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GEOGRAPHIC EVALUATION OF RADAR IMAGERY OF NEW ENGLAND

by

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There are no color illustrations in this report.

TABLE OF CONTENTS

TABLES

In Annex 1:

FIGURES

(gathered at back of volume)

ABSTRACT

This paper evaluates certain pre-existing, K-band, dual-polarized radar imagery of New England. It examines especially the capability of radar to reveal the density and distribution of population through revealing the size, shape and distribution of "built-up" areas. Limiting factors include not only those associated with the radar itself, but also those resulting from the complex clutter of the New England landscape.

To attain relative objectivity 38 experienced interpreters from campuses, industry and government were asked to provide their interpretations of the built-up areas of selected samples, and the resultant data were evaluated quantitatively.

Assuming that the results of this study are statistically valid the following statements can be made:

* Radar permits a typical interpreter to find 74% of the populated places of New England, including all cities of over 7,000 population; 80% of the towns having 800 to 7,000 people; and 40% of the hamlets of 150 to 800 people.
* Using a more rigorous scoring method, it can be said that radar will permit good interpreters to find 4 to 5 populated places correctly for every error. The average interpreter can distinguish between "built-up" and "non-built-up" squares on finely gridded imagery with more than 90% success for predominantly rural areas, and 62% success for the urban sprawl of outer Boston.

The study also briefly discusses signatures in the fields of hydrography, surface configuration, transportation and agricultural land use, and presents a new type of table for summarizing the confidence level that can be placed on the consistency of selected landscape items to leave signatures.

GEOGRAPHIC EVALUATION OF RADAR IMAGERY OF NEW ENGLAND

I. Introduction

This paper presents the results of a geographic study [1] of certain pre-existing, K-band, dual-polarized radar imagery of New England.[2] Specifically the imagery consists of a 15-mile swath across parts of northern New England, down the Connecticut Valley and over the suburbs of Boston (Figure 1).

The paper emphasizes evaluation of the capability of radar to reveal "built-up" areas: that is to show the location, size and shape of cities, towns and hamlets by picking them out of the complex clutter of the New England landscape, as well as separating them from the "noise" inherent in the electronic circuitry of the radar. To accomplish this the paper introduces a simple but rigid scoring system developed for distinguishing signals from noise in the engineering design of radars. It also provides conventional "found-not found" percentage figures.

In addition to the usual method of evaluating imagery capabilities in terms of the author's success in finding the objects he seeks, the populational part of the study utilizes the scored successes of 38 other interpreters from various parts of the United States, providing a statistical foundation for the conclusions reached.

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[1] Research sponsored by the Geographic Applications Program, U.S. Geological Survey, under USGS Grant No. 14-08-0001-G-8. My principal research assistant has been A. Edson MacNeill, Dartmouth '68.

[2] Imaged on 22 July 1966 for the USGS. The assistance of Mr. Alan Kover, Regional Geophysics Branch, in obtaining a copy of this imagery is acknowledged. The following Survey report also is based on this imagery:

Harwood, D.S. Radar Imagery: Parmachenee Lake Area, West-Central Maine. Earth Resources Survey Program Technical Letter NASA-81, June 1967, NASA Manned Spacecraft Center, Houston, Texas.

The capability of radar to reveal elements of the New England landscape other than built-up areas is briefly examined, without benefit of outside interpreters. The items thus evaluated include hydrography, surface configuration, transportation and agricultural land use. Findings are presented in the form of sketch maps comparing patterns as seen on the imagery with the ground truth.

Finally a new four-category means of portraying the relative ability of radar to reveal various items of interest in the landscape, called a "confidence-level" table, has been developed and is utilized herein.

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II. Radar Discrimination of Built-Up Areas

A. Definition of a Built-Up Area

The term "built-up area" connotes a concentration of population, as revealed by a concentration of structures, especially dwellings. Cities, suburbs, exurbs and industrial parks are built-up areas. But so are villages and hamlets, so the term is broader than the term "urban". On the other hand scattered farmsteads are excluded, so the term is narrower than the term "populated".

It is a descriptive rather than an analytical term. Ultimately it needs quantifying, probably in terms of number of structures per square mile plus some figure for minimum area. Inspection of New England topographic sheets, along with "county maps" showing the function of every building along every road in the countryside, suggests that an agglomeration of 50-75 structures can be thought of as having a population of 150 or more people, together with some service as well as residential functions. A density of 50 structures in a single square (or often linear) mile represents the lower limit of a built-up area for the purposes of this study. Transition from built-up to nonbuilt-up ordinarily is abrupt enough to permit reasonably sharp definition. However, in the urban sprawl around Boston every variation in structural density per square mile can be found, and over areas of greatly different size. The subject of discontinuity versus a continuum between urban and rural needs further study.

B. Imagery Evaluation Techniques

One way to evaluate imagery for its ability to reveal location, size, and shape of built-up areas is to "eyeball" it, visually comparing maps of built-up areas derived from imagery with those derived from ground truth. Another way is to quantify each deviation.

Regardless of which of these two methods is used, options still exist. First and most common is for the investigator himself to do an interpretation, in this case drawing boundaries around all recognizable built-up areas on the radar imagery and comparing the result with the ground truth. This method is quick and easy. Since the investigator probably knows considerable about the local area and radar's relation to it this system often gives the highest possible evaluation. It need not be unrealistic, since imaging equipment and techniques will improve in the future. It was used in this study.

An additional and more objective method also was used. Thirty-eight experienced interpreters from all over the United States, representing academic campuses, private industry and government, were given samples of the imagery and asked to draw their versions of the built-up area boundaries. The results of their work were evaluated, both by simple visual methods and by statistical scoring techniques.

C. The Sample Areas

New England embraces a tremendous range in population densities, from Megalopolis through extensive areas of rural landscape down to areas of almost uninhabited wilderness. Steep population gradients separate many of them. Areally, regions of sparse population predominate. Problemwise, the cities over-ride.

Fortunately the 1966 radar flight imaged all three types of area (Figure 1). For purposes of the population density study, three sample areas were selected: (1) part of a major urban-suburban complex, Boston; (2) an area which includes a small city: Burlington, Vermont and its satellites; and (3) a predominantly rural area with scattered towns and villages, the Claremont area in the Connecticut Valley. (Two additional sample areas were used for other than populational purposes)

Of the populational sample areas, Burlington is the most broadly representative. For its radar image see Figure 2.

The ground truth for the Burlington area, in the form of a line separating "built-up" from "nonbuilt-up" areas, is shown as Figure 3b. It is derived from the current topographic sheets[1] as modified by the latest conventional air cover of the area,[2] and finally by the Vermont "county maps".[3]

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[1] 1948. 1:24,000 USGS

[2] 1962. 1:20,000 Amman, Inc.

[3] 1963. 1:63,360 for urban areas, 1:31,680 for villages. Vermont Department of Highways.

Fifteen discrete built-up entities appear in the Burlington area, ranging from two hamlets of an estimated 150 people each through Burlington with an official 1960 population of more than 35,600.

D. What the Radar Reveals: Eye-Balling It

How various interpreters saw the built-up pattern of the Burlington area on the radar imagery is revealed in Figures 3 and 4.

Figure 3a is the author's concept based on several years experience with radar imagery, knowledge of the exact location of the imagery and a casual trip through the area on the major highway considerably prior to this research.

Among the 38 testee interpreters the most accurate rendition (as judged by later scoring of results) came from an interpreter with considerable photo, and some radar, experience but with no knowledge of the location of this area (Figure 4a).

The median testee of the 38 (as proven by later scoring) secured the results shown in Figure 4b.

The critical importance of the interpreter in the radar system is obvious.

E. What the Radar Reveals: Statistical Study[1]

1. The Approach

Although simple visual comparison of radar-derived patterns and ground truth is useful, quantification is necessary if radar's present capabilities are to be objectively evaluated, and even more essential if we ultimately are to improve them.

To provide an objective measure of interpreter success the built-up area overlays made by the 38 interpreters for each of the three sample areas were scored against gridded versions of the ground truth. Two kinds of scores were computed for each interpreter:

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[1] The assistance of Professors Victor E. McGee and John C. Baird, Department of Psychology, Dartmouth College, in the preparation of this section is acknowledged with thanks.

For the details of statistical study see Annex 1.

(1) his success in finding the separate, discrete built-up areas of each sample, and

(2) his success in differentiating between individual urban (built-up) and rural (nonbuilt-up) grid cells in the same areas.

2. Finding Discrete Built-Up Areas

For this analysis the Burlington and Claremont sample areas were used, involving populated places from hamlets of 150 persons to a city of over 35,000. The first test was simply to determine what percentage of the 19 built-up areas in these samples each interpreter found. Some interpreters found 100% of them. The average was 74%, and the poorest found 47% (see Table 1).

However, a moments thought will remind the reader that in looking for discrete built-up areas there are two sources of error and only one source of success. If an interpreter says "built-up" and is correct, he wins. If he says "built-up" and it is not, he loses. But also, if he says it is not built-up when it is, he also loses. There are errors of omission and commission, or Type I and Type II errors.

This duality of errors is recognized in radar statistical theory.[1] Transforming conservative but realistic electronic statistical practice, as well as its terminology, into the sidelooking radar interpretation field, the scoring matrix looks like this:

		(Ground Truth) Built-Up	(Ground Truth) Nonbuilt-Up
(Interpreter)	Yes	HIT	FALSE ALARM
	No	MISS	

The interpreter's score is computed as follows:

Score equals HITS-(MISSES plus FALSE ALARMS)

[1] See Skolnik, Merrill I., Introduction to Radar Systems. New York: McGraw-Hill, 1962.

TABLE 1

Interpreter Success in Finding Built-Up Areas:
Conventional (Percentage) Scoring Method

Percentage Success	Number of Interpreters
91-100	xxxxxxx
81-90	xxxxxxxxx
71-80	xxxxxxxxxx
61-70	xxxxxxxx
51-60	xxx
41-50	x
31-40	
21-30	
11-20	
1-10	

Total Number of Interpreters: 38

Total Number of Built-Up Areas: 19

$$\text{Score} = \frac{\text{Hits}}{\text{Total No. Built-Up Areas}}$$

	Hits (19 possible)	Score (%)
Highest score made	19	100
Median score	14	74
Lowest score	9	47

Table 2 shows the relative success of the 38 interpreters, scored in this way. Remember that these scores are not percentages, and that low scores may be negative, down towards the total number of grid cells in the sample area. To the highest scorers the radar revealed a hit-to-false-alarm-plus-miss ratio of 4 to 1 or higher. To the average scorer, 2 to 1 or 3 to 1.

3. Population of the Built-Up Areas related to the Possibility of Finding Them

To initiate this test the percentage of interpreters finding each specific agglomeration was plotted on semi-log paper in descending order of the population of the built-up area (Figure 5). Note that every town down to 800 people was found by at least 80% of the interpreters, and most of them were found by 95 to 100%. At the 800 population level, the two towns were found by an average of 79% of the interpreters (actually 95% in one case, 63% in the other). Among the very small towns, one hamlet of 200 people (Shelburne, Vermont) was differentiated by all 38 interpreters.

To evaluate this size-of-town data statistically, use of the F-statistic and t-test were considered, but discarded as inappropriate for application to discrete data such as radar interpretation results. Instead, binomial and chi-square tests were used. By these tests chance was ruled out as an explanation for the relationship between town size and interpreter success, except for the case of medium towns compared to large ones. In effect, success in finding medium towns was so close to that for large towns that one cannot rule out chance as the differentiating feature. For further detail see Annex 1.

4. Distinguishing between Rural and Urban Cells

The question here is, "Given K-band imagery of New England, how successfully can an interpreter distinguish between built-up and non-built-up areas on an individual grid cell basis?"

For this problem the Boston Suburban sample area (with 2/10" cells) was used in addition to the Burlington and Claremont ones (with 1/10" cells).

TABLE 2

Interpreter Success in Finding Built-Up Areas:
Radar-Theory (Rigorous) Scoring Method

Net Score	Number of Interpreters
17-19	
14-16	
11-13	xxxxxx
8-10	xxxxxxx
5-7	xxxxxxxxx
2-4	xxxxxxxxx
1 to -1	xxxxxxx
-2 to -4	
-5 to -7	
-8 to -10	
etc.	
etc.	

Total Number of Interpreters: 38
Total Number of Built-Up Areas: 19

Score = Hits - (Misses & False Alarms)

	Hits (19 possible)	Misses	False Alarms	Net Score
Highest score made	17	2	2	13
Median score	14	[illegible]	4	5
Lowest score	11	8	4	-1

TABLE 3

Interpreter Success in Distinguishing Between Rural & Urban Cells

Scoring Matrix:

(Ground Truth)

(Interpreter)		Urban	Rural
	Urban	HIT	MISS
	Rural	MISS	HIT

Total Number of Testees: 38

Total Number of Cells: 4,665

$$\text{Score (\%)} = \frac{\text{No. Urban Cell Hits - No. Rural Cell Hits}}{\text{Total No. Cells}}$$

	Burlington Area	Claremont Area	Boston Suburban Area	OVERALL
Highest score	95.3%	98.9%	77.3%	95.2%
Median score	89.9	96.3	62.5	91.4
Lowest score	75.7	92.4	48.2	84.1

The results (Table 3) show that, over the several hundred square miles represented by all three sample areas together, the median interpreter was able to determine the rural-urban nature of the several thousand cells with 91.4% success. The best interpreter scored 95.2% and the worst 84.1% correct.

5. <u>Interpreter Backgrounds and Scores in this Study</u>

This study is not directed towards evaluation of human factors in radar interpretation. Rather the interpreter is considered to be a part of the radar imagery system, an accessory to radar itself. However, since 38 trained and experienced interpreters of very diverse backgrounds were involved in this study, and the opportunity to compare their scores with those of an inexperienced "control" group came up, the opportunity was taken. This comparison suggests that experience (and where available, general knowledge of the area) pays off. However, the payoff is modest in the case of the best in each experience category, significant in the average situation, and of great importance among the lowest scorers. (See Annex 1)

* * * * *

III. Discrimination of Patterns of Other than Built-Up Areas

A. Background

The imagery utilized in this study was imagery of opportunity, having been recorded earlier for other purposes. But it afforded an opportunity to see New England through radar for the first time. Accordingly, evaluation was not limited to population distribution, but also briefly covered hydrography, landforms, agricultural land use and transportation. The latter evaluations were deliberate, but not exhaustive.

B. Hydrography (Figure 6)

Radar is well-known as a discriminator of water vs land. In this imaging,the shorelines of all major water bodies are clearly delineated. But how about the many small New England ponds, natural and artificial?

Figure 6 answers this question, using the Claremont sample area. The radar image under magnification revealed 26 ponds, which is 77% of those found on the topographic sheet (1:62,500) plus the standard Soil Conservation Service air photos (1:20,000), after field checking for currency. The threshold for the appearance of ponds on the topographic sheets and airphotos was a diameter of approximately 75 yards compared to a radar threshold of about 200 yards (a single pond of 300 yards was missed, but several down to 100 yards were found).
This radar cover is believed adequate for revision of pond hydrography on 1:250,000 map sheets and of considerable value for revision at the 1:62,500 scale.

C. Surface Configuration (Figure 7)

The returns were fully adequate for the recognition and bounding of landform regions (Figure 7). In addition, structural and topographic lineaments were revealed, and the highest regional eminences such as Mt. Monadnock, Mr. Ascutney and Mt. Mansfield were recognizable as such. Individual hills a few hundred feet high and a fraction of a mile across, which typify much of the texture of New England, generally can be differentiated. Occasional transverse strips of imagery, up to two or three miles wide and extending across the film, suffered unacceptable landform image deterioration due to antenna instability. The availability of a cross-polarized (HV) strip in addition to the normal (HH) one improved surface configuration delineation by an estimated 10%.

D. Transportation and Communication Routes

a. General

The capability of the K-band radar to discriminate New England transportation and communication patterns was examined in three sample areas, one of which has not been previously mentioned. The Jackman Area, Maine (see Figure 1) is representative of the timber-cutting, forested belt of northern New England. The population nucleus of Jackman is located at the intersection of a locally important highway and rail line. (The Claremont and Boston Suburban sample areas have been referred to earlier).

b. Radar and New England Roads (Figures 8, 10 and 11)

Roads in New England are revealed on radar in two principal ways:

(1) Generally as dark lines representing "no return" from energy beamed obliquely to the road pavement itself or as radar shadow along road cuts and city streets. Dark-line signatures include most Interstate dual highways, most of the major roads in the Boston Suburban area, and many stretches of smaller roads across open areas.

(2) Occasionally radar reveals roads as white lines representing a surrogate in the form of high reflectance from a wall of woodland rising at the down-beam edge of the road clearing. Recognizable returns of this type are possible even along minor country roads so narrow that there is a light interlacing of tree crowns above the road way (Figure 13). The poorest road signatures run transverse to the flight line.

Actual road surfacing has little significance. If aspect is favorable the typical gravelled, fully 2-lane, privately owned logging roads of the Jackman area image better than some of the 2-lane asphalt and concrete public roads of other areas.

c. New England Railroads (Figures 9, 10 and 11)

The radar signatures of railroads are very similar to those of roads, some being light, others dark. The distinguishing features of railroads normally are related to radius of curvature, and trace.

One railroad line in the Claremont area was missed, due to the right-of-way being parallel to and alongside of an important highway, orientation being normal to the line of the imaging overflight, and aspect angle being low.

d. Power Lines (Figures 9 and 11)

Major power lines frequently are the most conspicuous elements on New England radar imagery, because of the broad swath they cut through the woodland and because blooming often magnifies reflectance from the support towers. Smaller power lines give rise to problems, especially if alongside conspicuous roads and railroads close to urban areas, where they may sub-divide, go underground, or terminate.

E. Agricultural Land Use

Standard agricultural land use maps of northern New England appear relatively simple in that the variety of crop types is limited. Crops consist principally of hay, corn, fallow, pasture or woodland. The mix of these elements is complex, there being an infinite variety of shapes, sizes and textures and a large number of outliers. (Cultivated hay fields grade irregularly into wild hay fields, and wild hay fields into permanent pasture. The transition from permanent pasture to woodland normally is especially complex). These diversities result not only from the diverse physical environments but also from the fact that 75 years ago three-fourths of northern New England was cultivated, where now less than one-quarter is.

a. Land Use on the Connecticut River Terraces

Figure 12 accurately delimits the narrow strip of flood plain and terraces of the Connecticut River. Flanking it on either side and occupying the remainder of the image is the New England upland.

Corn can be differentiated on this radar imagery with 80 to 90% certainty (Figures 12 and 14), whereas the standard Soil Conservation Service photo cover of the area provides little basis for recognition of corn in spite of much larger scale.

Minimum recognizable field size appears to be about 100 yards.

The only other terrain type extensive enough to merit differentiation on the Connecticut River terraces is marshland (Figure 12). It appears mostly as small areas along the river, occupying not more than 2% of the terrain. Its dark tones permit it to be discriminated with an estimated 75% accuracy.

b. Land Use on the New England Upland

Away from the Connecticut terraces most of the land is occupied by second growth woodland, cut into a fine patchwork pattern in places by small cleared fields, most of them in hay and pasture (Figure 12).

Typically, the woodland is mixed deciduous and coniferous (the birch, beech, maple, hemlock association with a large percentage of white pine), but often these are relatively pure coniferous stands, some of them several acres in size. Like the transitions from cleared to wooded land, those from conifer to deciduous are complex and variegated. The leveler parts of the uplands were at one time cleared and intensively farmed and now possess "ghost" field patterns of variegated woodland. Many slopes also were cleared, either by timber men or farmers. However, the steeper slopes are the areas most apt to support a heavy conifer growth today.

Most of the foregoing subtleties of woodland differences are beyond the discriminatory power of synthetic aperture radar. A hill slope facing towards the aircraft line of flight tends to backscatter to whiteness regardless of vegetative type. A slope in the opposite direction is normally too dark to reveal vegetative differences.

It is on the intermediate slopes that most vegetative detail appears. For example Figure 12 suggests that there are very few cleared fields on the western half of the image, but many of them on the east half. Ground truth bears out this generalization, but not to the extent suggested by the figure. The slopes east of the Connecticut, sloping downhill to the west at approximately the grazing angle of the area reveal a greater proportion of field patterns present than do the east-facing slopes of the western half of this imagery.

Discrimination between various hay crops, as between woodland types, in beyond the capability of this imagery.

New England traditionalists ask "Does radar reveal the typical New England stone fences?" The answer is "Yes". However, this is not to say that simple 2 or 3 foot high stone fences made of glacial cobbles and flat field stones pulled from the fields during ploughing and piled around the borders, show up. Few such stone fences exist. The typical New England stone fence today, separating active fields, is topped by a thin line of high brush or low trees. These field separators often show up conspicuously, especially at grazing angles. Scores of them can be seen in the eastern half of Figure 12 and are illustrated by the ground photo in Figure 14.

* * * * *

IV. Comments on Radar Cover of New England Type Areas

It is believed that the foregoing sections reveal the great utility of imaging by radar over land areas comparable to those of New England. It is worth noting that up to 2/3 of the land areas of the world - the humid mid-latitudes - are similar. Some of these humid mid-latitude areas are among the most populous on earth. While radar is somewhat less successful in producing clean-cut detailed imagery of the cluttered New England landscape then it is over more flat, more geometric and more arid landscapes elsewhere, the same must be said of other sensors as well.

Another point: along with the heterogeneity of the New England type landscape also goes New England cloudiness. The sensors which differentiate complex landscape patterns best do not penetrate cloud or darkness.

Radar can be used with confidence to show the framework of the landscape patterns, either one-time or repetitively. Recent radar mosaics of Darien Province in Panama (a very inacessible area) and of the State of Massachusetts (made with a less suitable radar) bear this out. Details may be filled in later, using sunlight-dependent sensors.

On balance, the maximum practicable operational and developmental program for radar is called for to mitigate the delays and fill in the blank spaces, as well as to obtain detail not obtainable with more conventional sensors.

* * * * *

V. "Confidence Levels" in Radar Pattern Discrimination

In spite of many years of radar pattern study, no adequate format for expressing the degree of discriminability of landscape items exists.

In an attempt to develop such a format, Table 4 (fold-in, last page of Volume) was devised. It utilizes the degree of confidence an interpreter can have that he will find signatures for specific items of interest if they are present in the landscape. Three major levels of confidence can be recognized:

a. NEGATIVE CONFIDENCE: Confidence that normally the item in question will not provide a signature on the imagery, no matter how many cases of the item may be present in the landscape (example: head-stones in a cemetery). Under most circumstances these items are below the resolving power of the radar (or of the radar in question under the restraints and parameters of this specific operation).

b. ONE-WAY CONFIDENCE: Confidence that normally, if examples of the item are present, some of them will produce signatures (example: two-lane asphalt roads). Presence in the landscape of an item in this category implies that if conditions are optimal the item will image. Otherwise, not. The variable may be inherent in the item (as, size) or in the radar-target relationship (as, aspect angle), or in the surrogate for the item.

c. TWO-WAY CONFIDENCE: Confidence that not only will some examples of a given item leave signatures if present, but also that essentially all examples of that item in the area will do so (example: dual highways with interchanges). Two-way confidence items largely are independent of aspect, operational parameters, and the like.

A cataloguing system based on confidence levels such as the foregoing appears to serve the requirements of this study. In addition it is capable of:

(1) tremendous expansion or contraction (Table 4 could contain a few items, or thousands; they could be organized hierarchically or listed at random).

(2) infinite quantification (as well as utility on a simple descriptive basis).

(3) broad application and repeatability.

As with most categorizations, the three basic categories of this format can be spread apart, and transitional categories inserted as necessary. For the purpose of this study only one transitional degree of confidence has been added (between the one-way and two-way confidence levels). Thus Table 4 has four vertical columns rather than three.

* * * * *

VI Conclusions

1. In an orbital program of remote sensing for earth resources purposes, radar should be a strong competitor for a place in the sensor array. Enough significant landscape items enjoy high ("two-way") confidence ratings (Table 4) to fully justify taking advantage, in humid microthermal and mesothermal climates, of radar's celebrated weather-freedom.

2. Applying the rigorous but realistic evaluation system and terminology developed by radar design engineers to the problem of finding discrete populated ("built-up") areas amid the clutter and noise of New England imagery, the highest scoring interpreters had success-to-error ratios of more than 4:1 and the average competent interpreters 2:1 and 3:1. This scoring system is based on penalizing for "false alarms" as well as for "misses" (Table 2).

3. Assuming that the conditions of this study are representative, radar imagery can be expected to reveal on the average:

* 100% of the cities having populations larger than 7,000;
* 80% of the towns having populations of 800 or larger;
* 40% of the villages having less than 800 population (down to a minimum of 150 people, the smallest agglomeration considered in this study) (Figure 5).

4. As to differentiating rural from urban landscape, the average competent interpreter was 90 to 96% successful in predominantly rural sample areas, and 62% correct in the complex urban sprawl of outer Boston (Table 3).

5. Following are some of the items found to justify varying degrees of confidence in their discriminability on New England radar imagery of the type used in this study (Table 4):

a. <u>High ("two-way") confidence</u>

   Towns over 800 population
   Cornfields (estimated 90% accuracy)
   Dual highways with interchanges
   Major utility lines in forested areas
   Ponds over 200 yards wide
   Surface configuration lineaments

b. <u>Lower ("one-way") confidence</u>

   Towns under 800 population
   Two-lane highways
   Railways
   Forest vs grassland

c. <u>No (or negative) confidence</u>

   Individual buildings
   Extractive industry
   Quantitative evaluation of relief (on a single pass)
   Coniferous vs deciduous trees
   Orchards

* * * * *

ANNEXES

Annex 1. Details of the Statistical Study

1. The Thirty-Eight Interpreters

The 38 interpreters who submitted overlays of the built-up areas were affiliated as follows:

Academic: 15 (Florida Atlantic, East Tennessee State, and Northwestern Universities; Universities of California (Riverside), Kansas and Michigan).

Private Industry: 15 (Texas Instruments and Raytheon/Autometric)

Government: 8, plus an informal inexperienced control group (Army Terrestrial Sciences Center)

Experience: ranged from one month to 16 years of radar experience, and up to 21 years of conventional photo interpretation experience. Typically, one year of radar and several years of conventional PI. Almost none had significant experience in settlement pattern or urban radar interpretation.

2. The Five Sample Areas

As suggested in Figure 1 of the main text, these were selected to represent various parts of New England, and also a complete range in population density.

The 1/10" grid cells of the master scoring sheet for the Burlington and Claremont areas represent cells .3 miles on a side at the scale of the imagery. The 2/10" cells of the Boston Suburban area represent .6 miles on a side.

3. The Binomial Test of Town Size in relation to Interpreter Success

This was applied to the data of Figure 5 of the main text.[1] It shows that there is less than 1% probability that the high percentage of interpreters finding the towns in this test did so by chance.

Null hypothesis: the number of interpreters who found each town is strictly chance.

Significance level selected: .01

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[1] Frequency counts, rather than percentages, were used in the actual binomial computations.

TABLE A Statistical Evaluation of Interpreter Success at finding Specific Built-Up Places

Population Category	Population	Average Population	No. of Interpreters who found the Towns in the Group [1]
I	10,000-99,999 (2 towns)	23,600	38-38 (aver. 38)
II	1,000- 9,999 (7 towns)	3,800	31-38 (aver. 35.7)
III	100- 999 (10 towns)	340	10-38 (aver. 23.5)

[1] In this column the first number represents the number of interpreters finding the least conspicuous town; the second number, the most conspicuous town.

a. Overall

	I (Large)	II (Medium)	III (Small)
Hits	38	35.7	23.5
Misses	0	2.3	14.5

Chi-square equals 25.4381 on 2 degrees of freedom

b. Category by Category

	I (L)	II (M)
Hits	38	35.7
Misses	0	2.3

Chi-square = .757714 on 1 D.F.

	II (M)	III (S)
Hits	35.7	23.5
Misses	2.3	14.5

Chi-square = 9.58559 on 1 D.F.

	I (L)	III (S)
Hits	38	23.5
Misses	0	14.5

Chi-square = 15.5324 on 1 D.F.

Chance: determined for each town by comparing the number of 1/10" cells which compose it to the number of land cells in the sample strip to which it belongs.

Result: Null hypothesis rejected.

4. The Chi-Square Test of Category of Town Size vs Interpreter Success

The chi-square test was used to test the town-size data arranged by categories (Table A, this annex).

a. Overall examination (Subtable a)

Null hypothesis: there is no relation between size-of-town category and interpreter success:

Significance level: .05

Rejection region: 5.99

Chi-square: 25.4381 on 2 degrees of freedom

Result: Null hypothesis rejected.

b. Category by category (Subtable b)

Null hypothesis: same as foregoing

Significance level: same

Rejection region: 3.81

Chi-squares: .757714 / 9.58559 / 15.534 on 1 degree of freedom

Rejection region: 3.84

Result: null hypothesis rejected for medium vs small categories and for large vs small categories, but must be accepted for large vs medium categories.

5. Interpreter Backgrounds and Success in this Study

The data summarized in paragraph 5 of Section II-E of the text is given in somewhat more detail on Table B, attached hereto.

TABLE B

Interpreter Experience vs Success in Distinguishing between Built-Up and Nonbuilt-Up Landscape, Sample Areas

		Burlington Area	Claremont Area	Boston Suburban Area	Overall
I. Prime Interpreter [2]		98.6% [1]	98.6% [1]	83.9% [1]	97.4% [1]
II. Experienced Group [3]					
	Best	95.3	98.9	77.3	95.2
	Mean	89.9	96.3	62.5	91.4
	Worst	75.7	92.4	48.2	84.1
III. Inexperienced Group [4]					
	Best	-	94	-	-
	Mean	-	84	-	-
	Worst	-	47	-	-

[1] Percentage scores shown represent: No. urban cells right + No. rural cells right/total No. cells.

[2] The "Prime Interpreter" is the Principal Investigator of this project.

[3] The "Experienced Group" is the 38 experienced interpreters scattered around the United States who spent three hours each delineating their ideas of the boundaries of the built-up areas of the three images.

[4] The "Inexperienced Group" consisted of selected Army and Air Force officers, mostly Engineers, who were assembled at Hanover in 1968 for a short course in introductory (conventional) photo interpretation under Mr. Robert Frost, Head of the Photo Interpretation Research Division, U.S. Army Terrestrial Sciences Center. The officers were highly competent and motivated, but with one or two exceptions had no training or experience in imagery evaluation.

Annex 2. Selected Bibliography

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III. Settlement Patterns: Geographic References

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III. Settlement Patterns: Geographic References (continued)

3. Chorley, Richard J., and Haggett, Peter. Socio-Economic Models in Geography. London: Methuen, 1967.

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FIGURES

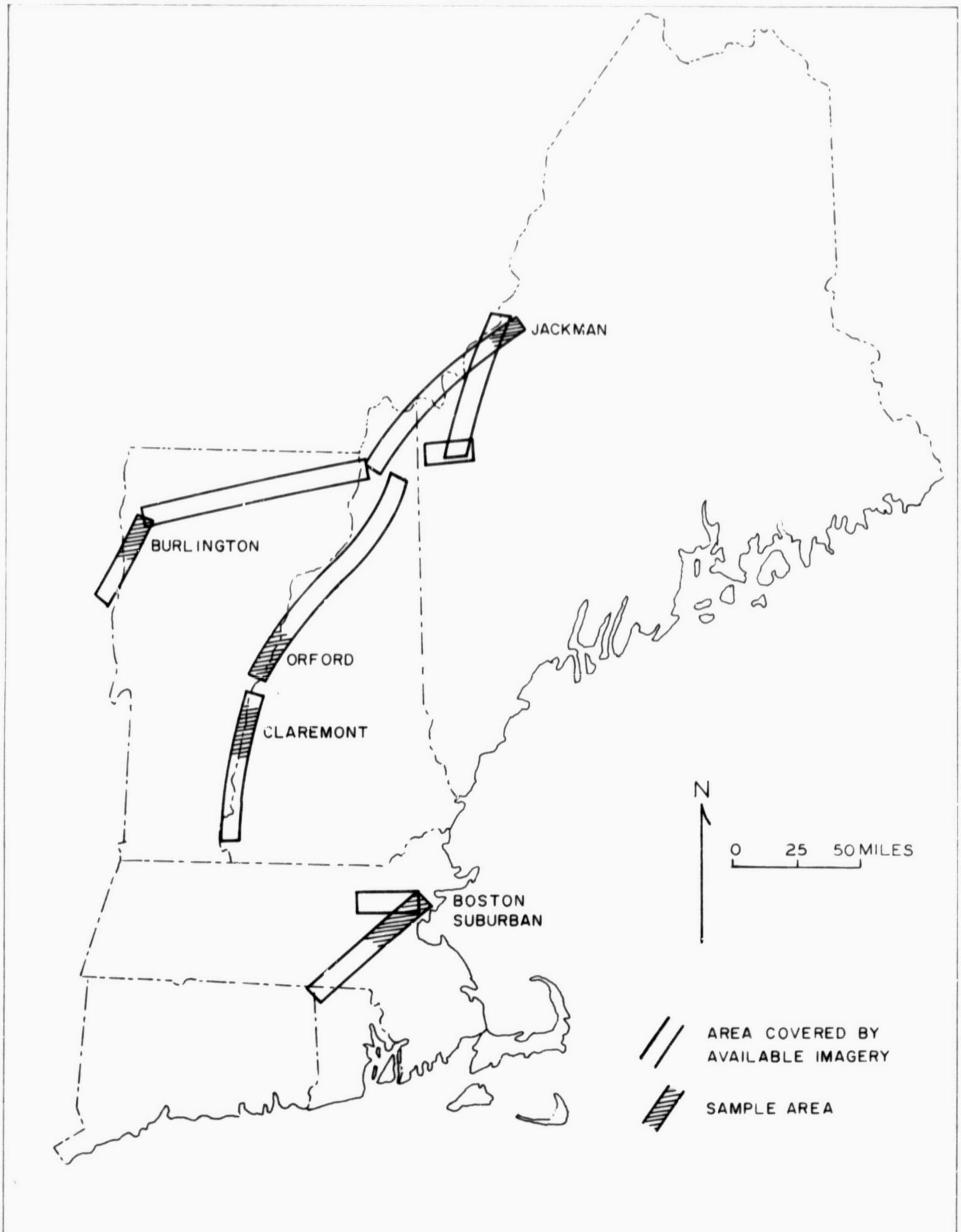


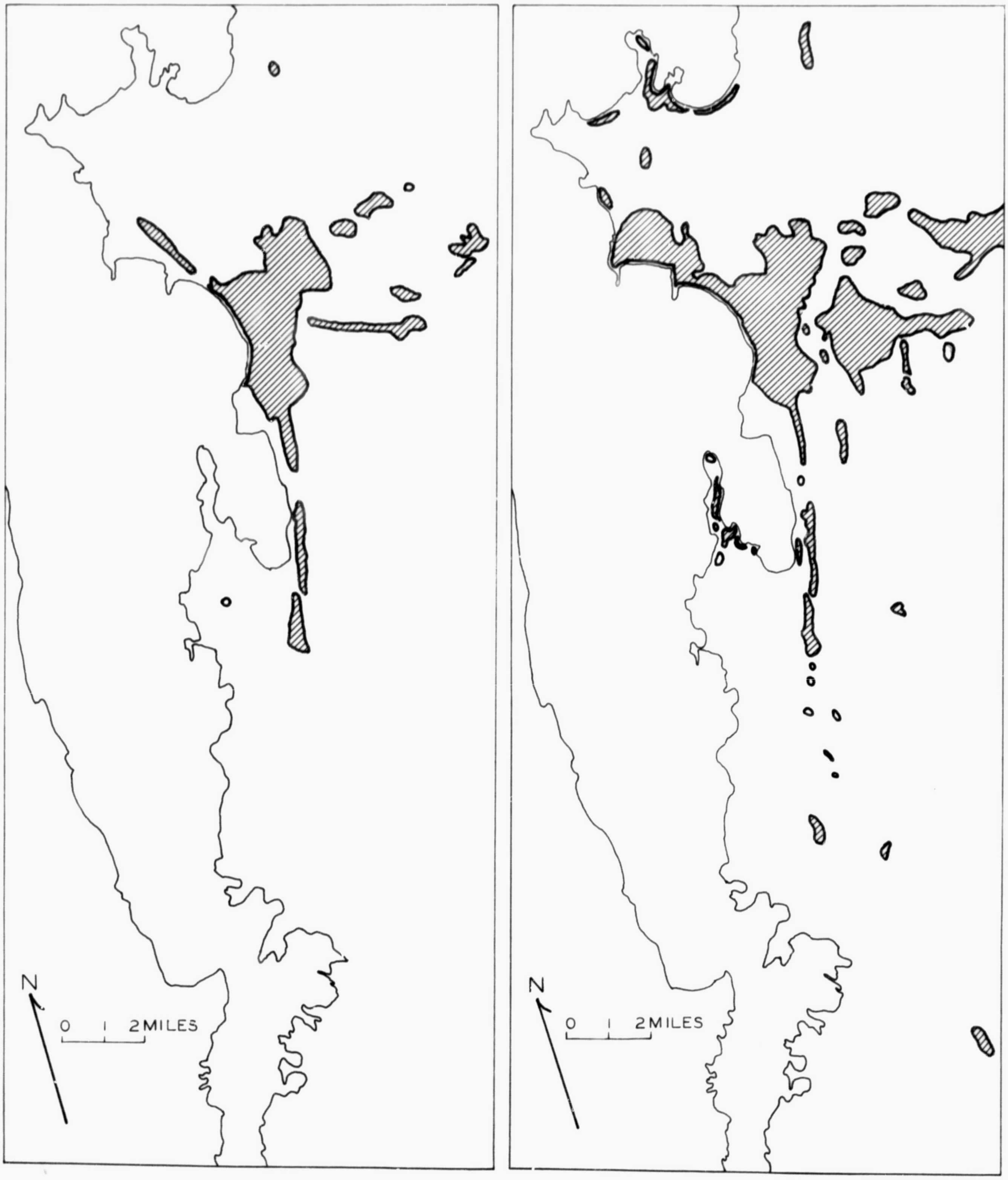
Figure 1. Index Map, Radar Coverage Available for this Study.

(HH mode; enlarged 1 1/2 times)

N

0 1 2 MILES

Figure 2. Radar Image, Burlington Sample Area.



a. Built-Up Area, Best Testee   b. Built-Up Area, Median Testee

Figure 4. Burlington Area Population Patterns, II.

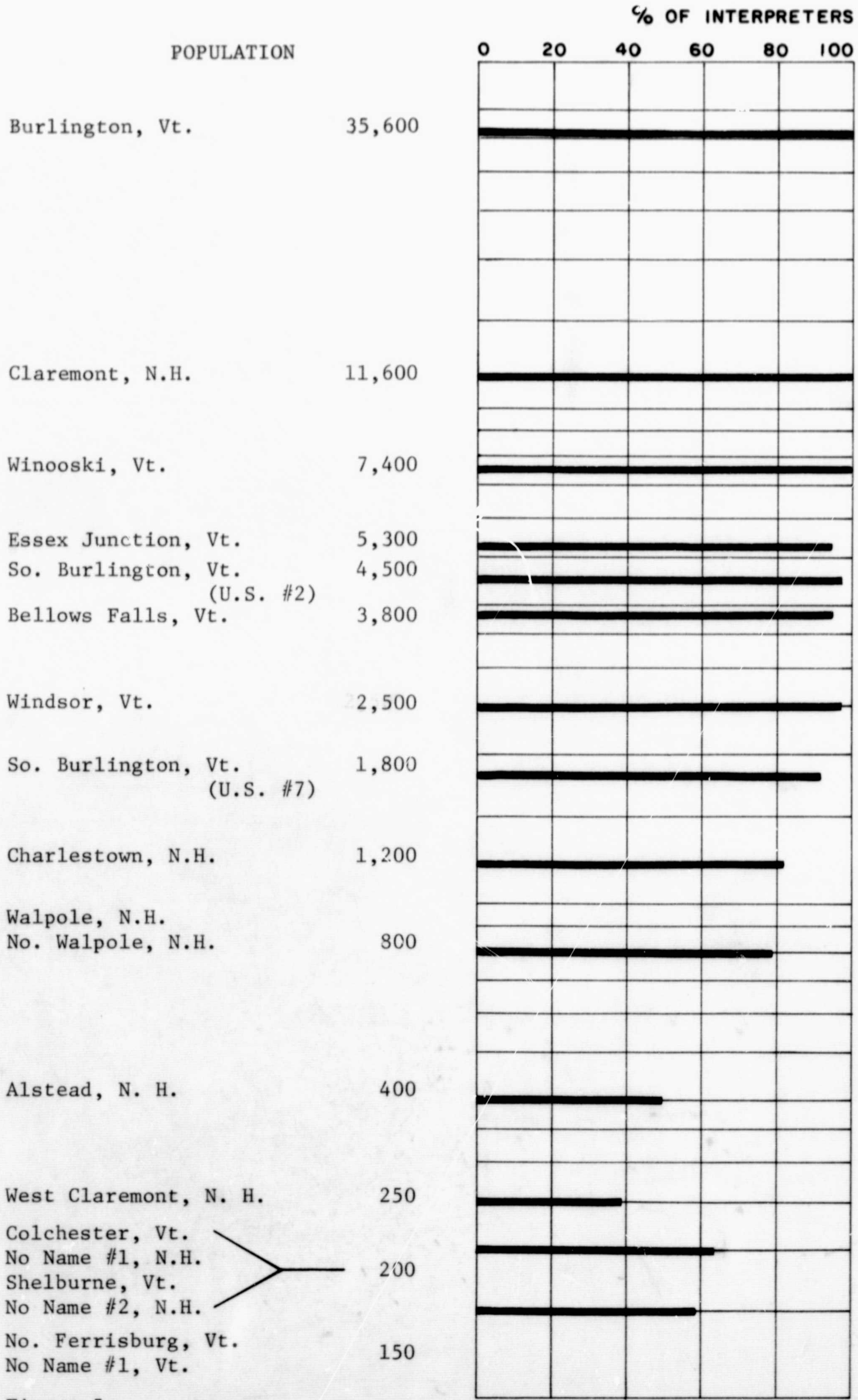


Figure 5.
Interpreter Success in Finding Specific Built-up Places, as Related to Population of Areas. (Semi-log Scale)

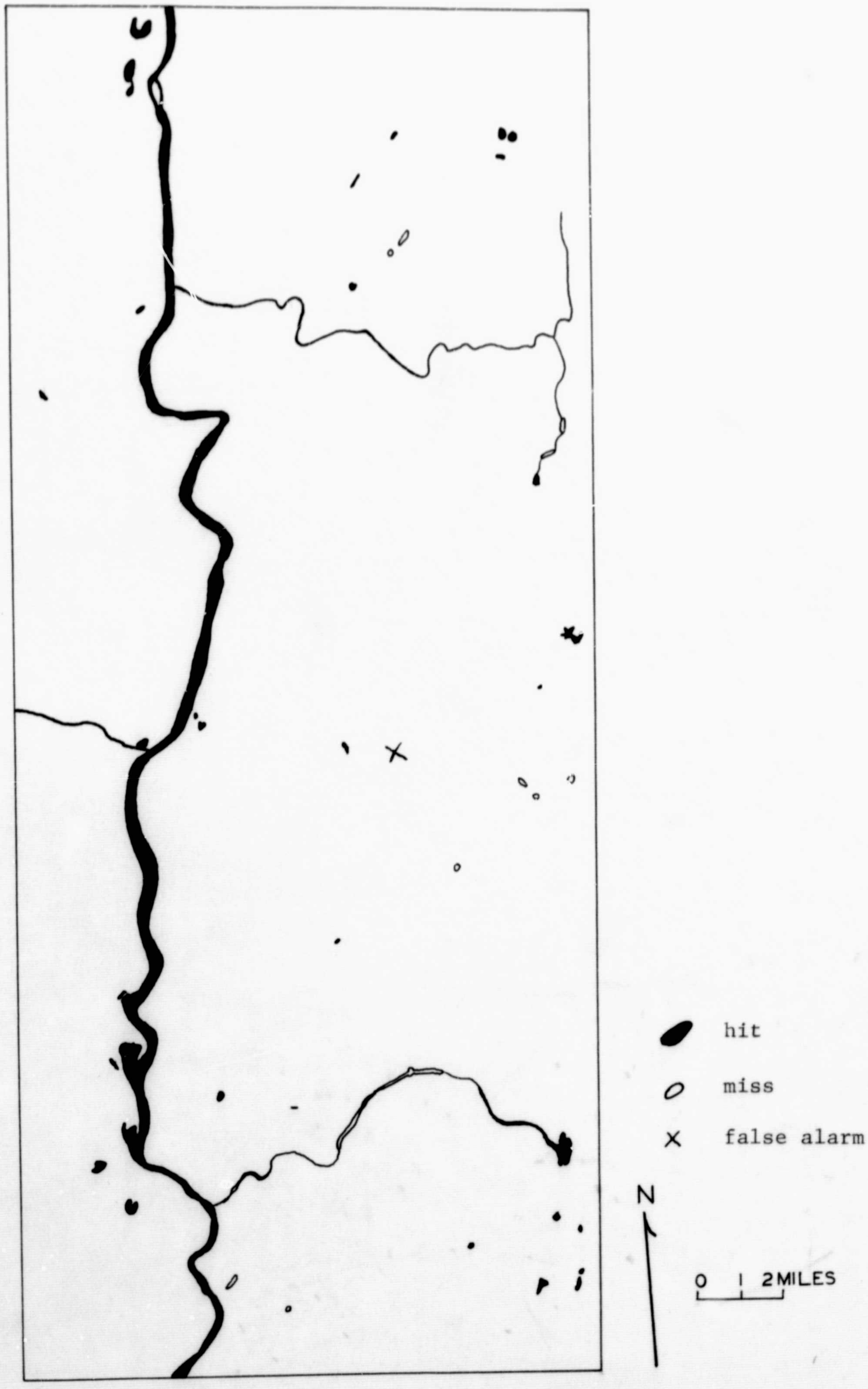


Figure 6. Hydrography, Claremont Sample Area.

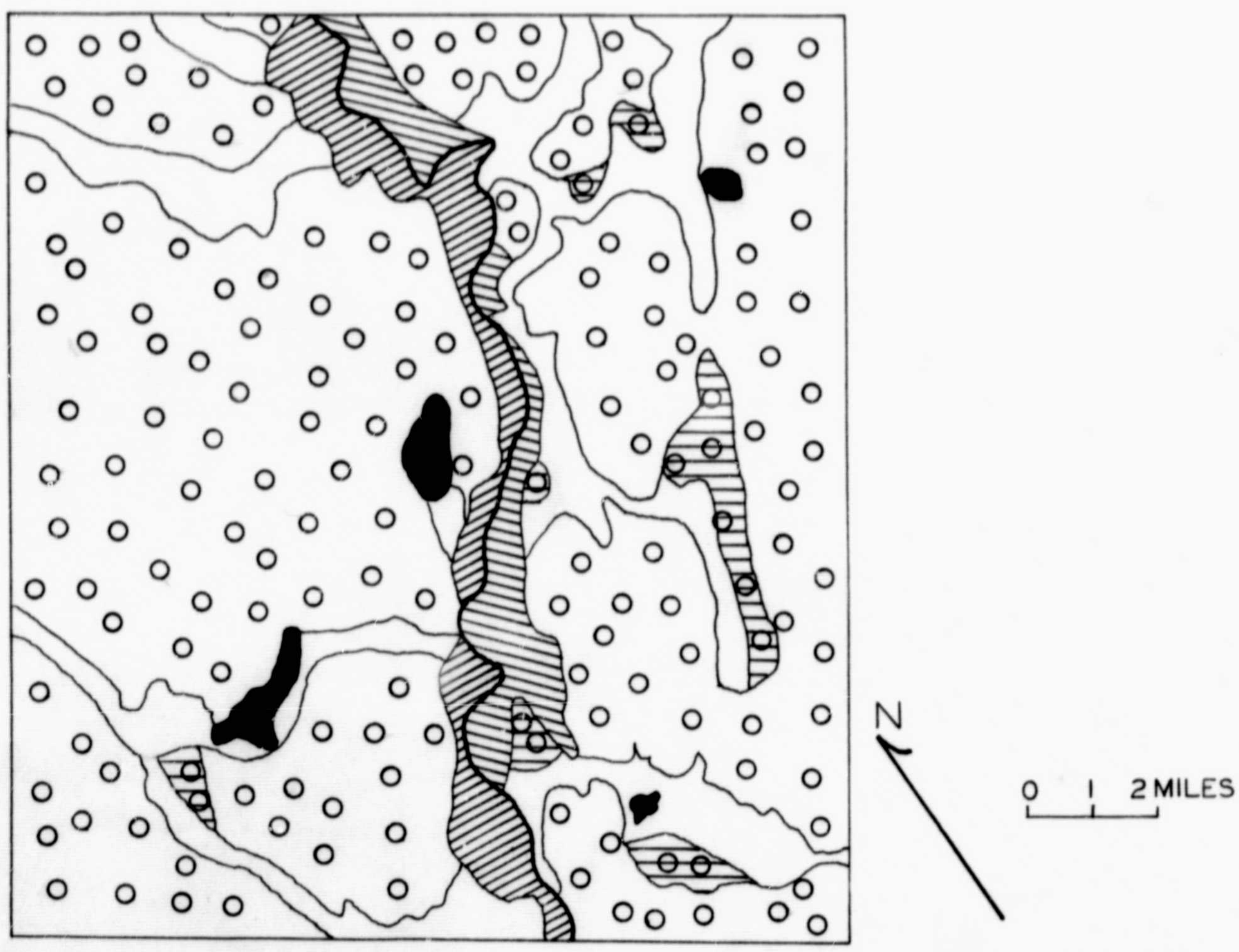


Figure 7. Landform Regions, Orford Sample Area.

- pond
- river terraces
- upland (as seen on HH channel)
- upland (added after reference to HV channel)
- corridor

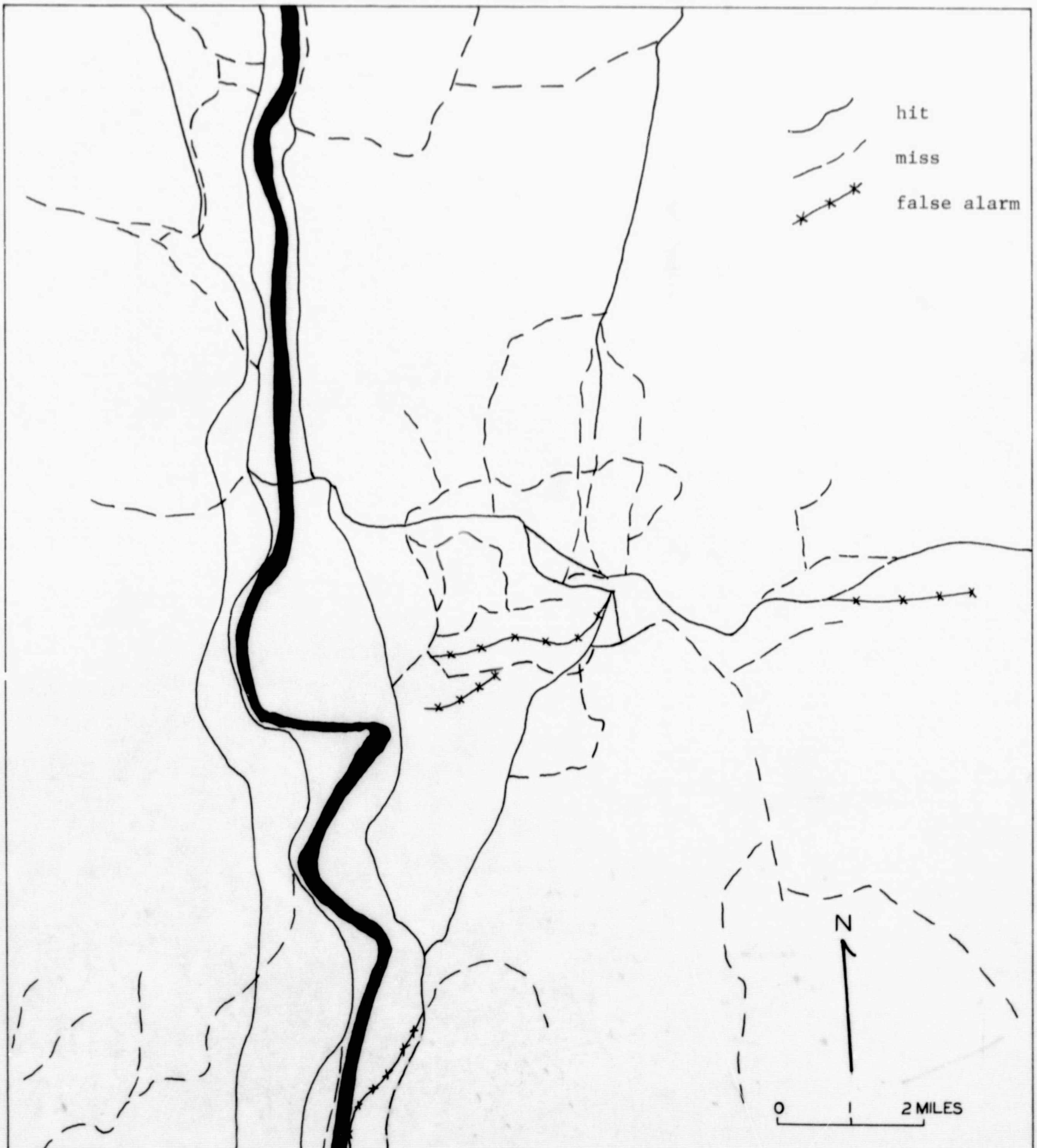


Figure 8. Medium and Heavy-Duty Roads, Claremont Sample Area.

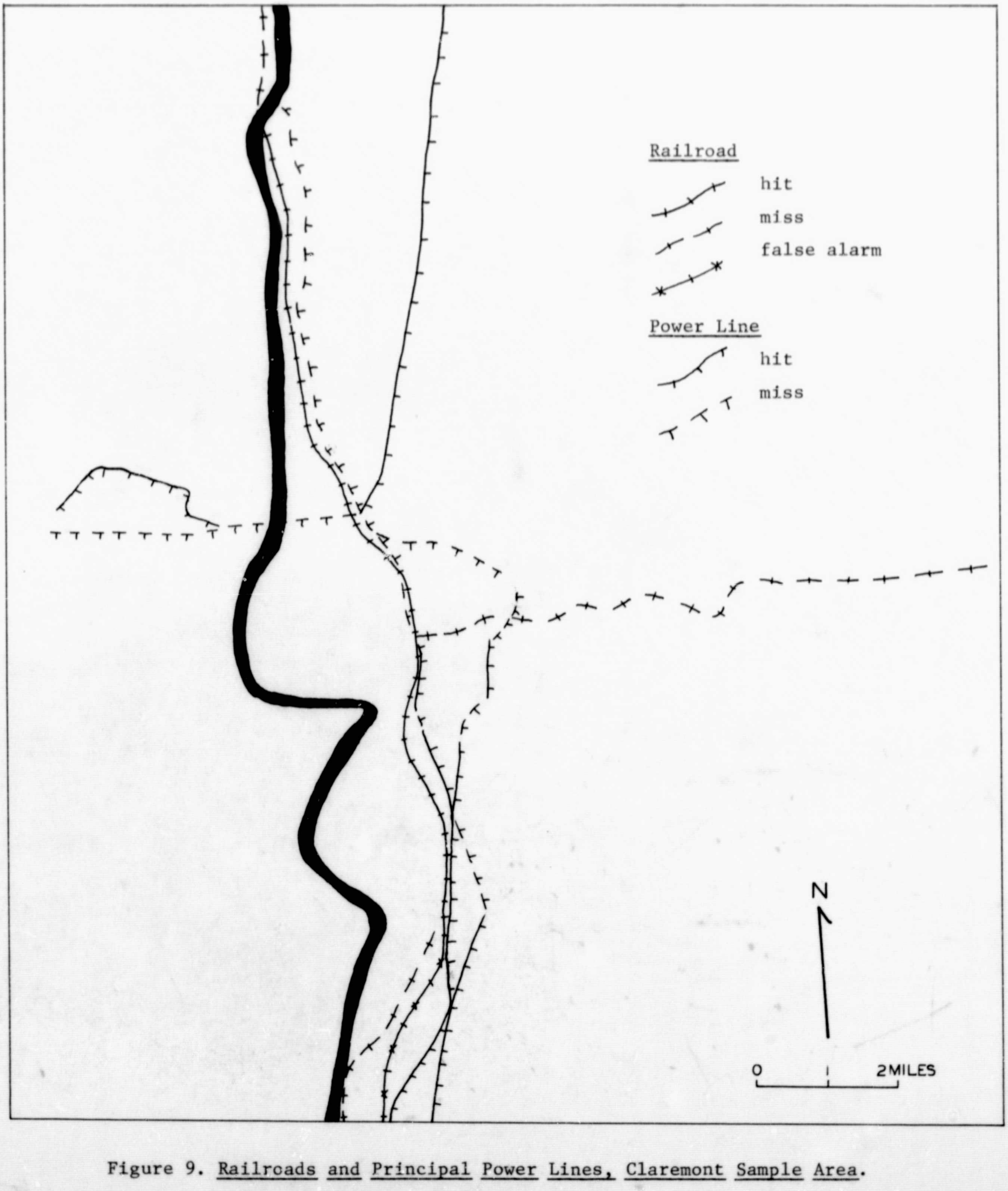


Figure 9. Railroads and Principal Power Lines, Claremont Sample Area.

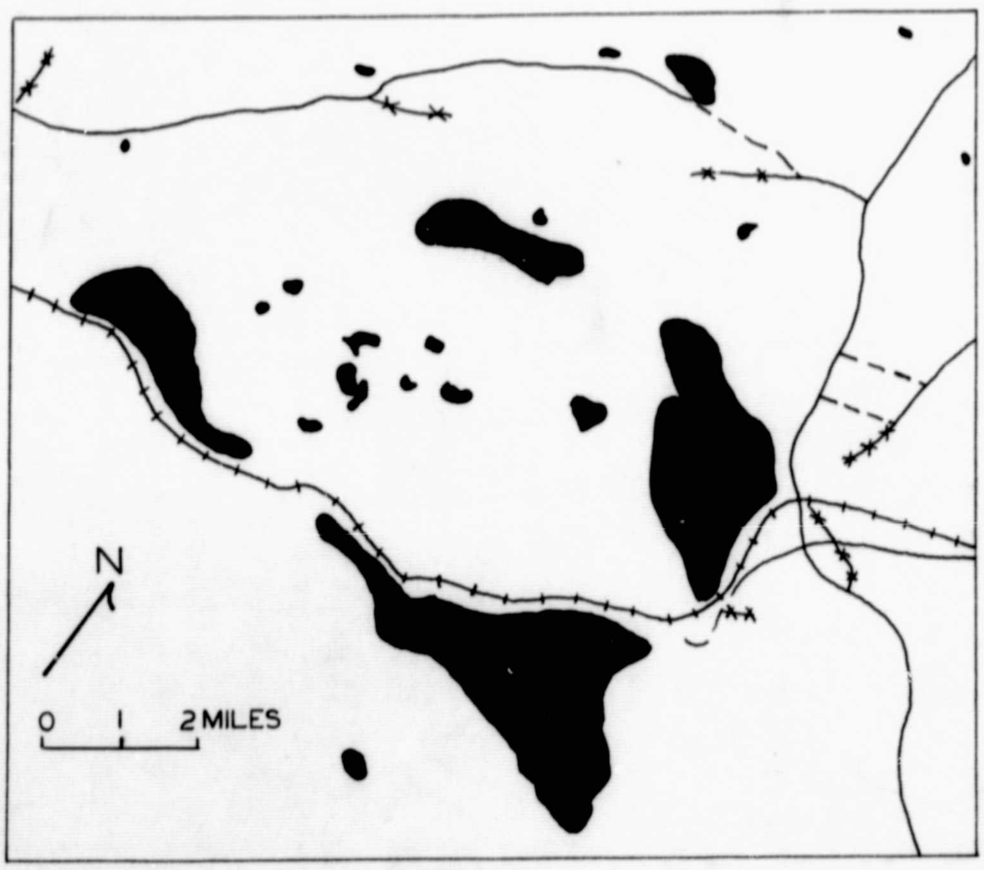


Figure 10. Transportation and Communications, Jackman Sample Area.

Roads

hits

misses

false alarms

Railroads

hits

Lakes and Ponds

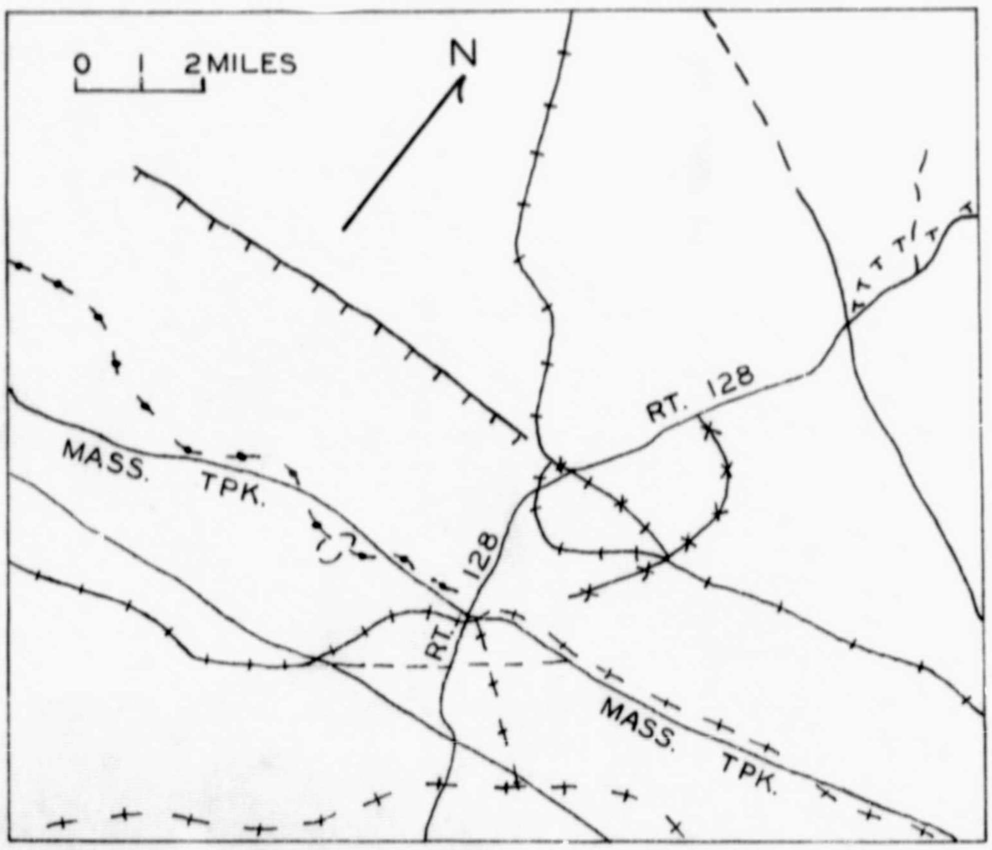


Figure 11. <u>Transportation and Communications</u>, <u>Boston Suburban Sample Area.</u>

<u>Highway</u>

hit

miss

false alarm

<u>Railroad</u>

hit

miss

f[illegible]

<u>Power</u>

hit

miss

<u>Aqueduct</u>

miss

Figure 12. Agricultural Land Use, Orford Sample Area.

a.

b.

Figure 13. Minor Road which Imaged Clearly.
This unsurfaced minor road imaged clearly in both the a and b sectors (1) because it was parallel to the line of flight and (2) because of the "wall reflectance effect" of the trees on the down-energy side of the road (left). The fact that tree canopies interlaced lightly over the road in b did not entirely eliminate the wall reflectance above.

a.

b.

Figure 14. Agricultural Land Use Patterns.

a. Cornfield in July, viewed at approximately the aspect angle of imaging radar. The radar imagery used in this study also was recorded in July. In it corn consistently gives a high reflectance signature.
b. "Cellular field patterns" of the kind responsible for most of the individual field returns in the eastern half of Figure 12.

CAPABILITY OF RADAR TO DISCRIMINATE SPEC

	Two-Way Confidence [2]	Intermediate Confidence [3]
SETTLEMENT PATTERNS	towns over 800 dual highways with interchanges major airports major utility lines (in forested areas) major bridges urban CBDs	steep population gradients (at city's edge) dual highways without interchanges urban large-building areas other than CBDs outdoor movies golf courses
HYDROGRAPHY	stream patterns lakes, ponds, reservoirs (+ 200 yds) extent of flooding major stream hierarchy and bifurcation	drainage basins extent of water body shrinkage from drouth ice cover
LANDFORMS	Hammond region boundaries local surface-configuration areas (as hills, mountains, corridors, upland and lowland flats) lineaments ("grain" of landscape)	
NATURAL VEGETATION		
AGRICULTURE	cornfields cover crop vs fallow (+ 200 yds)	field patterns lines of trees separating open fields

1 With special reference to New England, and K-band radar.

2 Two-way Confidence: Confidence that not only will some examples of a given item leave signatures if present, but also that essentially all examples of that item in the area will do so.

3 Intermediate Confidence: transitional between two-way and one-way confidence.

4 One-way Confidence: Confidence that normally if the item is present in the landscape, some but not all examples of it will produce signatures.

5 Negative Confidence: Confidence that normally the item will not provide a signature on the imagery, no matter how many examples are present in the landscape.

IFIC ITEMS IN TERMS OF CONFIDENCE LEVELS[1]

TABLE 4

	One-Way Confidence[4]	Negative Confidence[5]
	towns under 800 two-lane highways railways major dams	individual buildings extractive industry cemeteries
		ditches - irrigation or drainage (New England types)
	slopes, quantitative	relief, quantitative (on a single pass)
	forest vs grassland (biochores)	coniferous vs deciduous (formation classes) seasonal changes fire damage
	seasonal changes thick vs thin soil parent material	orchards natural pasture vs cultivated hay crop open woodland vs wasteland most agricultural practices