounced in the very late-night hours as both materials approach the ambient air temperature.

A railroad may be seen paralleling Highway 70. It was determined to be a line of the Atchison, Topeka, and Santa Fe Railroad. Note that the highway and railroad bridgements over the reservoir give similar returns (see Figure 3(a). However, it is not difficult to discern the light-toned thermal trace of the macadam highway in the center of the highway bridgement, while the tone of the railway is almost identical with that of its rockfill bridgement. Obviously, the metal of the railroad is emitting less infrared energy than the macadam of the highway at these wavelengths at the time of image generation.

A complex of buildings can be observed on the peninsula adjacent to Highway 70 (see Figures 3(a) and 8). The size of the buildings and their location in a rural resort area indicate that the buildings are not residential in nature. The signature was initially identified as an industrial complex. A patch of white in the middle of the complex is probably a sign of a discharge of combustion products into the atmosphere. Not too far away, just off the southern shore of the peninsula, can be seen a lighter-toned area of water which indicates discharge of heated effluents into the reservoir (see Figures 3(a) and 7). It is unlikely that a major industrial plant would be located here, in a rural area 68 km from the nearest large city (Abilene). Moreover, automobile parking facilities (based on size of asphalted area) seem inadequate for a large employee population. Finally, it seems unlikely that an industrial concern in this area would still be producing combustion products and liquid effluents after 1900 local time.

These suppositions were validated during the ground-truth survey. The complex is actually an electric power generating plant belonging to West Texas Utilities. Signs in front of the installation advising of the presence of a buried natural-gas pipeline suggest that the power plant is a gas-fired facility. Ground-truth investigation showed that such was the case. However, the plant also has the capability of burning fuel oil during periods of high demand and/or short gas supply. This fact explains the presence of three oil storage tanks on the grounds of the installation (see Figure 8). Very dark lines connecting the tanks with the generating facility can be seen on Figure 8. These signatures are indicative of metal pipelines feeding from the lower, colder levels of the oil tanks serving the power plant.

02-01 CROPLAND AND PASTURE

A contour-plowed area west of Highway 70 extending from the meander scar on Oak Creek to the point where the railroad intersects the shore of the reservoir can be discerned on the imagery (see Figures 3(a) and 9). The contour plowing and the subdivision of the tract into orderly rectangles suggest that the area is used for cropland rather than for pasture.

It is possible that the visibility of the meander scar on the infrared imagery is due to differences in soil types between the bed of the meander scar and the alluvium which surrounds it. Barnhill (1974) types both the scar itself and the area enclosed by it as Clairemont silt loam, yet the imagery shows a definte difference in thermal emissivity between the two features. The explanation may lie in a possible change in parent material of the alluvium deposited by the meander in the final stages before its cutoff by the main stream. A variation in water retention by the soils in the area of the scar may be another reason for the prominence of

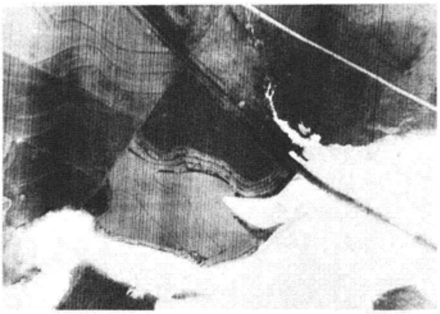


FIG. 10. Imagery enlargement showing cultivated land west of Highway 70.

the meander scar signature. Other factors involved could include topographic lows, presence of unusually high or low concentrations of organic matter, or a difference in grain size of the soils.

The meander scar treated above appears to be a phenomenon which can be noted on infrared imagery, but which requires detailed ground-level analysis for explanation. For example, C. L. Girdner of the U.S. Soil Conservation Service informed the writers that, according to research done near Weslaco, Texas, gross grain-size distinctions (e.g., between clays and sands) could be made by utilizing photographic infrared imagery. However, only very poor correlations were obtained when attempts were made to discern more subtle grain-size variations.

The plots of cultivated land southeast (downstream) of the meander scar can be identified from the terrace dikes between Highway 70 and Oak Creek Lake (see Figures 3(a) and 10). The visibility of these dikes on nighttime imagery may be at least partially explained through consideration of Lambert's Law of Cosines. This law states that, for a radiating plane surface which is a perfectly diffusing blackbody, the intensity of the emitted radiation at the receiving point varies only as the angle between the normal to the surface and the line of sight (see Hackforth, 1960, p. 19, and Tuyahov, 1972, p. 41). As applied to the study area, the preceding statement means that the scanner will perceive the nearly horizontal terraces as "warmer" than their dikes or berms even though the dikes may be made of material taken from those same terraces.

This can be demonstrated through reference to Figure 11. Assuming that all other factors are identical, the scanner will receive less intense radiation from berm *a* than from terrace *b*. (Cos ϕ decreases from positive to negative unity as ϕ goes from 0° to 180°. Because $\phi_1 > \phi_2$, it follows that Cos $\phi_1 <$ Cos ϕ_2.) Hence, the contour berms register cooler than the adjacent terraces (Tuyahov, 1972).

The uniform tonal texture of these terraces as contrasted with surrounding land can be readily seen on the imagery. The uniform textures indicate a certain uniformity in plant types, plant heights, and plant cover. It may also be noted that the various fields in the cultivated tracts differ from each other in intensity of return. The lighter-toned (warmer) fields were allowed to lie fallow following the harvests of September and October, while the darker-toned (cooler) fields were planted in a short-grass cover crop. The differences in radiometric temperature could be due to the shading effect of the grass and to heat dissipation through photosynthetic transpiration. These factors, in combination with the general nighttime cooling which occurs at ground level, serve to give the grassy areas a lower radiometric temperature than the neighboring fallow fields. Therefore, grass-cover areas will register cooler on early nighttime imagery than will areas of bare ground.

03-01 GRASS RANGELAND

Most of the study area not otherwise identified falls into this classification. It may be distinguished from the cropland discussed earlier by the rougher texture of the rangeland return. This situation is due to the much greater complexity of rangeland flora. Variations in size and shape of the natural plant cover vary the intensity of the infrared emission return. These differences in emissivities give rise to a vastly different return than that from mono-cropped cultivated fields.

The majority of grass rangeland in the study area is to be found east of Highway 277 and north of Oak Creek (see Figures 3(a) and 3(b). It is characterized by short grass with occasional patches of bunch grass and larger dry-climate shrubs. The entire study area appears to be a transition zone between grass rangeland and the savanna rangeland regime discussed below (a distinction between grassland and savanna made by the authors of Circular 671 when they devised the classification system discussed in this paper). According to Barnhill (1974), this grass rangeland is underlain by several different soil types, none considered well-suited for mono-crop cultivation.

03-02 SAVANNA RANGELAND

In the *In the Atlas of Texas* (Arbingast *et al.*, 1973), the study area is shown as being located in a "mesquite savanna" region. This

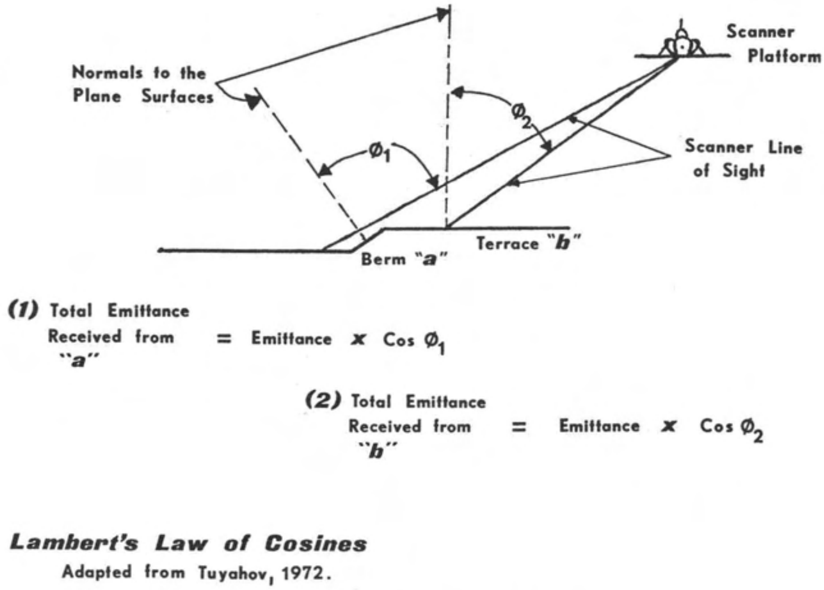


FIG. 11. Illustration of Lambert's Law of Cosines.

(a) Northwestern portion.

(b) Southwestern portion.

floral assemblage is characterized as "bunch and short grasses with mesquite trees." Near San Angelo, 65 km to the south, the regime is described as changing to "juniper-oak-mesquite savanna." On the imagery, land fitting this description lies mainly south of the dam and west of Highway 277 (see Figure 3(b). According to Barnhill (1974), this part of the study area is underlain by much the same soils as comprise the range grassland regime.

Two hypotheses may be suggested for this difference in biotic communities within similar environments. The Oak Creek Reservoir area, as previously theorized, may be a transition zone between the two rangelands mentioned above. On the other hand, much of the range grassland may be savanna rangeland thinned out through clearing to allow cattle to graze more easily.

On the imagery, the grass rangeland can be distinguished from the savanna rangeland by the lighter tone of the former. This difference could be due to a number of factors. For example, the mesquites provide enough shade to retard ground absorption of solar energy during the day. However, the mesquite cover might not be thick enough to trap at treetop level reradiated longer-wave energy emitted from the earth surface. As a result, emitted longwave energy from the ground escapes into space, giving the savanna an even lower radiometric temperature than the grass rangeland. As a result, the savannas show up in the imagery in a darker tone than do the grass rangelands.

04-01 DECIDUOUS FOREST

> Forest lands are lands that are at least 10 per cent stocked by trees capable of producing timber or other wood products that exert an influence on the climate or water regime.
> —Anderson *et al.*, 1972, p. 12

Under this definition, only one section of the study area can be considered as deciduous forest. That section is comprised of the wooded bottomlands immediately downstream from Oak Creek Dam. This location is characterized by stands of native hardwoods, such as cottonwoods, elms, mesquites, and ash-juniper.

On the imagery, this forest appears as a fairly light-toned patch of extremely granular texture. The trees register as warm partly due to convective heating (the nighttime inversion at treetop level which accompanies the extreme ground-level cooling mentioned in the cropland-and-pasture and savanna-rangeland sections). Also, the trees register as warm partly as a byproduct of daytime solar heating. The granularity of the imagery return stems from the differing heights and shapes of the trees involved and the resultant emissivity variations.

05-01 STREAMS AND WATERWAYS

In Circular 671, these are defined as "rivers, creeks, canals, and other linear bodies that meet the minimum width requirement of 1/8 mile" (201.2 m) (Anderson *et al.*, 1972, p. 13). The authors of Circular 671 do not state their reasons for adopting a 200-metre lower limit for stream widths. It is possible that they believe smaller linear water bodies should be considered part of the surrounding land areas. The authors might have established 200 metres as a *prima facie* navigability limit for commercial vessels. Perhaps they consider 200 metres a minimum resolution threshold for the small-scale satellite-generated imagery which is their primary concern. The real reason most likely is a composite of the preceding hypotheses.

Whatever their reasons, Anderson's, Hardy's, and Roach's definition of 200 metres as a minimum stream width is somewhat unrealistic as applied to the imagery treated in this paper. First, Oak Creek itself is not very large. The imagery trace of the main channel immediately upstream of the impoundment (at the head of the reservoir) was measured and found to represent a stream width of approximately 25 metres. Secondly, resolution of this imagery (longitudinal scale of 1:25,840) allows identification of fairly narrow linear water bodies. The imagery trace of a section of Bouzier Creek, an Oak Creek tributary upstream of the water impoundment, was measured. As with the Oak Creek analysis, mensuration was performed parallel to the flight line, in recognition of the fact that only longitudinal scale is constant on this imagery (see Taylor and Stingelin, 1969). Appropriate conversions showed that section to be approximately 1.5 metres wide. Absolute minimum resolution of such streams, which admittedly contrast greatly with the surrounding land, would be even less than 1.5 metres.

Consequently, it seems that a researcher wishing to apply the Circular 671 classification system to studies employing large-scale infrared scanner imagery easily would be able to adopt a far lower width threshold for streams and waterways than those postulated in Circular 671.

05-03 RESERVOIRS

According to Circular 671, a reservoir is an artificial water impoundment of more than 40 acres (16.188 hectares) in area. Only one body of water in the study area covers an expanse this large and that is the Oak Creek Lake reservoir itself. The linear form of the dam at the southeast corner of the lake identifies it as an artifical water impoundment. Therefore, under the terms of the Circular 671 classification system, Oak Creek Lake is not a lake, but a reservoir. According to TWDB Report 126 (1971), the surface area of Oak Creek Reservoir in normal times is 2,375 acres, or 961 hectares.

The dam across Oak Creek was built between 1950 and 1952. Water impoundment was initiated in 1953. The owner and major consumer of the reservoir's water is the city of Sweetwater, Texas, about 70 km to the north. Some water is also sold to Blackwell, 3.5 km north, and Brontë, 22 km south of the reservoir.

A reservoir, particularly in an arid inland region, usually serves a multiplicity of purposes. Oak Creek Reservoir is considered to have definite recreational value, otherwise the marina and motel complexes described earlier would not have survived economically. As discovered during the ground validation, many of the people seeking recreation at the reservoir are sport fishermen and waterfowl hunters. This implies that the reservoir is also a habitat for certain types of wildlife. In short, the reservoir designation implies multi-purpose utilization.

05-05 OTHER WATER BODIES

Linear water bodies less than 200 metres wide and non-linear water bodies less than 16 hectares in area are grouped, under the Circular 671 system, in this broad category. It has already been argued that the width limit for linear water bodies is unrealistic when dealing with large-scale imagery such as that analyzed in this paper. However, no objection has been raised to the Circular 671 definition for non-linear water bodies.

On the imagery of the study area can be seen numerous light-toned returns indicating presence of water bodies. Based on measurement of the imagery returns, the vast majority of these water bodies cover less than one hectare each. They are either circular with unnaturally smooth curvilinear perimeters, or are roughly triangular in shape with a definite linear base along one side. These attributes indicate that the returns delineate small artificial water impoundments.

Ground-based observation of those impoundments located nearest the highways showed that the water impoundments were earth-dammed stock tanks, or water storage basins for range cattle. Because almost all land in the survey area is privately owned, it was not possible to examine basins not visible from the highways. However, the similarity of the shape and thermal response of these traces to those of the features positively identified as stock-watering ponds validate suppositions concerning their actual identity.

Stock tanks leave highly visible traces on the infrared imagery. Moreover, they can be readily identified as artificial water impoundments. It is apparent that nighttime infrared imaging can be a quick and sure means of inventorying stock tanks and similar impoundments in Texas. One caveat should be borne in mind. In regions of karst topography, a water-filled sinkhole may give a return very similar to that of a circular stock tank. Obviously, available topographic sheets, preferably geological maps, of the area of interest should be consulted in the course of the interpretation process. If geological maps are not available, topographic sheets can be supplemented with available literature.

The Oak Creek Reservoir area is not in a region of karst topography. Sinkholes are not indicated on available topographic sheets (Blackwell and Church Peak 7.5′ quadrangles, 1969). Moreover, Barnhill (1974) designates the parent material of the area's non-alluvial soils as Permian shales. Consequently, the empirical evidence is strong that conditions conducive to the formation of karst topography do not exist in the Oak Creek Reservoir area.

Conclusions

Imagery

Remotely sensed infrared scanning imagery, although similar in appearance to standard photography, requires analytical skills different from those required for visible-light imagery. Primary among these is the recognition that, unlike visible-light imagery, an object's visibility under infrared scan is a function of several unique factors. According to TS-I-91 (1969), the intensity of infrared energy emitted by an object depends on its

- Absolute temperature
- Thermal capacity
- Texture
- Background,
- Emissivity.

A researcher working with infrared scanning imagery must bear these points in mind during the intepretation process.

Narrow-band infrared scanning acquires and displays a wide variety of information unavailable through exclusively photographic systems. Infrared scanning imagery serves as a valuable professional tool for geologists, hydrologists, and others working throughout the entire spectrum of scientific research. It has widespread utility in land-use surveys, crop and wildlife inventories, water resource studies, environmental planning, and numerous other applications.

However, infrared scanning, like other survey techniques, is not conducive to universal application. As became apparent in the course of this project, tonal contrast of a subject containing elements of widely differing thermal characteristics (e.g., land-water interfaces) can often reach or exceed the tonal limits of either the recording film or the print material. Therefore, a researcher must acquire imagery suited to his purposes or he must modify pre-existing imagery in accordance with his needs. For example, available imagery may be subjected to computer-generated tonal enhancement on specific areas of interest or highlighted by exposure variations or development modifications during photographic duplication of the imagery. Through these techniques, a researcher studying effluent discharge into water bodies would be able to increase readability of objects and thermal boundaries in the water areas, albeit at the expense of detail in the land areas (see Figure 7 of this paper, and also Taylor and Stingelin, 1969). Similar highlighting techniques have application in other areas of specialized imagery interpretation.

It should also be mentioned that visibility of targets on the imagery is not solely a function of the theoretical minimum resolution of the system as related to its instantaneous field of view. Target visibility depends in part upon the intensity of radiation emitted by the object in question. An object with a radiometric temperature vastly different from that of its surroundings will register more strongly on the imagery than it would if the object-environment temperature gradient were small. This situation is analogous to the concept of "contrast" in visible-light photography. Light objects are most visible against a black or dark background and vice versa.

The Classification System

Anderson *et al.* (1972) evidently conceived their Circular 671 classification system for use mainly with satellite or high-altitude aircraft imagery. Their threshold of a

200-metre width for defining the parameters of a stream possibly indicates an adjustment on their part for the resolution limitations inherent in satellite-generated imagery.

However, it is apparent that the circular 671 classification system also provides a useful framework for researchers dealing with imagery at scales much larger than 1: 1,000,000. Some modifications may be necessary in order to make the system compatible with large-scale imagery. For example, division 01-05 (Transportation, Communications, and Utilities) could be subdivided into three separate categories.

The rangeland classification could also be enhanced by a more definitive restructuring. The "grass-savanna-chaparral-desert shrub" sequence is a subtly changing continuum, one which requires somewhat more rigor in defining its categories than was given in Circular 671. Particularly careful distinction should be made between chaparral and desert shrub in terms of floral assemblages.

In light of changing remote sensing technology, it is obvious that the circular 671 system will require constant modification and redefinition. Nevertheless, the classification system as it currently stands is sufficiently inclusive to serve as an adequate framework for land-use surveys utilizing infrared scanner imagery.

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