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Remote Sensing for Detecting Feedlot Runoff

Possible application would presumably include a comparison of soil moisture content and vegetative differences.

Abstract: *Due to high concentrations of animals, pollution from feedlot runoff is becoming an increasingly serious problem. Aerial remote sensing may be capable of detecting the feedlot pollution in the overland flow region before it reaches perennial streams or infiltrates into the ground water. Several modes of sensing offer promising means of detecting the polluted runoff: panchromatic, color and infrared aerial photography, thermal-infrared imagery, and radar. With the present technology, the best possibility seems to be a multisensor approach combining color photography with either thermal-infrared imagery if little ground cover is present, or using infrared photography if heavy ground cover is prevalent.*

Introduction

Objective

One of the major sources of agricultural pollution is runoff from feedlots and other areas of high animal concentration. The liquid waste from these areas either combines with rain water and flows overland to pollute surface waters or percolates into the ground water.

In beef feedlots, animal densities of from 100 to 200 animals per acre are common. Feedlot size ranges up to 100,000 head; thus, it is easy to see that runoff can constitute a major problem. Many states either have instituted regulations or have proposals pending to govern the runoff pollution from feedlots. Many have been guided by the Colorado law that prohibits any runoff from a feedlot. Making a law that prohibits pollution and enforcing that law are two separate matters. The states with large animal industries and strong anti-pollution regulations are presented with problems of both detection and enforcement.

In this paper the author analyzes the use of Aerial Remote Sensing (ARS) as a means of detecting the polluted runoff. ARS's primary advantages are: (1) it provides a means of rapid surveillance of large areas of land with relatively little man power and (2) the problem of detecting the feedlot runoff is reduced to workable in-office procedures.

Procedure

The procedure used in this paper was principally a literature survey followed by the integration of techniques to develop a scenario. No literature directly related to the surveillance of feedlot pollution was located and conferences with professionals working in the related fields (E. P. Taiganides and R. K. White, *Agricultural Pollution;* G. O. Schwab, *Agricultural Drainage;* and O. W. Mintzer, *Remote Sensing*), revealed little knowledge of current research in this area. The procedure, therefore, became an integration and correlation of information concerning feedlot pollutants, hydrology, and remote sensing, followed by a scenario for applying remote sensing.

Feedlot Pollutants

To find a possible means of aerial detection of feedlot pollution, it is necessary to know the pollutants involved and their effects on the surrounding environment.

Physical and chemical composition of the

* The author received the Bausch & Lomb Photogrammetric Award for this, the best paper on photogrammetry by a college undergraduate student, at the Annual Convention of the American Society of Photogrammetry, Washington, D.C., March 1973.

TABLE 1. CONSTITUENTS OF BEEF ANIMAL EXCRETA[1]

	Lbs./day/animal
Total weight	72.0
Total solids	10.0
Nitrogen	0.36
P_2O_5	0.11
K_2O	0.32
Volatile solids	8.2
BOD	1.28
COD	10.5

runoff varies considerably with the type of animal, concentration, ration, size, and numerous other variables. This paper will concern itself primarily with beef feedlots, but the criteria, with some modification, could be applied to other types as well. Table 1 gives the constituents of the excreta from beef animals.

HYDROLOGY; RUNOFF

The amount and make-up of the runoff from a feed lot varies not only with the type of animal but also the type of precipitation. Table 2 shows the ranges of runoff concentrations from unpaved feedlots.

The effect of the pollutants in the runoff on the area of overland flow depends on soil and vegetation types as well as pollutant constituents.

The physical and chemical constituents of the soil govern the infiltration rate of the pollutant and the ionic exchange between the pollutant and the soil. This is especially important in saline and sodic soils and with salt-sensitive crops. As Table 2 shows, the electro-conductivity (a measure of ionic exchangeability and salt content) is from 1.0-11.5 mmhos/cm^2. This is poor quality water from which salt-sensitive crops should show water stress in response to this type of water in the root zone. Salt build-up in sodic and saline soils, especially in the more arid western states, without subsequent flushing, should limit the ground cover to only salt-tolerant vegetation types. Table 3 lists some ground covers and their tolerance levels.

In humid regions where salt build-up in the soil is not a problem, the increase in available plant nutrients from the pollutants should provide a lusher, denser vegetation cover which is relatively sharply defined from the adjacent nonpolluted area at the drain-

TABLE 2. RANGES OF RUNOFF CONCENTRATIONS FROM UNPAVED FEEDLOTS[2]

Analysis	*Range of Concentrations* *Winter Runoff*	*Rainstorm Runoff*
pH	6.7–7.6	6.6–9.4
Electro-conductivity (mmhos/cm^2)	3.0–11.5	1.0–3.4
Total solids (percent)	3.0–19.8	0.24–1.74
Volatile solids (percent)	1.5–10.7	0.12–0.70
Ash (percent)	1.5–9.1	0.12–1.04
COD (mg/1)	14,129–77,804	1,300–8,247
P (mg/1)	6.8–753.2	13.9–46.6
NH_4 − N (mg/1)	670–2,028	26–82
NO_3 − N (mg/1)	0–80	0–17
Total N (mg/1)	1,429–5,765	65–555

TABLE 3. RELATIVE SALT TOLERANCES OF VARIOUS GROUND COVERS[3]

Relatively Nontolerant	*Moderately Salt Tolerant*	*Relatively Salt Tolerant*	*Highly Salt Tollerant*
EC × 10^3 2.0–4.0	EC × 10^3 4.0–6.0	EC × 10^3 6.0–8.0	EC × 10^3 8.0–12.0
White clover	Tall fescue	Wheat-grasses	Aldali sacaton
Alsike clover	Meadow fescue	Sudan grass	Bermuda grass
Red clover	Orchard-grass	Sweet clover	Rhodesgrass
Ladino clover	Sour clover	Alfalfa	Blue grama
Rose clover	Birdsfoot trefoil	Ryegrass	Panicgrass
Burnet clover			
Crimson clover			

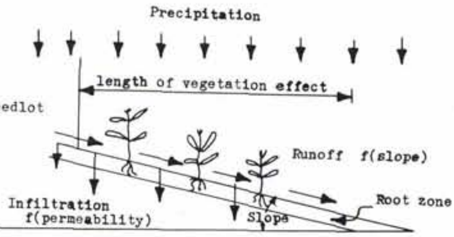

FIG. 1. Relationship between infiltration and runoff determines the length of pollution effect on vegetation.

age pattern boundary. The permeability of the soil to a depth below the root zone and the watershed slope would determine the distance from the source that the vegetation differences would be apparent. The permeability would determine the infiltration rate of the pollutant to a depth below which it would be unavailable to the plants. The watershed slope would define the overland flow velocity. Figure 1 illustrates this concept.

The width of the pollution effect would be determined by the local topography. Concentration of the effect in a narrow region would intensify the pollution effect and elongate it. A broad outflow would diminish the effect and shorten its length.

The relative differences in permeability between the feedlot and the adjacent undisturbed ground would govern the relative runoff rates and volumes for a given precipitation event (rainfall or snowmelt). The permeability of the soil is the separating mechanism that divides precipitation into groundwater and surface runoff. The initial few inches of depth of the soil of an established feedlot would have a lower permeability than the surrounding area of the same soil type because of the compaction caused by the repeated trodding by large numbers of cattle. For a given precipitation, this would cause more runoff from the feedlot area than from its surroundings. This, in turn, should cause a higher soil moisture content in that portion of the drainage pattern immediately below the feedlot because the excess runoff from the feedlot is available to this area for infiltration as well as the precipitation that would normally be available.

REMOTE SENSING

All objects with temperatures above absolute zero emit, absorb and/or transmit energy which is definable by wavelengths in the electromagnetic spectrum. The emission-reflectance pattern (that is, the position of high- and low-energy outputs throughout the spectrum) depends on physical and atomic characteristics of the object and the free energy available to the object. This pattern is analogous to a fingerprint; i.e., an object is identifiable by its energy level. Remote sensing is used to detect the fingerprints, by collecting detailed data about the object. Remote sensing is followed by the interpretation of the data and identifying the object. Figure 2 shows the electromagnetic spectrum and the band portion of the spectrum in which each of the usable sensors operates.

PANCHROMATIC PHOTOGRAPHS

Panchromatic aerial photographs are the oldest and most-used method of aerial remote sensing. They have been used successfully for everything from engineering plans to forest inventories. Equipment for procuring, processing, and interpreting panchromatic photographs is readily and relatively economically available. Panchromatic film is sensitive in the visible spectrum (0.4-0.7 micrometers).

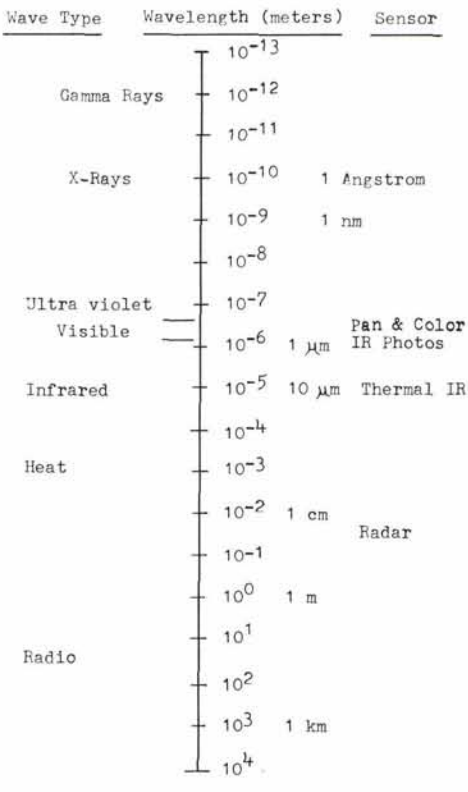

FIG. 2. The electromagnetic spectrum.

Several techniques developed for other usages could readily be adapted to the detection of feedlot runoff. One possible method is simply to delineate the drainage pattern below the feedlot and look for diversions or interceptors which rechannel the feedlot runoff out of the drainage pattern and into a lagoon or similar storage or treatment area. Even small diversions with a height of 1 to 2 feet and a bottom width of 10 feet would be visible on large-scale photos. An interceptor drain with gravel filtration is a popular interceptor method. Panchromatic film has been used successfully in the location of tile drainage.[4] The spring of the year is evidently the optimum time for the detection of tile drainage because the differential soil drying around the tile produces a lighter tone on bare soil. Increased plant growth adjacent to the drain is also evident because of the greater availability of nutrients and higher soil temperature.

The higher soil moisture in the area of overland flow would appear as a dark spot leading from the feedlot down the drainage pattern. In Figure 3, note the dark region emanating from the barn and following the drainage pattern. This field was used as a winter feedlot prior to this March flight. The dark region is an area of higher moisture content caused by the incorporation of organic material into the surface soil. The organic material has a higher moisture holding capacity and thus exhibits a higher moisture content in the wet seasons. In humid regions, the lusher vegetation would have a similar effect. Depending on the film-filter combination used, this would appear as a dark or light spot, but the contrast between this area and the adjacent non-polluted area should be apparent. In arid regions with sodic or saline soils, ground cover type differentiation should be a more noticeable factor than cover density or lushness. The polluted area should have more salt-tolerant vegetation than the non-polluted areas.

The angle of incidence is important to the reflective capacity of the ground cover. To illustrate this concept, Hoffer[5] used a model of closely planted Lambertian cactus crop, as shown in Figure 4.

In Figure 4 it is assumed that all the incident sunlight is either absorbed or reflected, and that there is no transmission. Four scenes are shown in the figure for four different viewing points. In (*b*) the field is viewed from the plane of incidence on the illuminated side, showing high response which

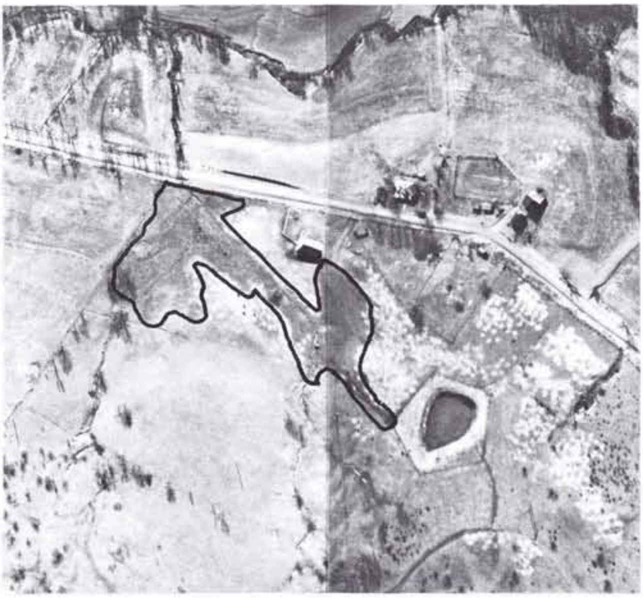

FIG. 3. Panchromatic photograph of a small feedlot in Noble County, Ohio, taken in March 1968. Compare the drainage channel running through the feedlot with similar channels elsewhere in the photo. Note the wide dark area around the channel caused by the incorporation of organic material in the soil. (Courtesy Civil Engineering Dept., The Ohio State University).

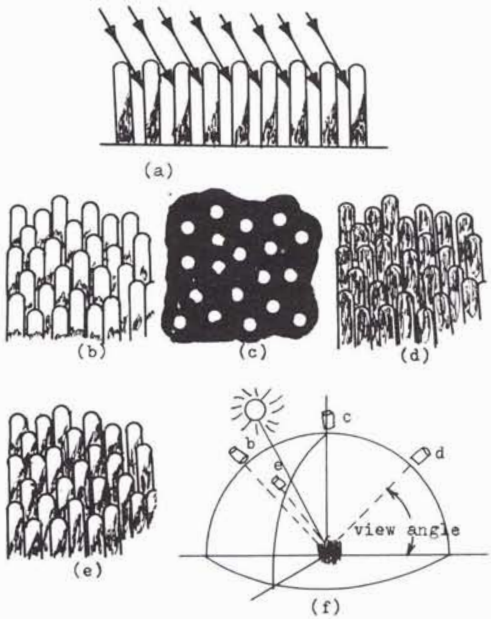

FIG. 4. The relation between the sun angle and viewing direction influences the relative brightness of a scene.

would become even higher as the view angle is lowered, seeing only the brightest top-lit portions. In (*c*) a nadir view shows lowest response due to the direct viewing of weakly illuminated soil. In Figure 4d the field is viewed from the plane of incidence opposite from the illumination side, showing crop portions moderately illuminated by scattered sunlight and skylight. Again, as the view angle is lowered the scene will brighten. Finally, in Figure 4e, the field is viewed transverse to the plane of incidence, giving a response intermediate between Figure 4b and 4d.

By altering the geometry of the model, the variation of response to altered view angle may be predicted. Dense vegetation, which would be expected in the polluted zone, would show a more abrupt rise in response to lower view angle than the less-dense adjacent vegetation. A stereo pair (one photograph with a higher view angle than the other) should provide the necessary data to detect this response.

COLOR PHOTOGRAPHS

Color aerial photographs and panchromatic ARS are sensitive in the same portion of the electromagnetic spectrum. The major advantage of color is ease of interpretation because features are in their natural colors. The dense, lush vegetation expected in the polluted area in a humid climate would appear as a dark green area relative to the surrounding vegetation on a color photograph. In more arid regions, the salt tolerant crops could more readily be identified because they appear in their natural colors. Schneider[6] describes the use of color aerial photography to determine the salinity level of the pot hole areas of North Dakota. Not only could the salinity level of the pot hole lake be determined by vegetation differences, but zones of fresh water influx could be located by the fresh water vegetation adjacent to it.

INFRARED PHOTOGRAPHS

Near-infrared radiation (0.7 to 1.0 μm) has the capability of penetrating to the interior of leaf structure of plants. This capability is due to the make-up of the chloroplasts in the leaves. As the chloroplasts reflect green light and absorb most of the rest of the visible spectrum, it allows the infrared to penetrate to the mesophyll. Near-infrared radiation is highly reflected by the spongy mesophyll. The mesophyll swells and shrinks with the availability of water to the leaf. If a mesophyll cell is turgid, it is highly reflective of near-infrared and the leaf appears to be bright pink in color-infrared imagery. If the cell is in tension, it is less reflective of infrared radiation. In a humid climate, the leaves of plants in the polluted zone would be more turgid and appear as a brighter pink than the adjacent non-polluted vegetation because the abundance of excess water and excess nutrients allows for more swelling of the mesophyll. In saline and sodic soils, the opposite reaction would be evident. The excess salt in the polluted zone would make water uptake more difficult for plants located there, whence the mesophyll would suffer a degree of water tension and would seem less reflective than the adjacent vegetation.

Figure 5 illustrates the reflection and absorption of different wavelengths of light by a green leaf. Green light is largely reflected by the chloroplasts. Blue and red light are largely absorbed by the chloroplasts and used in photosynthesis. Near-infrared light is unaffected by the chloroplasts but highly reflected by spongy mesophyll. Thermal infrared energy is emitted in amounts governed by reradiation, convection and transpiration.

Water absorbs infrared radiation and appears as a dark, nonreflective body on infrared photographs. This characteristic is helpful in locating small bodies of water, such as the small streams that might emanate from

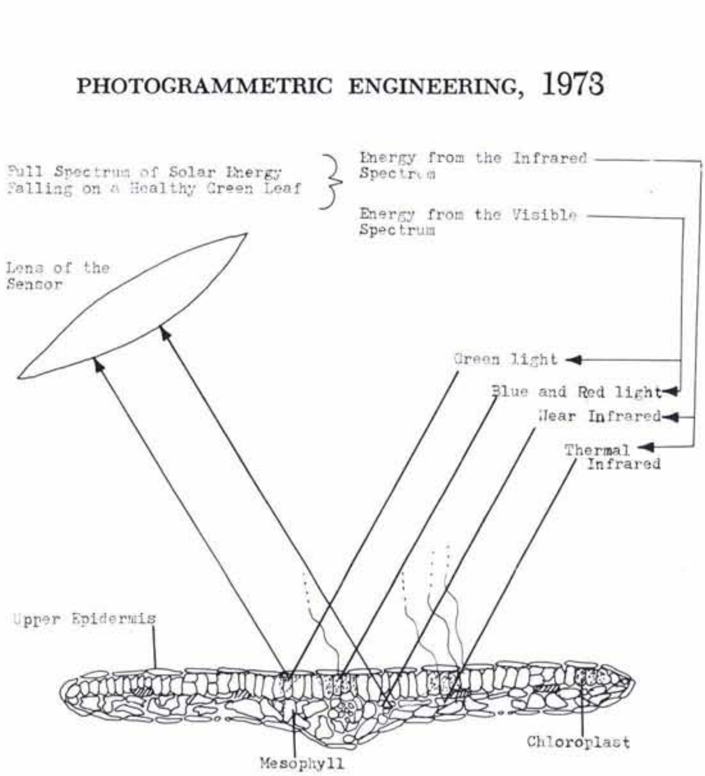

FIG. 5. Cross-section of a leaf of a typical broadleaf plant with annotations indicating the response to incident energy in various spectral zones, and in the visible and infrared regions of the spectrum.[9]

feedlots immediately after a precipitation event. J. T. Parry[10] notes that:

"The contrast ratio between water bodies and living vegetation is at a maximum in the infrared wavelengths because of the high absorption by the water and the high reflectance by the foliage."

INFRARED SENSING

The infrared portion of the spectrum is divided into three regions, the near, middle, and far infrared. Figure 6 shows the relative position of these regions to the visible spectrum as well as their places on the electromagnetic spectrum. The percent of transmission indicated on Figure 6 represents the portion of energy leaving an object that is actually detected by the sensor. The atmosphere, which acts as the energy pathway, is a variable absorber, reflector, emitter and

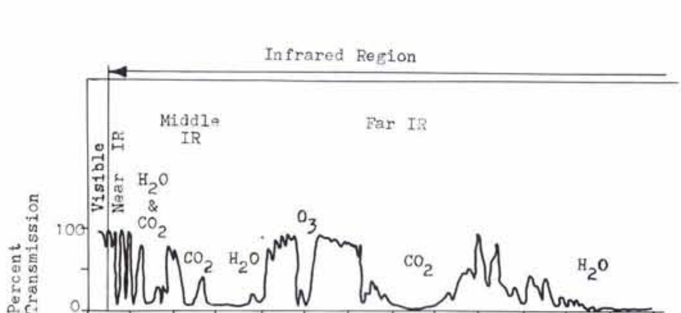

FIG. 6. The position of the infrared region relative to the visible region and the percentage of transmission through the atmosphere. Where the transmission is low, the component of the atmosphere that is primarily responsible for the absorption of the energy is noted.[7,8]

scattering medium at different wavelengths, and consequently imposes severe limitations on our ability to observe terrestrial objects. It is shown in Figure 6 that the middle infrared portion is almost blanked out by water and carbon dioxide absorption. The near and far infrared regions are both provided with areas of high transmission, the so called *windows in the sky*. To make use of infrared sensory, it is obvious that these windows must be the regions of the spectrum used. Fortunately, the maximum emittance of radiation for bodies with temperatures approximately equal to the Earth's ($T=300°$) is in the far infrared window (8-12 μm).

THERMAL IMAGERY

As previously noted, a window exists in the infrared region around the wavelengths of the energy emitted by the Earth. Van Lopik[11] estimated that the spectral distribution of radiation at 300°K is such that approximately 80 percent of the total radiant energy is emitted within a 3 to 25- μm portion of the spectrum. The total energy emitted by a body is a function of both thermodynamic temperature and emissivity, and is expressed by the Stefan-Boltzman law, $W = \varepsilon\delta T^4$, in which W is the total radiant emittance, ε is a dimensionless emissivity factor, δ is the Stefan-Boltzman constant, and T is absolute temperature.

Most earth surface materials exhibit emissivities ranging from 0.7 to 0.98 compared with a blackbody emissivity of 1. Water closely approximates blackbody emissivity, whereas soil has a somewhat lower emissivity. In addition, water has a higher specific heat. Soil with a high moisture content shows a lower diurnal temperature fluctuation than soil with lower moisture content. Nocturnal temperatures would be significantly higher whereas daylight temperatures would be lower. Weigand[12] showed a temperature spread due to moisture content of more than 20° C for a 1400 flight time. The expected difference in soil moisture content between the pollution zone and the non-polluted area, as previously outlined, should be readily detectable. For daylight flights, the higher moisture content of the polluted zone would appear darker than the adjacent area. The reverse would be true for nocturnal flights; the polluted zone would be warmer and appear as a brighter area.

Thermal imagery is capable of comparing the percent of ground cover obtained. Myers[13] obtained a ground cover percentage by comparing the bare ground to crop cover. The difference in ground cover between the polluted and non-polluted zone should be readily apparent.

RADAR

Unlike the previously discussed sensors, radar depends on the reradiation of energy supplied by the radar system. Nwa[14] divides the factors governing the strength of reradiation into two groups: those determined by the sources and receiver (wavelength, polarization, and direction) and those determined by the surface (roughness, physical resonance, dielectric and conducting properties, surface slope, and subsurface effects).

Leighty,[15] used radar to estimate the moisture content of deep homogeneous soils. Radar has the advantage of not only sensing the soil surface, but also sensing to some depth.

SUMMARY

The sensors described have certain uses in detecting feedlot pollution; they are summarized in Table 4.

PROPOSED SCENARIO

A multispectral, multi-sensor approach to the detection of feedlot runoff has many advantages. Because each object has its own wavelength of peak emittance and each sensor is sensitive to only a limited portion of the spectrum, it follows that the more types of sensors that are used, the more objects that can be identified. Most of the objects which are involved in this problem have maximum reflectance in the visible and near-infrared portions of the spectrum and maximum emittance in the thermal-infrared regions. A combination of sensors sensitive to these regions would make up a logical multisensor approach.

A combination of color photography and thermal imagery should provide useful data. A standard 70-mm aerial camera could be used to obtain the color photographs and a thermal scanner to obtain the thermal imagery. As was noted in the explanation of panchromatic photography, a large-scale photo is needed to detect small details such as diversions (1:3,000 appears to be adequate). This would necessarily require relatively low-altitude flights, but the exact altitude would be governed by the focal length of the camera used. Thermal imagery of the same scale would greatly ease interpretation. It is proposed that the camera and scanner be sequenced in such a way that color is taken near noon and scanner imagery after

TABLE 4. SENSORS THAT ARE DESCRIBED IN THIS ARTICLE AND THEIR USAGES IN DETECTING POLLUTION IN OVERLAND FLOW ZONE

Sensor	*Wavelength (micrometers)*	*Characteristics Detected*
Panchromatic Photos	0.40–0.76	Absences of interceptor structure. Higher soil moisture in polluted zone would appear as dark zone. Vegetal differentiation: (1) in humid regions vegetations would be denser; (2) in sodic or saline soils salt tolerant vegetation would be apparent. Use change of angle of incidence to note cover height and density.
Color Photos	0.40–0.76	Same as for Pan. Photos. Easier differentiation of vegetation because of natural colors.
Infrared Photos	0.76–1.0	Moisture turgidity or tension of leaves in polluted zone. Water absorption of IR would appear as a dark area on imagery.
Thermal Infrared	8–14	Differences in soil temperatures caused by differential soil moisture are sensed. Compare ground cover by differential soil moisture.
Radar	10^4–10^5	Compare soil moisture contents and vegetation differences due to dielectric and conducting properties.

midnight. The physical layout is observeable on the photograph and the imagery would provide a means of discriminating moisture and vegetation.

Photo-interpretation has been developed as a qualitative science and only recently has good quantitative information been available by the application of new techniques and devices. The method outlined here was developed with a qualitative interpretation in mind, i.e., comparing the polluted zone with the adjacent nonpolluted area. This method would also lend itself to quantitative study, however. Careful correlation with field data would have to be maintained and the data compared with the photographs and imagery by use of densitometers to obtain a quantitative evaluation of the pollution. Relationships between the sensor imagery and the parameters of the pollutants would have to be developed. The parameters most likely to have an effect on the imagery are: *BOD*, *COD*, total solid content *TS*, organic solid content *VS*, nitrates and nitrites *N*, phosphorus *P*, and the pollutant flow rate per unit area *Q/A*.

CONCLUSIONS

Remote sensing does seem to have definite applications in the detection of the overland flow of pollutants and specifically to detect runoff from feedlots. All of the sensing modes outlined in this paper give possible means of detecting pollutants. The most promising method of detection seems to be the comparison of relative soil moisture content and vegetative differences. Most modes of sensing will detect one or the other difference with varying sensitivity. Although much research must be done in the area to verify specific procedures, at the present a multispectral approach appears to be the most promising, especially combining color photography with either thermal infrared where little ground cover is present, or near-infrared imagery where ground cover is prevalent.

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