INTERIM REPORT

TO

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Determination of Points of Entry for Potential Contaminants into Limestone Aquifers Using Thermal Infrared Imagery

Center for Environmental Studies

The University Of Alabama In Huntsville

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(Contract No. NAS8 - 30216)

(Control No. PR-R-30216)

F. L. Doyle

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Principal Investigator

31 October 1974

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Interim Report

This report was prepared by the University of Alabama in Huntsville under Contract Number NAS8-30216, Study to Define Points of Entry for Potential Contaminants into Limestone Aquifers, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration.

Interim Report

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1.0 Introduction

1.1 Purpose and Approach of Investigation

The research reported here is being conducted in order to find applications of remote-sensing techniques to ground water hydrology. Because such an attempt involves the subsurface, an indirect approach must be used. Hydrologic applications of remotely-sensed data are straight forward and direct for surface waters. Flooded areas, sediment plumes, and thermal differences in water bodies are amenable to direct sensing. Ground water, on the other hand, is usually several feet to several 10's of feet below the surface and not directly recordable. Soil moisture, however, can be related to ground water, and, furthermore, under certain circumstances it can affect surface temperature differentials. The effect of soil moisture on surface temperature and the relationship between soil moisture and ground water is exploited in this research.

1.2 Personnel and Materials

Thermal differences at the earth's surface were recorded before dawn on 26 and 27 June 1974 over the southwestern part of Madison County and adjacent Limestone and Morgan Counties by a Bendix LN 2 thermal scanner mounted on a C-45 airborn platform. Contracting Office's Representative is Mr. Herman Hamby. Mr. Rex Morton was chief of operations; Mr. William Scarbrough operated the instruments. Interpretation of the imagery was made by Dr. F. L. Doyle. Research assistants were O. E. McCartney and Steven C. Vavra.

2.0 Summary of Previous Research (Phase One)

This research continues that started in June 1973 (phase one) and reported in November 1973. During that phase of the research natural linear features were identified on ERTS imagery of north Alabama, and on high altitude daytime thermal imagery. This imagery was also enhanced by density slicing on a Data Color Model 703-32 in order to minimize subjectivity in interpretation.

The second phase of research is based on the lineations recognized in phase one. The results of the second phase are described in this report.

3.0 Relations of Present Investigation to other studies.

3.1 Lineations (lineaments) have been identified by Drahovzal and others (1974) in NASA-sponsored research involving the application of ERTS imagery to geologic and hydrologic problems. Their interpretation of the southwest Madison County area is substantially in accord with the lineations reported in the first interim report of F. L. Doyle (dated 21 November 1973).

A major linear trend has been named the Anniston lineament by Drahovzal and his colleagues. They also report that in general the bearings of surface fractures (joints) do not parallel the bearings of the lineations (p. 93). This finding re-enforces the belief expressed in the first interim report that the lineations are probably associated with deep-seated, "basement" faults below the sedimentary veneer. Drahovzal and others also report (p. 452) that gravity anomalies they have determined in western Madison County can be interpreted as being caused by faulting at the stratigraphic level of the Knox Dolomite (roughly 1500 feet below the surface). Such a finding is also in accord with the suspected origin of the lineations (Doyle, 1973, p. 5).

3.2 The tracing of the Beech Grove lineament (Hollyday, Moore and Burchett, 1973) to the northern boundary of Madison County (Hollyday, personal communication) raises the question of its relationship to the trend of lineations (including the Anniston lineament of Drahovzal and others, 1974) in southwestern Madison County. A study of the bearings shows that they are at an angle to each other--Beech Grove: N 20-25° E; Anniston: N 40-46° W. The Beech Grove trend, furthermore, enters Madison County near the Flint River and topographic analysis suggests that it occurs elsewhere in Madison County. It, however, is not well-developed, and is not easily identified (if at all present) in the vicinity of the Anniston group of lineations.

3.3 Reported results on studies in which remote sensing techniques are applied to subsurface hydrologic problems are rare. Coker, Marshall and Thompson (1969) working in limestone terrane in Florida, used thermography and color infrared photography and found that cooler subsurface temperature zones delineated areas of active sinkhole formation. These results suggest the possibility that a similar effect might be expected as a result of other subsurface processes involving ground water, and would act as a clue to subsurface conditions.

3.4 The use of thermography as an indication of soil moisture has been addressed by many workers. For example, a recent report (Blanchard, Greely and Goettelman, 1974) contrasts the use of spectral reflectance and soil temperature methods to determine soil moisture and concludes that "the reflectance method appears promising for estimating soil moisture at the surface, and the temperature method appears promising for estimating soil moisture near the surface (0 to 10 cm.) and perhaps slightly deeper." Either technique is applicable to the present research.

4.0 Experiments Conducted During Phase Two Research

4.1 EREP Photographs

An examination of photographs taken as part of the Skylab Earth Resources Experimental Package (EREP) was made. None proved to have included the area of study.

4.2 Hybrid Optical/Digital Data Processor

An experiment to further minimize subjectivity in interpretation of linear features on ERTS or other imagery was conducted. The experiment involved the use of a hybrid optical/digital data processor in which a laser beam and horizontal bar filter were intended to produce a Fourier transform analysis. This is further explained in Appendix B - Lineation Detection System.

Density contrasts in the imagery were intended to be transformed in such a manner that natural lineations were enhanced and printed by a computer-plotter combination. Scan lines on the imagery, however, were recognized by the optical data processor instead of natural lineations, and the computer memory bank was overloaded. An optical method of de-emphasizing the scan lines may permit conversion of the ERTS imagery into a form compatible with the hybrid optical/digital data processor.

4.3 Thermal Infrared Imagery

4.3.1 Instrumentation

The main thrust of the research was an experiment using thermal infrared imagery. Thermal radiation in the 8 to 14 micron range was recorded on 70 mm film by the Bendix LN 2 thermal scanner. Relative temperature differences between adjacent areas were evidenced by light and dark gray hues, cooler areas being darker, and warmer areas lighter. Soil moisture differences cause temperature differences because of water's capacity to retain heat.

4.3.2 Rationale of the Experiment

The rationale in using thermal imagery to locate points of entry of potential contaminants of limestone aquifers is as follows:

Entry of contaminants into the limestone aquifer is more likely to occur where solution has occurred on the limestone bedrock surface and in the underlying limestone. Such solution most often occurs along bedding planes, or natural fractures in the rocks such as faults or joints. However, in north Alabama a regolith (overburden, or "soil" in the engineering sense) usually several 10's of feet thick is derived from the insoluble residue left as limestone or other carbonate rocks weathers. This overlies the bedrock and as a consequence solution openings are hidden.

To overcome the effect of the covering of the bedrock surface an indirect approach must be used. Textural differences in the soil profile which develops on the regolith probably occur and may be pronounced enough to permit such an indirect approach to the subsurface. The textural differences develop in the following manner. In the weathering process, slightly acid water descends along fracture surfaces and removes the calcium carbonate comprising the limestone. This enlarges the fracture, allowing it to act as a drain. Then water tends to move toward the opening. The movement through the sands, silts and clays of the regolith causes gradual removal of some fine particles with a consequent increase in pore space. The greater pore space permits a greater volume of water to be present during a period of recharge after a rain. Conversely, it allows a lesser volume of water to be present after a period of uninterrupted drainage. In either case a moisture differential would exist in the soil profile above a solution opening, as opposed to the profile above an area where no solution opening is present. Inasmuch as water has a heat holding capacity which can affect the soil temperature at the land surface, a moisture content differential may be reflected by a soil temperature differential that can be recorded by thermal infrared imagery. If thermal imagery is recorded under circumstances permitting the differences in temperature due to soil moisture to be shown, it becomes an aid in evaluation of subsurface geology and hydrology. Ground truth data is used to corroborate the information of the thermography.

4.3.3 Availability of Thermal Scanner

The thermal scanner became operable in the late stages of the research period, consequently, thermography was available for only one season or meteorological condition - at the height of the growing season on June 26 and 27. Only the eastern half of the coverage was usable.

4.3.4 Interpretation of Thermal Imagery

Throughout most of the area, thermal differences recorded in in June 1974 are attributable to the difference between the temperature of cropland and woodland. However, soil moisture differences may be responsible for short, linear thermal anomalies observable in areas judged to be covered with essentially homogeneous vegetation (Figure 1). The main value of the thermal features is in identifying the presence of presumed solution openings. This permits the taking of proper precautions to prevent contact of potential contaminants with the land surface near the linear features.

4.3.5 Ground Truth Data

Ground truth in the form of soil temperature and moisture was recorded to help callibrate the imagery. Appendix A describes instrumentation and methods used in collecting the ground truth data.

Figure 2 shows soil moisture determined gravimetrically by drying and weighing. Samples were taken a few hours after the overflight of June 27. Moisture ranged from 4.0% to 14.4%. Such moisture differences do not appear to be adequate to cause sufficient thermal differentials to override the thermal differences between crop and woodland.

Figure 3 shows soil temperature determined by electrical resistivities recorded as the soil samples were collected for moisture determinations.

4.3.6 Conclusions

Under certain conditions (where vegetation is essentially homogeneous) temperature contrasts can be interpreted as indicating presumed fractures. By assuming greater solution of the limestone bedrock along the fractures, some areas can be identified where contaminants could find easier entry to the aquifer, thus permitting proper precautions to be exercised.

The identification of presumed solutionally-enlarged fractures can also be used as an aid in selecting locations for drilling to tap the ground water reservoir.

5.0 Recommendations

5.1 Experiments should be conducted in order to determine the optimum conditions under which to record the thermal imagery for the given purpose under investigation. Inasmuch as maximum thermal contrast due to soil mo ure is desired, the imagery should be recorded under one or all of the following conditions:

- In late autumn or early winter when vegetation is nearly dormant, so that the masking effect caused by the contrast between woodland and cropland is minimized.
- After a dry cold front lowering temperatures, for maximum temperature contrast between moist and dryer areas.
- Two to three days after a widespread rain, for optimum difference in soil moisture.

5.2 Red is sensitive to soil moisture occurring in red soils. This color soil occurs in north Alabama. (Consequently, photographs using natural color Ektachrome, taken when vegetation is dormant and soil exposed to the maximum degree, should also be part of the experiment.) When exposed and processed so as to emphasize varying shades of red, the differences in soil moisture may be apparent.

5.3 In order to test the supposition that differences in soil texture occur above solutionally-enlarged fractures in limestone, field studies should be made. Such studies should include locating, if possible, exposures of the bedrock surface which include solutionally-enlarged joints. During field examination soil samples should be collected vertically above the solution features and laterally from them. It is expected that soil densities will be indicative of any textural differences not recognizable in the field. Similar sampling can be accomplished by soil augering on the ground surface if opportunities occur in which solutionally-enlarged fractures can be projected from exposures to beneath the soil cover.

Soil temperature and soil moisture data should be collected as needed.

6. <u>References Cited</u>

Blanchard, M. B., Greeley R., and Goettelman, R., 1974, Use of visible, near-infrared and thermal infrared remote sensing to study soil moisture, NASA Tech. Memo. TMX-62,343.

Coker, A. E., Marshall, R., and Thomson, N. S., 1969, Application of Computer Processed Multispectral Data to the Discrimination of Land Collapse (Sinkhole) Prone Areas in Florida, in Second Annual Earth Resources Aircraft Program Status Review, Vol. 1, Geology and Geography, Manned Spacecraft Center, Houston, Texas., National Tech. Info. Ser. No. N71-19251 through N71-19268, (p. 2-1 through 2-17).

Doyle, F. L., 1973, Study to Define Points of Entry for Potential Contaminants in Limestone Aquifers, initial report to National Aeronautics and Space Agency under Contract NAS8-3016.

Drahovzal, J. A., and others, 1974, Investigations using data in Alabama from Earth Resources Technology Satellite (ERTS-A), Part VII, Geology Section., Final Report to National Aeronautics and Space Agency under Contract NAS5-21876.

Hollyday, E. F., Moore, G. K., and Burchett, C. R., 1973, Preliminary Assessment of a Tennessee Lineament, <u>in</u> F. Shahrokhi, editor, Remote Sensing of earth resources, V 2., University of Tennessee Space Institute, Tullahoma, Tennessee, p. 119-128.

Appendix A

Ground Truth Data

by O. E. McCartney

Soil samples were collected a few hours after the second overflight on June 27. The sites of collection were based on expectable locations of thermal (and moisture) anomalies as predicted from lineations on ERTS imagery.

Gravimetric methods was used in determining soil moisture. The calculations used weights before and after drying in the following formula:

$$\text{Percent Moisture Content} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

Electrical resistivity cells were implanted near the collection sites a few days before collection. Measurements were made at the time of collection. Conversion of resistivity to temperature was possible through the use of callibration graphs. Several sequential determinations of soil moisture at a given site would allow preparation of correlation graphs of moisture versus resistivity (each correlation must be for a given site, because of differences in soil characteristics).

Table A summarizes the data.

Table A

Soil Moisture and Temperature - Field Stations

Station	Location (Sec-T-R)	Date 1974	Hour	Depth (cm.)	Soil Temperature	% of moisture (by weight)	Resistance (Ω@ 60°F)
B	SE-SW-SW-8-3S-2W	6-27	1100	0-4	n/a	6.1%	n/a
C	SW-SW-SE-13-3S-3W	6-27	1130	0-4	20°C	8.4%	$10^{6.14}$
D	SW-NW-NW-31-3S-2W	6-27	1145	0-4	26.1°C	9.8%	$10^{6.72}$
E	NW-SE-NW-30-4S-2W	6-27	1200	0-4	24.4°C	14.4%	$10^{4.56}$
F	NW-NW-NE-5-5S-2W	6-27	1215	0-4	29.7°C	4.5%	$10^{6.44}$
G	SE-SE-NE-8-5S-2W	6-27	1240	0-4	25.6°C	11.4%	$10^{4.64}$
H	SE-NW-SW-16-4S-2W	6-27	1320	0-4	30.3°C	10.5%	$10^{6.17}$
I	SE-SE-NE-21-4S-2W	6-27	1410	0-4	29.4°C	10.0%	$10^{6.44}$
J	NW-NW-NW-22-4S-2W	6-27	1425	0-4	n/a	9.9%	n/a
K	Field in which soil cell implanted plowed since installation						
L	SW-NW-NE-14-4S-2W	6-27	1445	0-4	22.5°C	9.2%	$10^{6.35}$
M	NE-NE-NW 35-4S-2W	6-27	1517	0-4	26.4°C	9.0%	$10^{5.5}$
N	SW-NW-SW 35-4S-2W	6-27	1530	0-4	25.8°C	6.9%	$10^{6.11}$
O	NW-NE-NE-3-5S-2W	6-27	1545	0-4	29.4°C	4.0%	$10^{6.24}$
P	SE-NE-NE-21-5S-2W	6-27	1600	0-4	30.3°C	10.3%	$10^{4.36}$
Q	SW-SW-NE-9-4S-2W	6-27	1355	0-4	n/a	12.1%	n/a
R	SW-SW-NE-34-4S-2W	6-27	1613	0-4	n/a	11.9%	n/a
S	SE-SE-NE-36-4S-3W	6-27	1300	0-4	n/a	13.3%	n/a

NOTE: n/a = not available (soil cell lost or not used)

Appendix B

Lineation Detection System

by Joseph Kerr

The hybrid optical/digital processor used to attempt to identify, locate, and record lineations from ERTS imagery was configured as shown in Figure 4.

The optical portion of the system performed the analysis necessary to identify lineations in the film. The control computer is a HP-2116B with a disc operating system supported by such peripherals as a Calcomp plotter, X, Y, Z modulated scope, A/D and D/A converters, and a digital voltmeter. This control computer scans the laser light across the surface of the film by controlling a set of X, Y galvanometer stages. The laser beam (1.5 millimeter) is always perpendicular to the film plane because of the scanning laser optics which is composed of the Galvos, laser, parabolic mirror and the associated optics which are mounted on a fixture that rests on the Stable Table.

The 1.5 millimeter beam of coherent light is diffracted by the ERTS image transparency which is located in the input film plane of the optical processor. This diffracted light is gathered by the transform lens and is focused onto a rotational slit where its intensity is proportional to the magnitude of the Fourier transform of the image illuminated by the 1.5 mm laser beam. The rotational slit is driven through 360° in discreet steps by a motor that is controlled by the control computer. Since lineations in the image appear as lines in the Fourier transform plane, the slit serves as a filter to locate the direction of any lineation that appears in the input film transparency. The photodiode provides an analog signal that indicates the magnitude of the light level. This analog signal is sent to the control computer storage disc via a digital voltmeter. The storage disc contains the position location, direction, and magnitude of each lineation detected.

After the entire film transparency has been scanned and analyzed, the contents of the lineation data on the disc are displayed on the X, Y, Z scope so that the data points displayed are scaled to provide a one to one correspondence to the input image. These data can also be plotted on the Calcomp plotter on a mylar-type material to provide an overlay that indicates the location of the lineation with respect to the image on the film transparency.

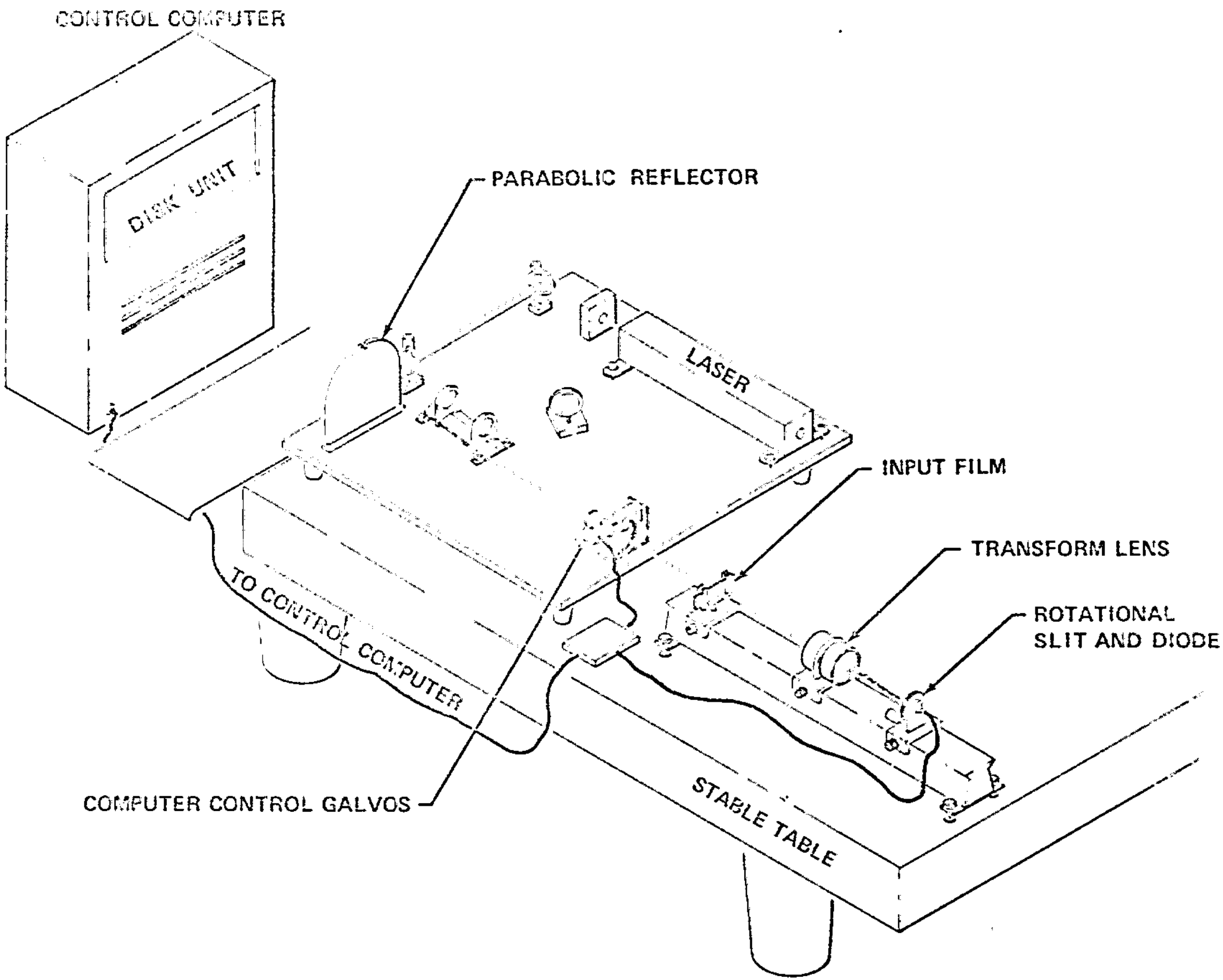
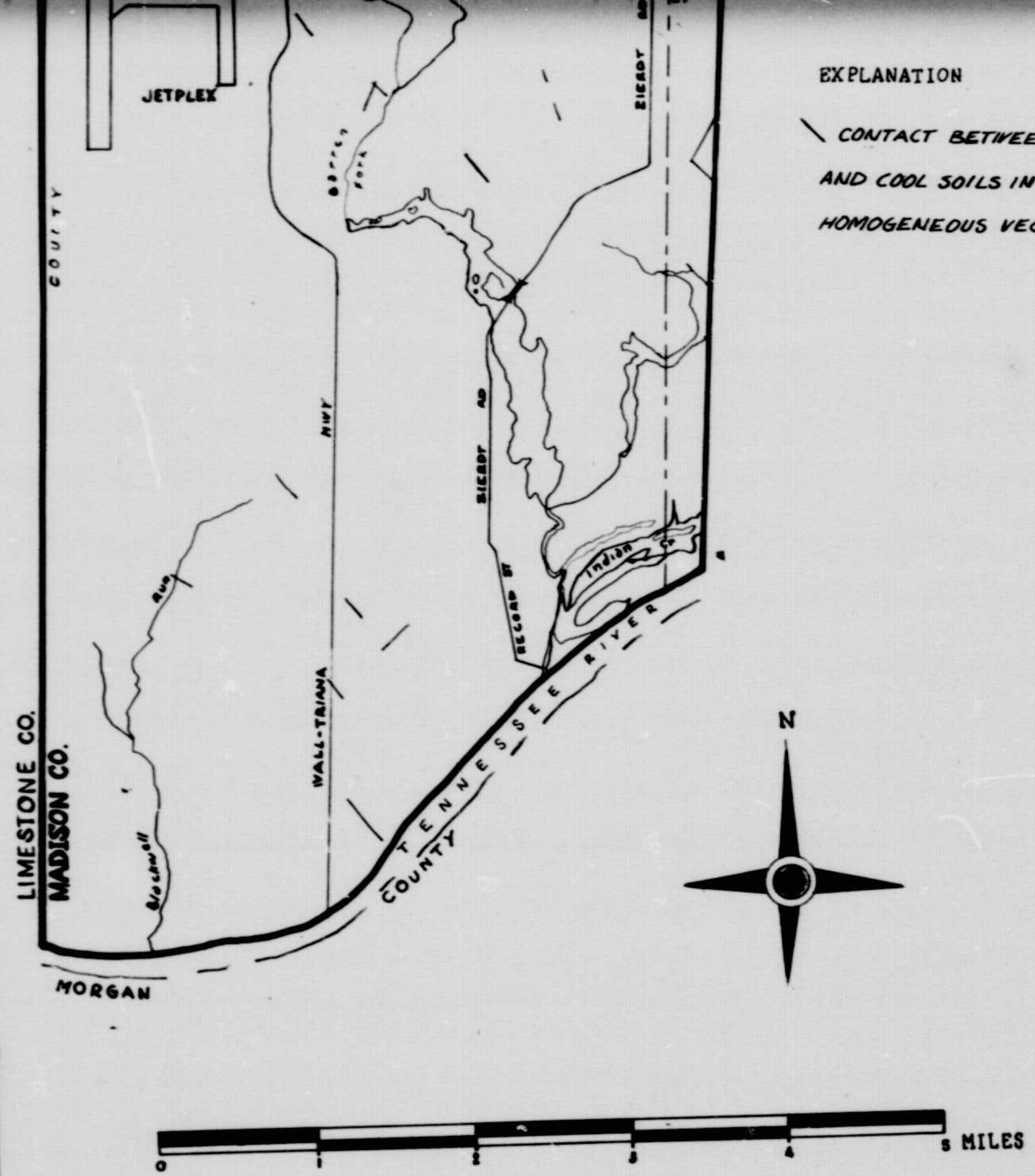


FIGURE 4

OPTICAL LINEATION DETECTION



EXPLANATION

CONTACT BETWEEN WARM AND COOL SOILS IN AREAS OF HOMOGENEOUS VEGETATION

FIGURE 1

THERMAL ANOMALIES IN AREAS OF HOMOGENEOUS VEGETATION (EASTERN HALF OF PROJECT AREA)

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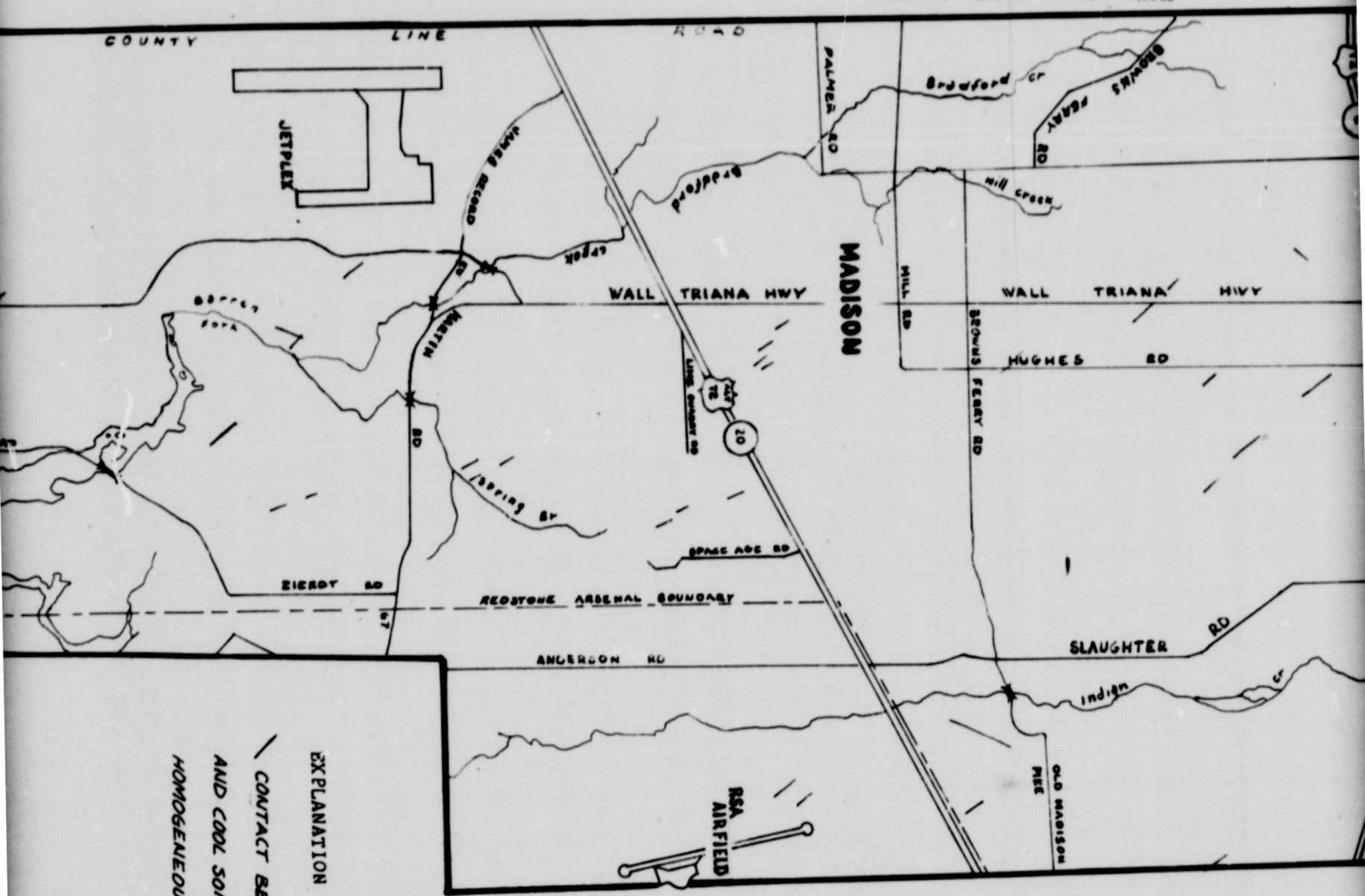

EXPLANATION

CONTACT BETWEEN WARM AND COOL SOILS IN AREAS OF HOMOGENEOUS VEGETATION

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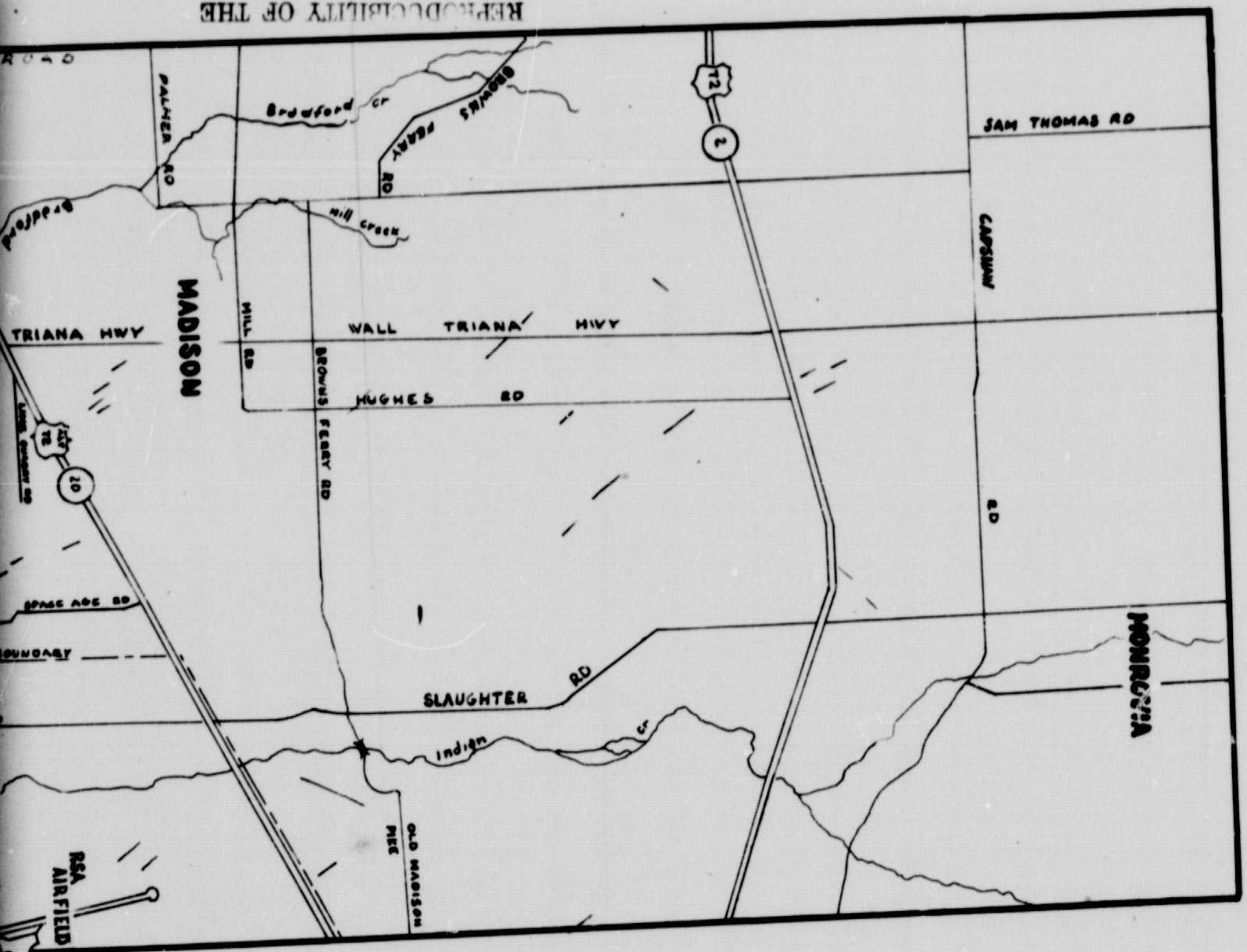

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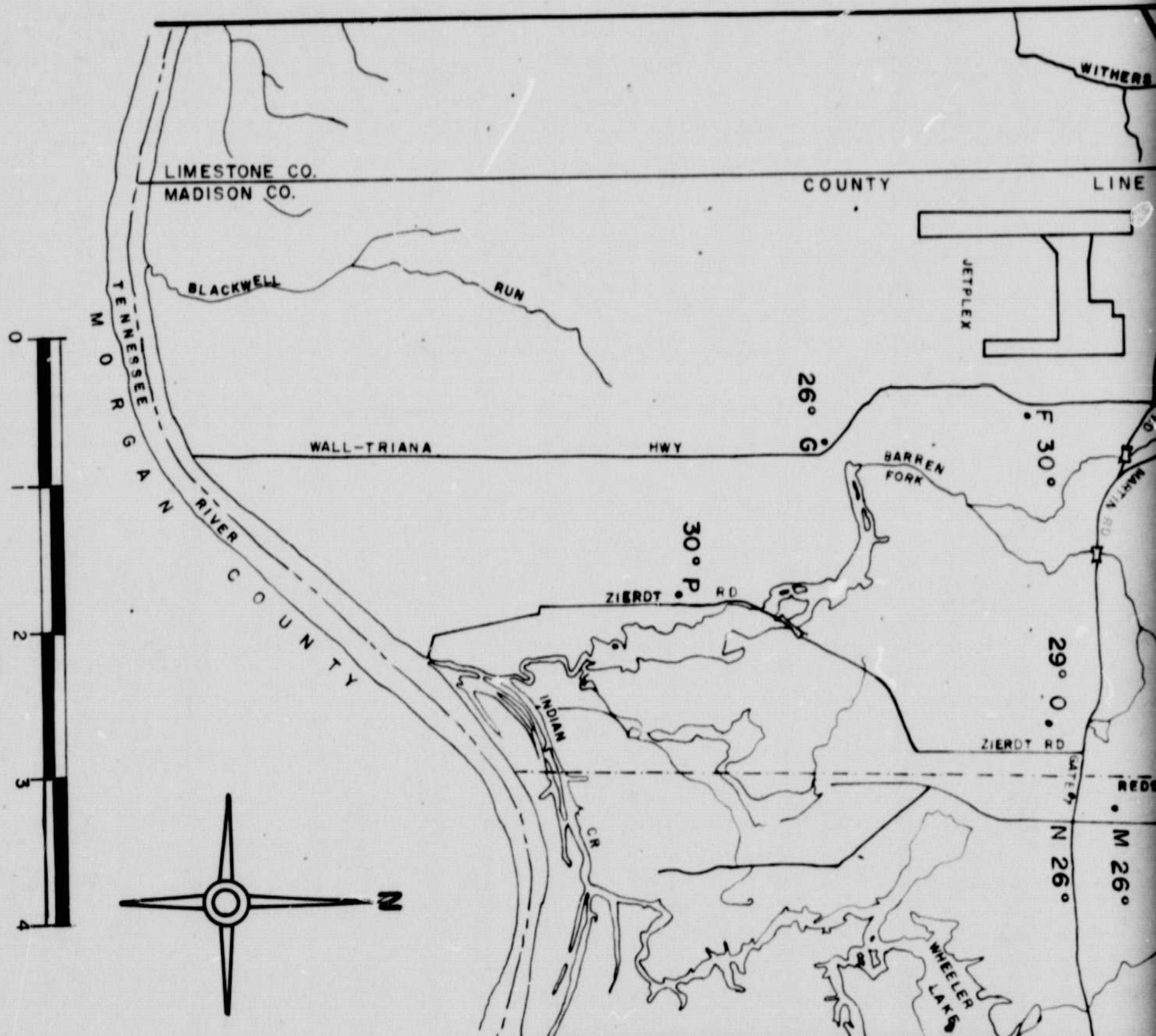

FIGURE 3

SOIL TEMPERATURE (°C) ON 27 JUNE 1974

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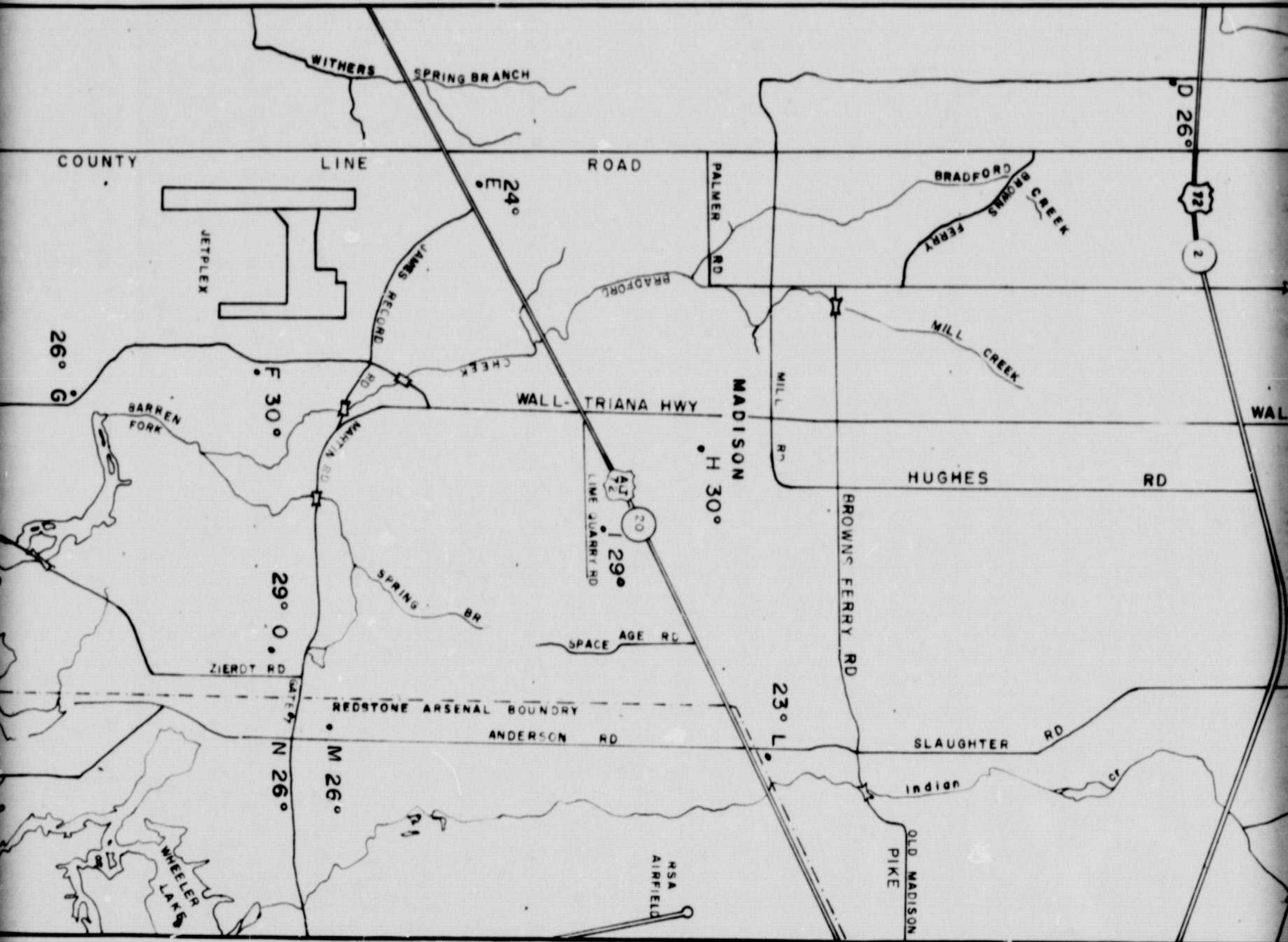

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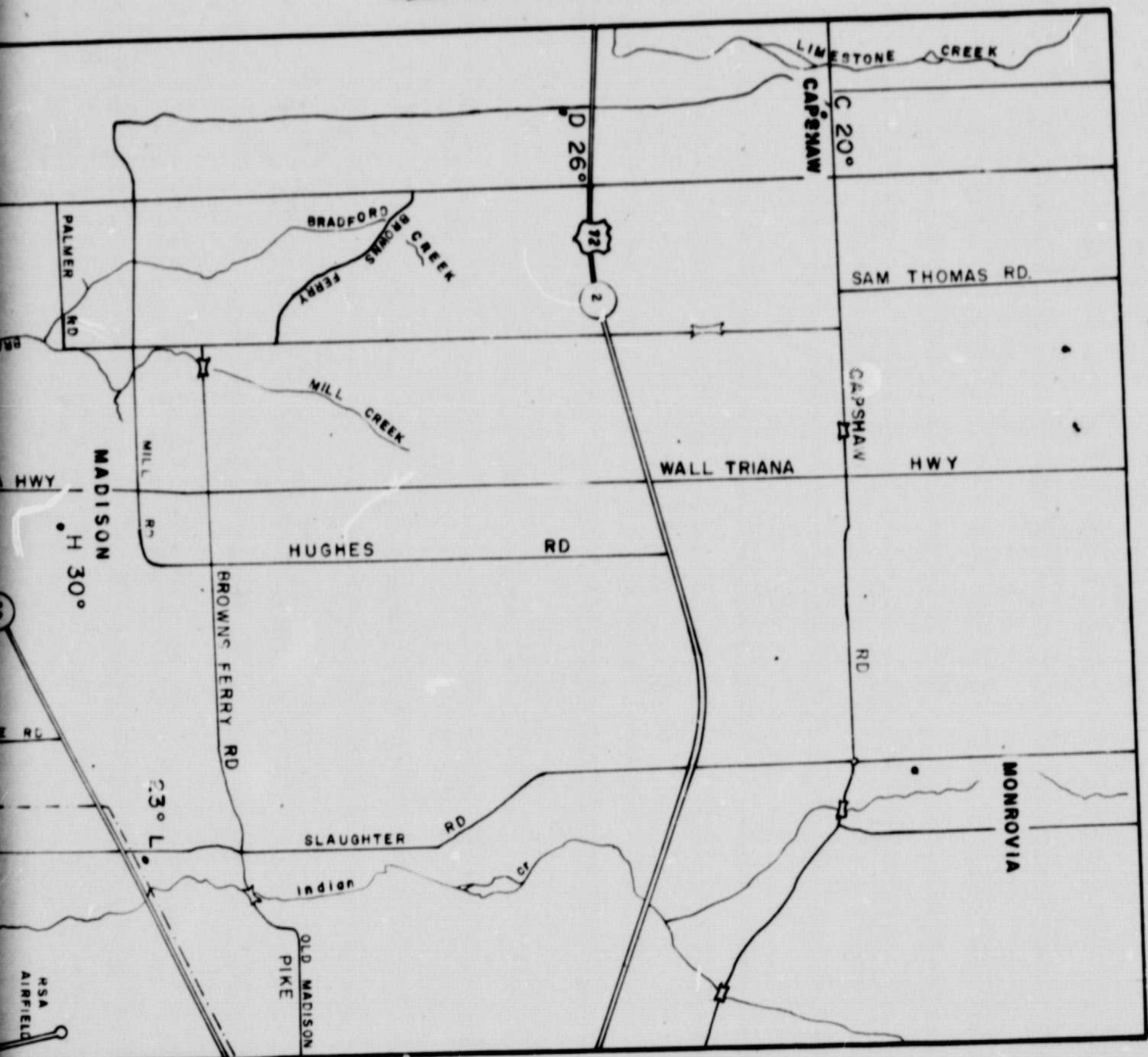

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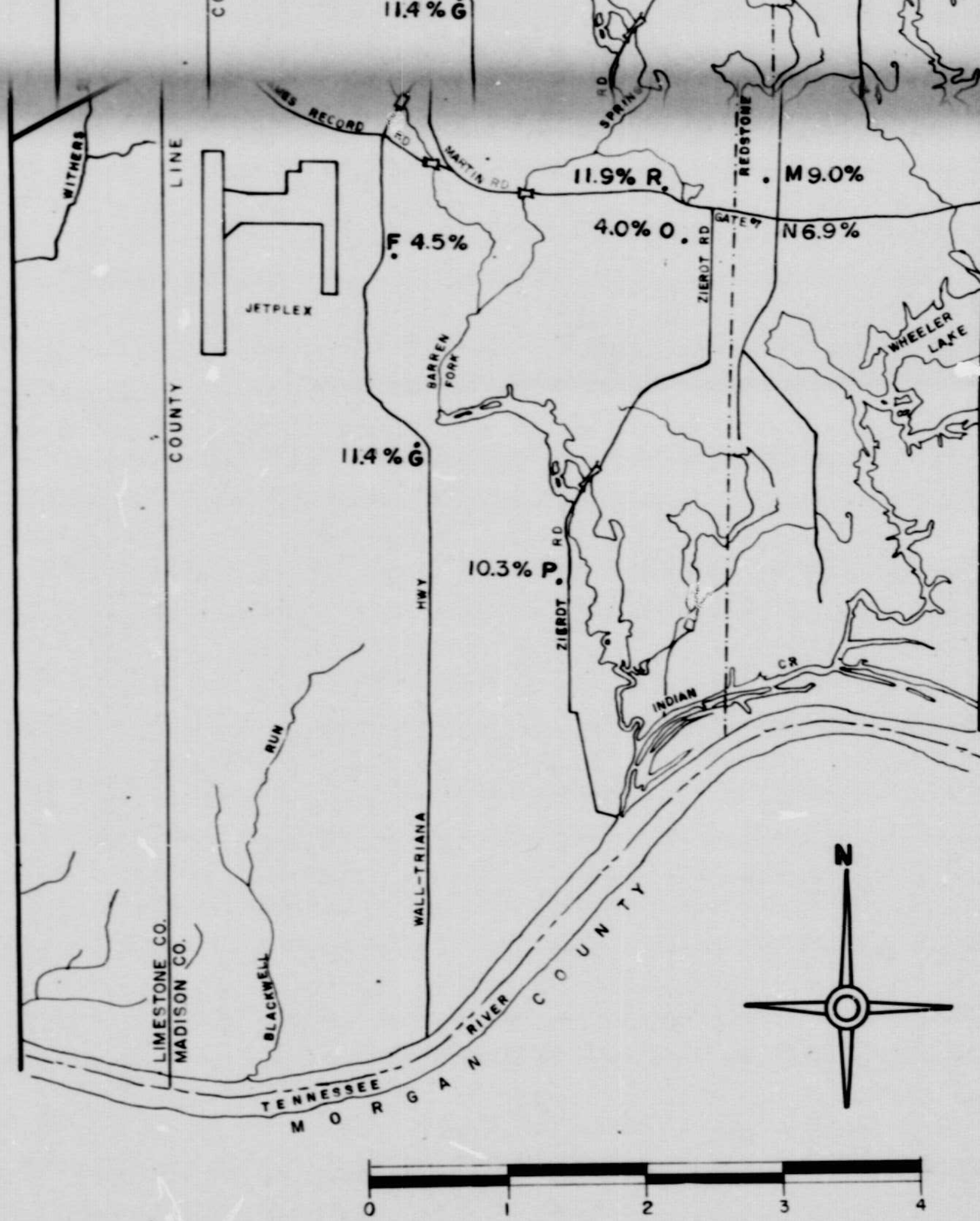

FIGURE 2

PERCENT SOIL MOISTURE ON 27 JUNE 1974

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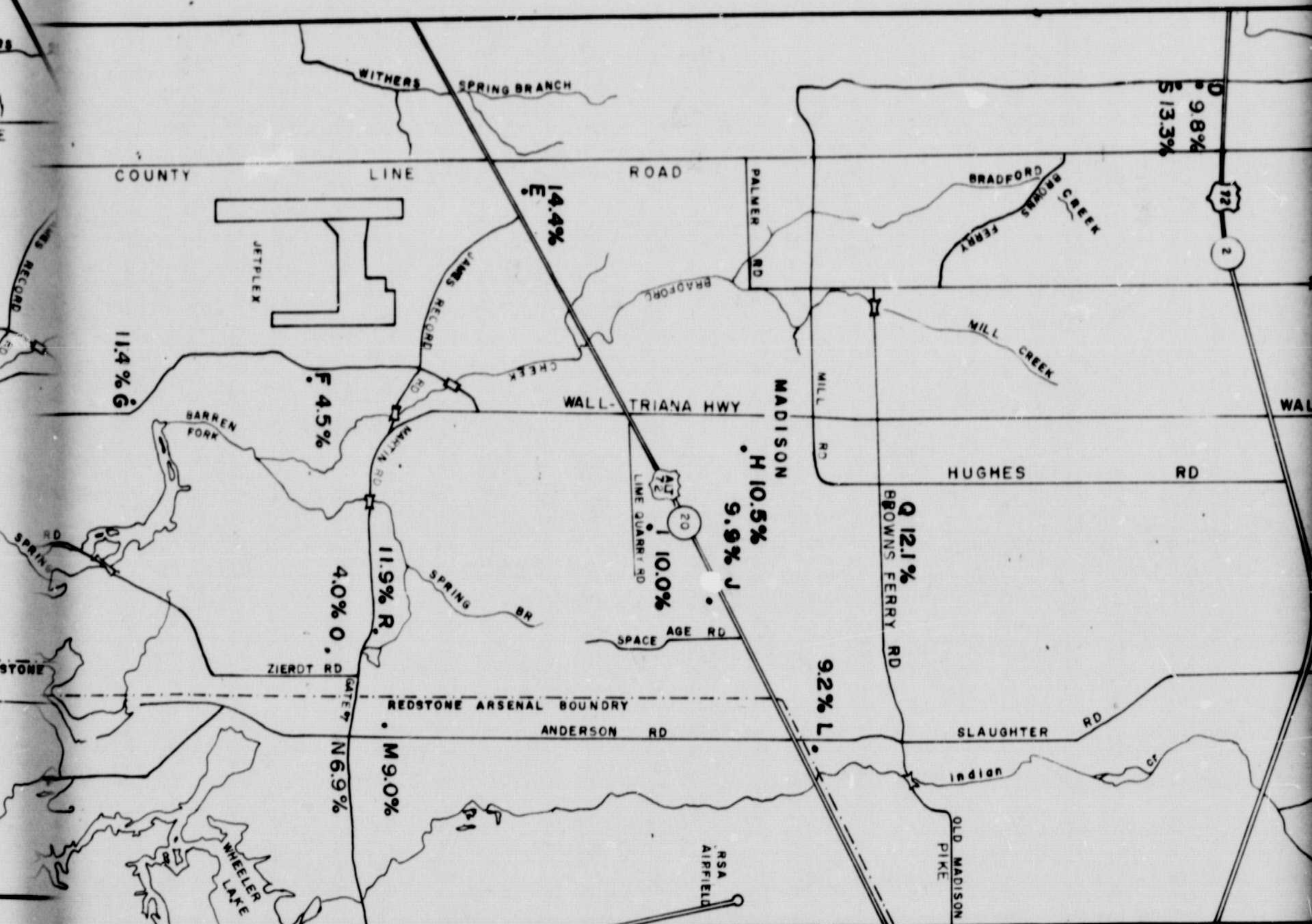

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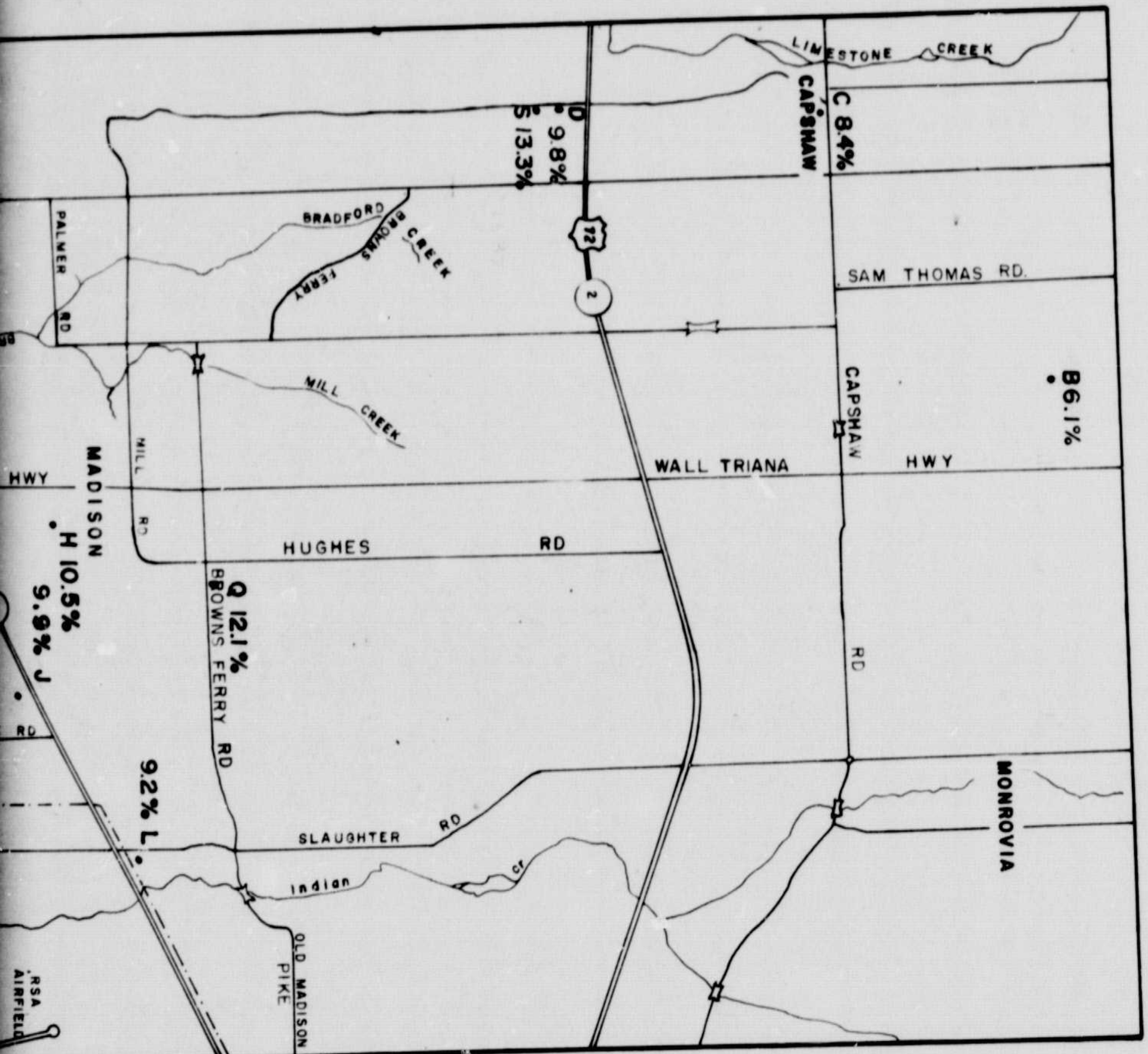

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