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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

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May 1968

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Mr. Robert Porter
Acting Chief, Earth Resources Survey
Disciplines Program
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith is one copy of:

INTERAGENCY REPORT NASA-119

GENERATION OF HOUSING QUALITY DATA FROM

MULTIBAND AERIAL PHOTOGRAPHS*

by

Barry S. Wellar**

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Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. 14-08-0001-10654, Task 160-75-01-44-10
**Northwestern University, Evanston, Illinois

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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Space Administration (NASA)

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**Northwestern University, Evanston, Illinois

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by

Barry S. Wellar
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ABSTRACT

Determining the spatial distribution of different grades of housing quality, in particular the identification of areas where standards are low, is of considerable importance in the fields of urban planning, geography, sociology, business, and public health. Current methods for evaluation of housing quality are time-consuming, expensive, and frequently inadequate. The purpose of this study is to attempt to discover significant correlates of poor housing quality using data obtained from multiband aerial photographs. A procedure is developed which is claimed to be a rapid, reliable and objective source of housing data, with an inherent flexibility for changing the boundaries of the study area.

The conclusions drawn from the analysis are represented in appraisal forms, similar in format to those established by the American Public Health Association, containing structural and environmental indicators of housing quality which can be generated from the multiband aerial photographs. The most consistent indicators of low quality housing are found to be:

(i) the presence of litter, garbage, wrecked or derelict cars, and piles of lumber and other rubbish on occupied as well as vacant lots;

(ii) lack of landscaping (shrubbery, patios, and grass) in yards and parkways (strip between street and sidewalk), presence of weeds on vacant lots;

(iii) the number of vacant lots;

(iv) non-residential hazards and nuisances, including industrial plants (smoke, refuse) and warehouses (refuse); and

(v) the degree of lot-crowding, that is, lack of "free space" per lot.

The above criteria have not yet been established by statistical analysis, but, on the basis of frequency of appearance per criterion, and level of association per criteria, there are plausible grounds for selection of those criteria that are consistently present in low housing quality areas.

PREFACE

Determining the spatial distribution of different grades of housing, in particular the identification of areas where standards are low, is of considerable importance in the fields of urban planning, public health, commerce, economics, sociology, housing, etc. Current methods for evaluation of housing quality are both time-consuming and expensive. The purpose of this study is to attempt to discover significant correlates of housing quality using data obtainable from a set of multiband aerial photographs, and to produce a housing quality appraisal form based on this data.

While it is evident that many of the features relative to housing quality are only to be observed inside given residential units, the hypothesis is erected that these internal factors are consistently associated with other external criteria which may be observed from the air. When several or more parameters are taken into account in the analysis and interpretation of multiband aerial photographs, there is need for multivariate statistical analysis. Until such analyses are undertaken, the approach suggested here provides a rapid survey method for determining areas having the greatest probability of exhibiting poor quality housing.

Like most studies, this too, is the product of a number of peoples' efforts and intellectual stimulation. Special appreciation is due to Dr. D. F. Marble who read and re-read the manuscript, and who provided a number of constructive criticisms. Dr. M. F. Dacey made a number of suggestions during the early stages of the study. Dr. E. G. Moore read an early draft of the manuscript, and has served as a sounding board on a number of occasions.

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I am grateful to the Department of Geography, Northwestern University, for making money and materials available through its co-operation with the Earth Resources Program of the National Aeronautics and Space Administration and the United States Geological Survey.

I must assume full responsibility for any conclusions contained herein, as well as for any omissions weaknesses, or errors of fact.

Evanston, Illinois
April, 1967

Barry S. Wellar

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Chapter I

INTRODUCTION

This report attempts to determine the extent to which information relating to housing quality can be extracted from low altitude multiband aerial photography.[1] The study probes the question of whether or not the evaluation of housing quality can be done by objective criteria,[2] and if so, can an appraisal form, consisting of a number of objective criteria, be designed so as to lead to some determination of housing quality from multiband aerial photography.

In order to strengthen the objectivity scale (appraisal form), an attempt is made to provide qualitative statements as to the relative importance of different imaged characteristics for recognizing and measuring low quality housing. In this way, it may eventually be possible to develop a procedure for statistically weighting the importance of the characteristics associated with housing quality.

A major difficulty encountered at the outset of the study lay in a precise determination of the definition of housing quality. Sound, deteriorating, and dilapidated housing are categories defined by the United States Bureau of the Census, but a number of other institutions, groups and individuals who generate and utilize similar data are in substantial disagreement as to the precise

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[1] Multiband aerial photography is discussed in detail in Appendix B, "The Electromagnetic Spectrum and Multiband (Multispectral) Aerial Photography." Housing quality observations and inferences are discussed in detail in Appendix C, "Case Studies," and Appendix D, "Signatures."

[2] U.S., Bureau of the Census, Department of Commerce, Papers Presented at the Census Tract Conference on September 10, 1965 at Philadelphia, Pa., Census Tract Paper GE-40, No. 1 (Washington: 1966), p. 12.

U.S., Bureau of the Census, Dept. of Commerce, Self-Enumeration as a Method for the 1970 Census of Housing, Working Paper No. 24 (Washington: 1966), p. 12.

U.S., Bureau of the Census, Dept. of Commerce, Papers Presented at the Census Tract Conference December 28, 1961, Working Paper No. 12 (Washington: 1962), p. 3.

definition of housing quality.[3] Housing data most frequently presented by the Bureau of the Census relate to the physical condition of the housing unit together with a description of certain interior facilities, e.g., plumbing facilities in the housing unit. Sound, deteriorating, and dilapidated housing conditions are defined by the Census (Housing) as follows:[4]

> *Sound housing* is defined as that which has no defects, or only slight defects which are normally corrected during the course of regular maintenance. Examples of slight defects include: lack of paint; slight damage to porch or steps; small cracks in walls, plaster, or chimney; broken gutters or downspouts; slight wear on floors or doorsills.
>
> *Deteriorating housing* needs more repair than would be provided in the course of regular maintenance. It has one or more defects of an intermediate nature that must be corrected if the unit is to continue to provide safe and adequate shelter. Examples of intermediate defects include: shaky or unsafe porch or steps; holes, cracks, or missing materials over a small area of the floors, walls, or roof; rotted window sills or frames; deep wear on stairs, floors, or doorsills; broken or loose stair treads or missing balusters. Such defects are signs of neglect which lead to serious structural deterioration or damage if not corrected.

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[3] There are numerous publications which could be mentioned here. Several are referred to as a means of indicating the scope of this topic.

Advisory Committee on Intergovernmental Relations, Performance of Urban Functions: Local and Areawide, Report M-21-Revised (Washington: U.S. Government Printing Office, Sept. 1963), pp. 232-234.

J.F. Kain, "The Development of Urban Transportation Models" in Papers, Regional Science Association, Vol. XIV, 1965. See especially fn. 22, p. 165.

U.S., Bureau of the Census, National Housing Enumerators Manual, Department of Commerce. Form 8B-14, House Division, Field Division, Nov. 1956. See especially pp. 23-24, 86, 113, 114.

Louis Wirth, "Housing as a Field of Sociological Research," American Sociological Review, Vol. 12, No. 2, April 1947.

G.W. Hartman and J.C. Hook, "Substandard Urban Housing in the United States: A Quantitative Analysis" in Economic Geography, XXXII. Clark University, Worcester, Mass., April 1956, pp. 95-114.

Carol Aronovici, Housing the Masses, John Wiley and Sons, Inc. New York, 1939. See especially pp. 243-245 in Chapter X, "The Housing Survey and Housing Research."

[4] U.S., Bureau of the Census, Department of Commerce, U.S. Census of Housing: 1960, Vol. III, City Blocks, Evanston, Ill. Series HC(3) No. 138 (Washington: U.S. Government Printing Office, 1961), p. x.

Dilapidated housing does not provide safe and adequate shelter. It has one or more critical defects; or has a combination of intermediate defects in sufficient number to require extensive repair or rebuilding; or it is of inadequate original construction. Critical defects result from continuous neglect or indicate serious damage to the structure. Examples of critical defects include: holes, open cracks or missing materials over a large area of the floors, walls, or roof; damage by storm or fire. Inadequate original construction includes structures built of makeshift materials and inadequately converted cellars, sheds, or garages not originally intended as living quarters.

The plumbing facilities are categorized as follows:

With all plumbing facilities consists of units which have hot and cold piped water inside the structure, and flush toilet and bathtub (or shower) inside the structure for the exclusive use of the occupants of the unit. Equipment is for exclusive use when it is used only by the persons living in the one housing unit, including any lodgers living in the unit.

Lacking some or all facilities consists of units which do not have all the plumbing facilities specified above. Units without hot water, toilet, or bathtub (or shower) are included in this category. Also included are units whose occupants share toilet or bathing facilities with the occupants of another housing unit.

Lacking some or all facilities--with flush toilet consists of units which do not have all plumbing facilities but do have a flush toilet inside the structure. The toilet may be for the exclusive use of the occupants of the unit or shared with the occupants of another housing unit.

Lacking some or all facilities--no flush toilet consists of units for which there is no flush toilet available in the structure. These units may lack other plumbing facilities also.

The problem at hand is not just one of semantics. The Building Commission of the City of Chicago has claimed that a weakness exists in the terminology used (sound, deteriorating, dilapidated) and that this limitation has resulted in markedly different evaluations for the areas studied.[5] A publication by the Building Commission notes that the 1960 Census on Housing recorded 34 of 59 dwelling units in a block as dilapidated, while the City of Chicago's own inspectors

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[5]City of Chicago, Memorandum, A.H. Zimmerman to G.L. Ramsay, Commissioner, Department of Buildings, "U.S. Department of Commerce, Bureau of Census Criteria for Determining the Quality of Housing," May 10, 1962.

classified 3 of the 59 dwelling units as dilapidated.[6] This precise definition is critical with respect to public investment in urban renewal programs, etc.

With respect to content or composition of housing quality data, Twichell charges that the Census on Housing does not secure enough information about the quality of dwellings to determine their degree of conformity with modern housing standards.[7] Houses may be wholly free from the defects reported by the Census and yet be unlivable or poor enough to provide problems of definite concern in public policy decisions. Significant factors not covered by the Census include natural lighting, some means of egress in case of fire, size of rooms, operability of plumbing, dampness, specific fire hazards and rat infestation. Twichell further notes that the Census does not evaluate the physical environment of dwellings.[8] The best house may be unfit to live in if lack of surrounding open space robs it of light and air; if nearby business, industry, or railroads create excessive smoke, noise, vibration, or odors; if children are forced to play in hazardous streets, etc.

The American Public Health Association (APHA) has been, and is, active in investigations of housing quality, and it has designed an appraisal form which investigators may use to assign a housing quality rating to housing units. The APHA has attempted to design its appraisal form in such a manner as to make the appraisal procedure as objective as possible. This involves a removal of the need for the investigator (enumerator) to express personal preferences or dislike for a dwelling unit.

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[6] City of Chicago, Department of Buildings, "Comparative Study Census Tract 670, Block 9," May 1962.

[7] Allan A. Twichell, "Measuring the Quality of Housing in Planning for Urban Redevelopment" in Coleman Woodbury (ed.) Urban Redevelopment, Problems and Practices (University of Chicago Press: 1953), p. 21.

[8] Ibid., p. 22.

The APHA appraisal form has met with considerable approval, but indications are that significant advances are still to be made in terms of satisfying the demand for housing quality data, depending upon the agency using the data, its purpose, nature, and the level of reliability required.[9] Examples of some current problems in this area are:

(1) the need to generate data to satisfy Federal or other criteria, e.g., for an urban renewal project, when it is not appropriate or possible to use the money- and time-saving Census of Housing data, and when the information obtained by the APHA appraisal method does not satisfy the criteria for receiving Federal funds;[10]

(2) Speed in acquiring the needed data set. Twichell concludes that a practicable abridgement of the APHA dwelling appraisal will probably be one that tells little or nothing about the adequacy of repair and sanitary upkeep. Abridgement assumes importance for those who are of the opinion that even a slightly quicker or cheaper method might be advantageous when great speed is essential or when cost cannot be

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[9]For a discussion of what the housing quality data set should contain see:

Twichell, p. 35.

U.S., Bureau of the Census, Department of Commerce, Papers Presented at the Census Tract Conference December 29, 1958. Working Paper No. 7 (Washington: 1959), pp. 1-13.

For a discussion of the reliability factor see:

U.S., Bureau of the Census, Department of Commerce, The Post Enumeration Survey--An Evaluation Study of the 1950 Censuses of Population and Housing, (Washington: 1960), p. 14.

U.S., Bureau of the Census, Department of Commerce, Sampling Applications in Censuses of Population and Housing, Technical Paper No. 13 (Washington: 1956), p. 2.

U.S., Bureau of the Census, Department of Commerce, Self-Enumeration as a Method for the 1970 Census of Housing, Working Paper No. 24 (Washington: 1966), pp. 12-16.

U.S., Bureau of the Census, Department of Commerce, Evaluation and Research Program of the U.S. Censuses of Population and Housing, 1960: Accuracy of Data on Housing Characteristics, Series ER60, No. 3 (Washington: 1964).

[10]City of Chicago, Department of Urban Renewal, Enumerator's Manual for Basic Structure Surveys (Chicago: Sept. 1963), p. 1.

spread among a group of co-operating agencies;[11]

(3) The need for a more careful definition of "housing quality." The APHA is currently in the process of re-evaluating and possibly restructuring its appraisal form.[12] The World Health Organization is also studying the problem of appraisal on an international basis. Suggestions of possible contributions from aerial photography were well received by all groups studying the problem. The indications are that although the APHA and others are concerned with the development of reliable means to generate, classify, and present housing quality data, they have not as yet developed a full appreciation as to the type and degree of housing quality data that can be extracted from remote sensors in general and multiband photography in particular.

A number of cities have developed their own appraisal forms based upon the APHA guidelines, as well as introducing a variegated terminology. St. Louis, for example, in its 1953 study defines areas of housing as reconstruction, rehabilitation, and acceptable (or slum, blighted, and good housing) but the criteria used to so designate these housing areas were markedly different from those established by the APHA.[13] Terms frequently encountered in other studies but seldom defined include "decent living," "liveability," and "desirability." Added to the growing list of terms and phrases are the less nebulous criteria relating to health (garbage, smoke, light and air, dampness, glare, noise), safety (traffic, fire, dual egress), and amenity considerations (neatness; i.e., no litter, recreation facilities, some

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[11] Twichell, "Measuring the Quality of Housing in Planning for Urban Redevelopment," in Coleman Woodbury (ed.) Urban Redevelopment, Problems and Practices, p. 92.

[12] Correspondence with Mr. Charles L. Senn, Chairman, Program Area Committee on Housing and Health, Los Angeles, Calif.

[13] City of St. Louis, Joint report by City Plan Commission, Division of Building and Inspection, Division of Health, St. Louis Survey Report (St. Louis, Mo.: Aug. 1953), pp. 1 and 7.

aesthetic satisfaction in housing and yard, i.e., trees, shrubs, lawn arrangement, parking facilities, accessibility within and between areas, space per person, and stability of neighborhood).

Census data at the present time are tabulated at the block level for housing quality. The present investigation does not have the capability to generate useful and reliable data at the cluster and/or the neighborhood level. Evaluation of the areas contained in the imagery could involve few or many structures, but need not be confined to using discrete blocks to form statements about housing quality in areas of varying shapes and dimensions.[14] That is, the user may treat blocks and parts of blocks in a number of ways to generate the required data, but he is not confined to a predetermined format. This is one means of surmounting the inflexibility charge levied against Census data by a number of users. The benefits of such an approach are obvious, but accounting problems preclude its full application in this paper. However, the cluster approach will in fact be illustrated if a set of prints in the Case Studies in Appendix C contain an area which is not variegated.

An appreciation of the utility promised by the successful development of a system for determining housing quality from multiband aerial photographs is basic to the study. Features such as flexibility of scheduling flights, rapidity of coverage, plus the fact that the data contained in the photographs are close to real-time represent several of the advantages inherent in the use of remote sensors. Advances in technology such as better cameras, programmed photo scanners, and efficient and high-capacity data storage and retrieval systems combined with aerial photographs and signatures of accepted identificatory character suggest an

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[14] The nature of the data set (organized by geographic area or organized by subject matter) is clearly and concisely discussed by Evelyn S. Mann, "Experience in the Development of a Program of Analysis Utilizing 1960 Census Magnetic Tapes" in U.S., Bureau of the Census, Department of Commerce, Papers Presented at the Census Tract Conference December 28, 1961, Working Paper No. 12 (Washington: 1962), pp. 23-26.

almost unlimited source of information about the world in which we live.

Much of the information obtained must be in the form of surrogates or proxies, such as those used in the present study to form inferential statements pertaining to housing quality. The images on photographs are assumed to be "true" images; that is, what we see on the photographs is assumed to exist in the real world. From these "true" images streets, houses, rivers, cars, etc., can be identified. This study goes one step further by assuming that the features imaged may be interpreted to represent housing quality. The study then attempts to develop an objectivity scale or appraisal form for measuring the realtive importance of those surrogates as indicators of housing quality.

Chapter II

BACKGROUND

It is apparent from the discussion in the preceding chapter that a large number of agencies and individuals have attempted to utilize existing data on housing quality for a variety of purposes. During the course of the present investigation, a number of city officials who were or are active in housing quality surveys were queried to determine if aerial photography had played a part in any of the surveys.[15] It was learned that aerial photography had not been utilized by any of the contacted officials (or their departments) in a housing quality survey. Some officials noted cost as a deterrent when their studies were undertaken, but the majority stated that aerial photography simply was not considered and that the housing quality studies were carried out under the guidelines established by the APHA appraisal form. This means that no direct precedent has been established concerning the APHA appraisal form and aerial photographs, upon which the present study could build.

A literature search was instituted to investigate the extent to which conventional aerial photography has been utilized in the study of urban areas in general and residential areas in particular. In developing this review of the state of the art, close attention was given to determining how previous studies had analyzed and interpreted imagery, and the meaning of the keys that were developed.[16]

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[15] City officials contacted were from Evanston and Chicago (Illinois), Battle Creek (Michigan), Brookline (Massachusetts), Philadelphia (Pennsylvania), St. Louis (Missouri), and Los Angeles (California).

[16] The application of electronic instrumentation to the collecting, processing, and storing of data generated from the imagery is important in terms of the future (Chapter IV), but it is not fundamental to the basic propositions of this paper. A number of articles which discuss the procedures of electronic data collection, processing, and storage are contained in the bibliography as suggested readings for extension of a number of ideas included in this paper.

Utilization of Conventional Aerial Photography in Urban Areas

A review of aerial photography as a tool for urban planners is provided by M. C. Branch for the period from 1920 to 1948.[17] Part 1, "The Use of Aerial Photographs for Urban Planning and Research," is particularly relevant. Branch considered the urban area in terms of land, water, structures, movement and people. With respect to land, information concerning hills, valleys, slopes and surface irregularities is noted as extractable. Such information is valuable for evaluation of the range of suitable uses for a specific site. For example, roads, airports, industries, railroads, as well as higher-income residential districts are a few familiar examples of installations whose location is frequently limited to sites meeting specific physical requirements. In addition, other land uses such as parks and playgrounds, open or vacant land, paths, cemeteries, parking lots and coal yards have been identified in the imagery by Branch and others.[18]

Information about water in the urban area has covered such features as marshy land, irrigation ditches, shore lines, muddy water, river rapids and falls, waste outflow, and beaches. The following quote is an indication of the widespread, practical usage of aerial photography over four decades ago: "No factory or plant using the waterway for illegal purposes can avoid the eye of the aerial camera. It has demonstrated its efficiency in scores of cases and has been accepted by the courts as material and relevant evidence."[19]

Branch notes that because structures are man-made and a most familiar aspect of the urban scene, the more common forms are immediately identifiable; comprehensive and detailed classification is possible in many instances with careful study. In

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[17] M. C. Branch, Aerial Photography in Urban Planning and Research, Harvard City Planning Studies No. 14, Cambridge, Mass.: Harvard University Press, 1948.

[18] Ibid., p. 12.

[19] Ibid., p. 13.

addition to buildings, streets, sidewalks, highways, railroads, docks, piers, stadia, water and fuel tanks lend themselves to precise photo identification and classification. Examples of the practical use of aerial photographs include the following excerps:[20] (1) "Air photographs supply more than nine-tenths of the information needed to make the existing-use [land use] map," (2) "...rehousing development around Manchester...was planned and revised from the air."

The level of application of aerial photographs to traffic studies (movement) is illustrated by the following quotation, dated 1928: "...when the Commissioner of Police re-organized the control and parking of traffic for the Epsom Summer and Spring Meetings, including Derby Day, a firm...was officially appointed to secure aerial photography of congestion at certain points en route, and these records proved of immense value in devising new schemes and rules for diverting the traffic of succeeding years. A complete survey was also made of the parking of transport on the race-course."[21]

It is in terms of his discussion of people that Branch comes closest to the present area of concern. He notes that less direct data are derived concerning people, than any other of the categories discussed. On the other hand, it is also apparent that certain information of a general nature is reflected in various characteristics of the physical city. The proportions of different residential types disclose one aspect of the mode of life of the inhabitants, and the density, arrangement, and spacing of houses--as well as their situation and character--are ecologically meaningful. Broad conclusions can be drawn in this area, their scope and validity depending on the extent of urban knowledge.[22]

The remainder of Branch's article deals with the special knowledge pre-

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[20] Ibid., p. 15. The two statements were made in 1944 and 1935, respectively.

[21] Ibid., p. 16.

[22] Ibid., p. 17.

requisite to the effective use of aerial photographs for urban planning and research. Such knowledge concerns types of photographs (vertical, oblique, stereopairs), photoruns and planning, photo mosaics, flight planning, photographic quality, cameras and film, night photographs (flash-bomb or photo-flare method), and photographic interpretation.

Photo interpretation as summarized by Branch essentially consisted of identification and classification of urban features under the general headings of land, water, structures, movement, people. Witenstein advanced the basic concepts set forth by Branch by carrying the operations of identification and classification into the study of land-use as applied to the sequence of urban inventory, analysis, and plan.[23] (Inventory, analysis and plan were inherent in different reports reviewed by Branch, but they were not tied together). Inventory included (1) location and classification of all features, as distribution patterns, (2) measurement of size and capacity, to develop basic statistical assemblies, (i.e., data sets for selected features) and (3) computation of ratios of land used and land zoned, service availability and facility accessibility to residential commercial and industrial needs. Analysis was defined to mean the combination of inventoried data with planning multiplier factors. Planning culminates the operations of inventory and analysis, and in the study area reported on by Witenstein resulted in several major changes in the pattern of land utilization in the urban area.

In 1960 the American Society of Photogrammetry published its Manual of Photographic Interpretation.[24] A geographer, J. Wray, directed the preparation of Chapter XII, "Photo Interpretation in Urban Area Analysis." After discussing basic

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[23] M. M. Witenstein, "A Report on Application of Aerial Photography to Urban Land-Use Inventory, Analysis and Planning," Photogrammetric Engineering, XXIV, 1954, pp. 656-663.

[24] Manual of Photographic Interpretation, American Society of Photogrammetry, Menasha, Wisconsin. The George Banta Co., Inc., 1960.

considerations (properties of area, photograph and map), the urban area, and urban area analysis and photo interpretation (these sections are essentially refinements and extensions of the basic concepts initially expressed by Branch), a number of case studies are presented. One of these, "Photo Interpretation of Social Structure in Birmingham, Alabama" by Norman E. Green is an attempt to analyze the social [socioeconomic][25] structure of an urban area by setting up surrogates such as (1) location, (2) residential desirability, (3) prevalence of single-family homes, and (4) density of homes for social [socioeconomic] facts.

The case study presented by Green developed from an earlier study where he attempted to develop a scale of "residential desirability" based upon returns from analyzing an interpreting imagery of an urban area (Birmingham, Alabama).[26] In the original study, identification of the numbers and type of residential structures represented the main objectives. It was then a simple exercise to locate the area under study and compute the numbers of single-family homes, and the density of homes for the area. The next step was to develop a measure of residential desirability based on the three items. For example, a single-family home located in a low-density suburb was held to be highly desirable. Conversely, an area containing multiple-family homes in a high-density area located close to the central business district was expected to have little residential desirability.

It has already been pointed out that aerial photography frequently serves as a useful and valuable tool for planners, local governments and others who are concerned with spatially oriented socioeconomic statistics. However, if research utilizing aerial photographs is to advance beyond the identification-classification stage to some more advanced level of inventory, analysis, and plan and to have more

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[25]Social facts as used by Green are also referred to as socioeconomic statistics by others.

[26]N. E. Green, Aerial Photography in the Analysis of Urban Structures, Ecological and Social. Unpublished Ph.D. (Chapel Hill: University of North Carolina, 1955).

than an ad hoc significance, a certain level of generality must be a major goal of such research. Green's attempt at generality is supposedly supported by means of such statistical techniques as correlation analysis (Spearman Rank correlation coefficient) and scalogram analysis. The present study will take exception to Green's results and will demonstrate that his too-simplistic approach does not accurately portray the social structure of urban areas.

Green established three trichotomous attribute items, zonal location (inner, middle, outer), prevalence of single-family homes (less than 30 per cent, 30-60 per cent, more than 60 per cent), dwelling-unit density per block (more than 30, 19-30, less than or equal to 18) in his study. Land use, a dichotomous attribute item (unfavorable, favorable) completed the attribute items that Green used in attempting to develop generalizations about residential desirability. The nature of the exceptions to Green's work is as follows.

(1) Zonal location. (a) There are many anomalies in the zones (concentric or elliptic) which emanate from the central business district which render this generalization untenable. For instance, within each zone there are activities which reproduce the central city on a smaller scale and create more zones about them. If zoning laws are imperfect or incomplete, or if they are not strictly enforced, the same factors which cause Green to give the inside zone a lower rating may again appear in outer zones.

(b) Many cities are rebuilding the downtown section (central city) or inner zone, and as a consequence high-rise apartment buildings which are highly desirable (if rents are any indication) are being constructed.

(c) The Advisory Commission on Intergovernmental Relations in its paper, Metropolitan Social and Economic Disparities, notes on page 19 that "unsound housing...is much more conspicuous in the suburbs than in the central cities, especially outside the Northeast." If unsound housing and residential desirability

are related, then the zonal location item is very suspect.

(2) Prevalence of single-family homes. In many large cities currently undergoing urban renewal (either by public or private enterprise) high-rise apartment buildings and condominiums can be found in large numbers. These structures are direct confrontations to Green's generalization. If demand is such that these buildings are constructed, then the number of single-family homes may not be an accurate measure of residential desirability.

(3) Dwelling unit density per block. This item is suspect in that there are no definitive statements such as persons per structure. In the fashionable Chicago suburb of Oak Park, 12 blocks were selected at random from the available imagery, and all 12 exceeded Green's cut-off point of 30 structures per block.

(4) General land use characteristics. Green's scale of residential desirability scores heavily against any land use intermixture. A railroad line cutting through a block, an air or water polluting industrial plant, and a high-volume, high-speed street, are generally accepted as non-compatible with residential land use. However, to claim that commercial activity and residences are strictly incompatible is not always correct. There are too many cases where high-rent apartment buildings are located adjacent to commercial buildings (or vice versa) simply because residents, such as elderly persons, desire accessibility to such shops. With increasing frequency, commercial activity is found to occupy the ground floor of primarily high-density residential structures, a further counterexample to the land use generalization.

It is felt that there are too many exceptions to each of Green's four items, and that the items are too broad. As a consequence, results (levels of desirability) generated by Green are felt to be unreliable.[27] Operations at the block level,

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[27]For further discussion of N.E. Green's work the interested reader is referred to; M.M. Witenstein "A Review of--'Aerial Photographic Interpretation and the Social Structure of the City' by N.E. Green," Photogrammetric Engineering, XXII, 1956, p. 97.

although they may be advantageous in terms of how data are presently collected by many agencies, may be one source of difficulty in Green's approach. This paper suggests that such data must first be treated at more disaggregated levels. That is, the basis should be the cluster level, and aggregation should begin from the cluster. Clusters as used here refer to groupings of buildings, for example, which are similar in some way. Size (single or multiple unit dwelling), style (colonial or ranch), density (30 or 60 structures per given area), and quality (sound or unsound) are characteristics pertaining to structures which could be grouped into a cluster based on a similar feature. Aggregation of these structures into one group would result in a bounded area (cluster) containing structures which are similar in terms of size, style, density and quality.

The use of aerial photography by the Chicago Area Transportation Study (CATS) is the final example presented here. Under the direction of Samuel M. Hadfield, CATS produced a study report entitled, An Evaluation of Land Use and Dwelling Unit Data Derived from Aerial Photography.[28] The objective of this pilot study was to develop and test a synthetic approach toward obtaining origin-destination (O-D) data which had previously been obtained from expensive and time-consuming house interview surveys. The specific data obtained from aerial photography in this case were the number of dwelling units, and land area and nonresidential building floor area classified by land use type for each small study area.[29]

The CATS report notes that the use of aerial photography depends on the type

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[28] S.M. Hadfield, An Evaluation of Land Use and Dwelling Unit Data Derived from Aerial Photography, Chicago Area Transportation Study, Chicago, Illinois. 1963.

[29] Both Hadfield and Green attempted to develop a correction factor for errors made in dwelling unit estimation. Correction factors are extensively treated in: R.E. Binsell, Dwelling Unit Estimation from Aerial Photographs, unpublished B.A. Thesis, Department of Geography, University of Toronto, 1967.

Hadfield's study is also reviewed in D.F. Marble and E.N. Thomas, "Some Observations on the Utility of Multispectral Photography for Urban Research," Proceedings, Fourth Symposium on Remote Sensing of Environment.

of area on which data are to be collected, type of data needed, accuracy needs, availability of other source materials, etc. For the CATS study, aerial photography was best suited for areas of relatively low density--for suburban areas, small cities, or rural areas. One reason for this, Hadfield notes, is that no other source is usually available for either floor area or land area data in these areas except sometimes in central business districts.[30]

Analysis and Interpretation of Imagery

The Manual of Photographic Interpretation devotes a full chapter to fundamentals of photo interpretation. Rather than attempt to reproduce that thorough and expert treatment, we will merely define analysis and interpretation in the way that they are used in this report. R.E. Frost discusses analysis and interpretation, and his approach is closely aligned with that taken in the present study.[31]

Analysis of photographs results in the presentation of data. It involves recognition of patterns such as a transportation network or the morphology of a city in terms of buildings of certain types, and then studying the components (freeways, arterial streets, side streets, alleys) from the standpoint of what each represents, and from the standpoint of the relationship of the components to each other. In other words, analysis involves pattern recognition and data presentation.

Image interpretation is a synthesis, based on the application of processes of logic and deductive reasoning in performing an analysis of the features of an area (in the present investigation, a cultural or urban area as opposed to portions of the natural environment) which collectively are responsible for the creation of a pattern, or patterns. The data gained after analysis are arranged in such a manner

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[30] S.M. Hadfield, p. 22.

[31] R.E. Frost, "Discussion of Photo Recognition, Analysis, and Interpretation and Photo Keys," Photogrammetric Engineering, XVIII, 1952, pp. 502-505.

as to convey the desired results, i.e., some statement as to what is contained in the area is made with regard to the objectives of the study.

Keys

The purpose of a key is to facilitate analysis and interpretation by pointing out objects or features of a pattern, and thereby assist in data generation. Basically, keys may be of two kinds: (1) positive, and (2) inferential.

Positive keys promote direct identification of objects by pointing out easily recognized objects on the basis of identificatory characteristics. For example, industrial buildings, golf courses, switching yards and airport runways are usually readily identifiable.

Inferential keys require the use of logic and deductive reasoning in an attempt to identify an object which is foreign or infrequently encountered by the interpreter. As used in this paper, however, inference takes on a slightly different meaning. Inferencial procedures will be used to generate statements relating to overall housing quality when, in fact, only the exterior elements of a dwelling are observed. That is, statements will be made about the probable interior conditions of structures based upon surrogate observations dealing only with the exterior of the structure and its environment.

An integral part of analysis, interpretation and key development, is the process whereby objects are identified. Process involves interaction between entities, and the transmission of information. In most real events not all of the information content of an entity enters the transmission process, i.e., only a fraction of the features of an entity are transmitted in a given interaction. For example, one may quickly recognize a celebrity from a sketch. This is known as a signature. The identificatory character of the signatures of some of the features considered in this

study are found in Appendix D.[32]

From Conventional Aerial Photography to Multiband Aerial Photography

All the investigations outlined here have been concerned with conventional aerial photographs, usually black and white, but occasionally color (See Manual of Photographic Interpretation). The present study was established to investigate the possibilities made available by utilizing multiband aerial photographs. All bands in the visible part of the electromagnetic spectrum have conventionally been "lumped together," resulting in an image which does not distinguish the contribution made to the overall image by each band of the e-m (electromagnetic) spectrum. This paper utilizes imagery which does discriminate, i.e., filters are used to obtain separate returns for each of six bands in the visible part of the e-m spectrum, and separate returns for each of three bands in the photographic infrared portion of the e-m spectrum. Appendix B, "The Electromagnetic Spectrum and Multiband (Multispectral) Aerial Photography" considers this topic in somewhat greater detail.

In terms of perspective, this paper represents one part of a program being carried out in the Department of Geography, Northwestern University to investigate the application and use of remote sensors for obtaining information on urban and transportation phenomena. The program is being conducted in cooperation with the Earth Resources Program of the National Aeronautics and Space Administration and the United States Geological Survey.

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[32]For a more lengthy discussion of the concept of signature see: H.H. Quastler, The Emergence of Biological Organization (New Haven: Yale University Press, 1964).

Chapter III

DEVELOPMENT OF HOUSING QUALITY APPRAISAL FORMS BASED ON DATA GENERATED FROM MULTIBAND AERIAL PHOTOGRAPHS

In order to provide greater scope and application in the present study, the housing and environmental characteristics utilized by the American Public Health Association (APHA) are detailed and compared with the information that can be extracted and identified from the multiband photographs. That is, standards set by the APHA are used as a precedent, and the information extracted from the aerial photographs is directly compared to what is included in the APHA appraisal form. A revised appraisal form is then presented which is based completely upon data generated from the imagery.

The detailed results of the photo-analysis and photo-interpretation are contained in a series of case studies of portions of the Chicago area [Earth Resources Program test site #43] (Appendix C). For the most part, data derived from the imagery were sufficiently well-interpreted so as to provide a strong correlation with ground truth records. At the grossest level, streets, buildings, vacant lots, trucks and cars can be readily identified from the imagery utilized in this study. In more complex cases, data extraction becomes somewhat more difficult, e.g., to determine the number of units in a large multiple-unit structure,[33] or to determine if a building is used for commercial purposes on the first or second floor. It is also difficult to determine the quality of a structure if the structure is entirely abstracted from its surrounding environment. This

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[33] R.E. Binsell, Op. Cit., Dwelling Unit Estimation From Aerial Photographs. See also: N.E. Green, Op. Cit., Aerial Photography in the Analysis of Urban Structures, Ecological and Social, p. 57.

observation may be modified in cases of extreme elegance or dilapidation, but since most structures fall somewhere between these two extremes, this is an important consideration when utilizing aerial photographs as a source of housing quality information. The exploratory case studies presented here were intended to serve as a trial run. The analysis and interpretation of the imagery were designed to extract and identify whatever features pertained to housing quality at the given scale and given quality of imagery.

The American Public Health Association Appraisal Forms

The APHA appraisal form consists of two parts: a structure rating and an environment rating. The two rating scales measure deficiencies with penalty points assigned according to each deficiency. Each dwelling unit carries the environment score of the block and street frontage in which it lies, and the environment score when added to the dwelling score gives the housing total score. Tables 1 and 3 outline the items included in the APHA forms. Table 2 provides a brief explanation of those items which require further definition.

Features Generated by Analysis and Interpretation of the Imagery

Analysis and interpretation of the multiband photographs has established that a wide variety of features can be extracted and identified, some of which are not contained in the APHA form. These features and a brief account as to why each is offered as a housing quality "indicator" follows. An important point to be made here (and expanded in detail later) is that the power of the indicator is on a relative and not an absolute basis.

(1) Building frontages (distance or offset from the sidewalk)

In the case study areas, and in other study areas not specifically covered in this report, housing classified as poor or substandard by APHA-criteria

TABLE 1

DWELLING SURVEY: APPRAISAL ITEMS AND MAXIMUM STANDARD PENALTY SCORES

Item	Maximum Penalty Score
A. FACILITIES	
1. Structure: Main Acess	6
2. Water Supply (Source for Structure)	25
3. Sewer Connection	25
4. Daylight Obstruction	20
5. Stairs and Fire Escapes	30
6. Public Hall Lighting	18
7. Unit: Location in Structure	8
8. Kitchen Facilities	24
9. Toilet[1]	45
10. Bath	20
11. Water Supply (Location & Type for Unit)	15
12. Washing Facilities	8
13. Dual Egress	30
14. Electric Lighting	15
15. Central Heating	3
16. Rooms Lacking Installed Heater	20
17. Rooms Lacking Window	30
18. Rooms Lacking Closet	8
19. Rooms of Substandard Area	10
20. Combined Room Facilities[2]	--
a. Subtotal: Facilities	360
B. MAINTENANCE	
21. Toilet Condition Index	12
22. Deterioration Index[3]	50
23. Infestation Index[3]	15
24. Sanitary Index[3]	30
25. Basement Condition Index	13
b. Subtotal: Maintenance	120
C. OCCUPANCY	
26. Room Crowding: Persons per room	30
27. Room Crowding: Persons per sleeping Room	25
28. Area Crowding: Sleeping Area per Person	30
29. Area Crowding: Nonsleeping Area per Person	25
30. Doubling of Basic Families	10
c. Subtotal: Occupancy	120
MAXIMUM DWELLING TOTAL	600

Source: City of St. Louis, Housing Survey Report, 1953.

[1]Item score is total of subscores for location, type and sharing of toilet or bath facilities.

[2]Item score is total of scores for items 16-19 inclusive. This duplicate score is not included in the total for a dwelling but is recorded for analysis.

[3]Item score is total of subscores for structure and dwelling unit.

TABLE 2

BASIC DEFICIENCIES OF DWELLINGS

Item No.	Condition Constituting A Basic Deficiency
	FACILITIES
2	Source of water supply specifically disapproved by local health department.
3	Means of sewage disposal specifically disapproved by local health department.
9	Toilet shared with other dwelling unit, outside structure, or of disapproved type (flush hopper or nonstandard privy).
10	Installed bath lacking, shared with other dwelling unit, or outside structure.
11	Water supply outside dwelling unit.
13	Dual egress from unit lacking.
14	No electric lighting installed in unit.
16	Three-fourths or more of rooms in unit lacking installed heater.[1]
	MAINTENANCE
22	Deterioration of class 2 or 3 (penalty score, by composite index, of 15 points or over).
	OCCUPANCY
26	Room crowding: Over 1.5 persons per room.
27	Room crowding: Number of occupants equals or exceeds two times the number of sleeping rooms plus 2.
28	Area crowding: Less than 40 square feet of sleeping area per person.

Source: City of St. Louis, Housing Survey Report, 1953.

[1]The criterion of basic deficiency for this item is adjusted for number of rooms in the unit.

TABLE 3

ENVIRONMENTAL SURVEY:
APPRAISAL ITEMS AND MAXIMUM STANDARD PENALTY SCORES

Item	Maximum Penalty Score
A. LAND CROWDING	
1. Coverage by structures	30
2. Residential building density	
3. Population density	
4. Residential yard areas	20
	50
B. NONRESIDENTIAL LAND USES	
5. Areal incidence of nonresidential land uses.	
*6. Linear incidence of nonresidential land uses	20
*7. Specific nonresidential hazards and nuisances.	30
*8. Hazards to morals and public peace	
9. Smoke incidence.	
	50
C. HAZARDS AND NUISANCES FROM TRANSPORTATION SYSTEM	
*10. Street traffic	15
*11. Railroads and switchyards.	25
12. Airports	
	40
D. HAZARDS AND NUISANCES FROM NATURAL CAUSES	
13. Surface flooding	
14. Swamps or marshes.	
15. Topography	
E. INADEQUATE UTILITIES AND SANITATION	
*16. Sanitary sewerage system	20
*17. Public water supply.	20
*18. Streets and walks.	
	40
F. INADEQUATE BASIC COMMUNITY FACILITIES	
*19. Elementary public schools.	18
20. Public playgrounds	
21. Public playfields.	
22. Other public parks	12
23. Public transportation.	
24. Food stores.	
	30
	210

*Item scored separately for each block frontage.

Source: Table 3 combined St. Louis Housing Survey Report (items with penalty score) and Twichell's paper, "Measuring the Quality of Housing in Planning for Urban Redevelopment" (items without penalty score). This is necessary because the St. Louis study does not refer to all the

regularly was between 6 and 10 feet from the sidewalk. Housing of significantly improved quality averaged between 12 and 18 feet for some cases, and between 25 and 30 in others. The setback of poor quality housing usually did not vary more than several feet for all the street segments imaged, whereas along streets in better quality housing areas, setbacks varied by about 10 feet on either side of the average.

(2) Non-structure-supporting land

Land may be non-structure-supporting for a number of reasons, including its use for parking, recreation, etc. It may also mean that poor layout or inaccurate surveying in urban areas has resulted in angular or irregular plots that cannot be built upon. Such land may have at one time supported a structure which has been torn down and not replaced. It may also mean that at the present time, no one desires to build on the land, because of poor location, undesirable neighborhood characteristics, or objectionable adjacent land use. Research has shown that, in high or good quality residential areas based on APHA criteria, the amount of non-structure-supporting land is at a minimum. The converse appears to be true in poor quality areas. In the latter case, this may be an indication of stagnation at less than full land utilization, or of incipient withdrawal from a declining area.

APHA items while, on the other hand, Twichell's paper does not contain deficiency scores for the APHA form. Thus, although the forms supplied by the City of St. Louis contain weighted deficiency scores, there is no way of knowing either (1) how the weighting scale was originally derived, or (2) how to allocate deficiency scores for each factor. The APHA publication, An Appraisal Method for Measuring the Quality of Housing: Part I, Nature and Uses of the Method, was published in 1945, in New York. This publication had not been obtained by the time of final writing. Consequently it has been necessary to rely upon organizations and individuals who have worked with the APHA appraisal form. Attempts are still being made to locate this publication in the event that the present research is extended.

(3) Unpaved versus paved parking lots

In the poor quality areas studied, the majority of parking lots were covered with cinders or dirt. Conversely, in better housing quality areas, all parking lots were paved. This latter feature may be the result of certain commercial establishments (e.g., apartment houses) trying to maintain or improve their image, but it is confined almost completely to the better quality housing areas.

(4) Amount of on-street parking

In better quality housing areas, garages are invariably found on each lot. Since density per household is relatively low and incomes are relatively high, these structures normally accomodate two vehicles. In the poor quality housing areas studied, multiple-unit residential structures (often conversions) prevail, and these are usually accompanied only by a single-car garage. If six families live in such a structure, and all six have cars, or even if two families have cars, then at least one and possibly five cars must seek parking on the public streets. More fashionable multiple-unit structures provide parking for all tenants, so that this feature is almost invariably associated with multiple-unit structures providing poor or sub-standard housing.

(5) Proportions of multiple-unit and single-unit dwellings in an area

In criticism of Green's second item, it was noted that some urban dwellers prefer to reside in apartment buildings instead of in single-family or even duplex structures. The point made here is that the existence of multiple-unit dwellings may create pressure on open space; for example, 30 people may potentially have to share a 300 square foot back yard or a small neighborhood park. Also, it would appear easier to add additional persons to multiple-unit dwellings than to single-family dwellings. This is frequently done in poor quality housing areas by converting a three- or four-room apartment into two or three or even four living units housing many more persons than the number for which the unit was originally

intended.[34] Attachments consisting of wood and tin, with several of these exhibiting stove pipes, were very common in the poor quality areas, but were almost nonexistent in the better quality areas.

(6) Architectural style

If variety in style may be taken as an indication that a subdivision was not built as cheaply as possible, this may provide another general indicator of housing quality. In the areas imaged, higher quality housing tended to be associated with the existence of a variety of housing styles such as ranch, colonial, and split-level. On the other hand, in the poor quality housing areas studied, only a limited amount of style variation was observed. The point made here is somewhat marginal since operations of the building industry have not been studied in detail, but as a first approximation based upon items readily perceived in the imagery, it has been useful.

(7) Landscaping

In the better areas, landscaping appears in the form of shrubs, elevated lawns, rock gardens, flower beds, etc., and is quite widespread. The opposite tends to hold true in the poor quality housing areas. Occasionally a single-family structure in an area of predominantly poorer multiple-unit structures will also exhibit landscaping.

(8) Condition of lawn

The imagery obtained in the photographic infra-red clearly differentiates between grass and dirt. Grass lawns prevail in the better quality housing areas without exception. In the poor quality housing areas, if the "lawns" are not

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[34] See pages 148-149, Part II Section II, "Urban Growth and Deterioration" in Housing and Citizenship: A Study in Low-Cost Housing by George H. Grey, Reinhold Publishing Co., New York. 1946.

dirt, the quality of grass is poorer, i.e., not as healthy, and is frequently patchy.

(9) Presence of litter

This feature will be discussed at much greater length in the following pages, and is set forth here as one of the outstanding indicators of poor quality housing. In the poor quality housing areas studied, litter, garbage, and junk are wide-spread. In the better quality housing areas, their occurrence is a rarity.

(10) Lack of curbing along parkways

The cement curbing along parkways appears as a solid line in imagery of the better quality housing areas. In the poor quality housing areas, curbing has either been broken or worn away, or has not kept pace with building. Frequently, the photographs in the infra-red will reveal sections of parkways which have been run over by car tires, and the grass worn away.

Appraisal Forms Based on Data Generated from Multiband Aerial Photographs

The following tables represent tentative appraisal forms which have been developed in an attempt to make maximum use of the multiband aerial photographs in the generation of housing quality data. The general format follows the APHA forms for the present, that is, features will be dichotomized as to either structure or environmental indicators.

The penalty scores shown are derived in part from the APHA appraisal form. The remainder were established on the basis of data generated during the present study. At the time this report was prepared, the APHA had furnished only a brief outline pertaining to the computations which led to the exact derivation of their penalty scores. The APHA scores are particularly useful when two items are regarded as similar by the APHA and this study and can be compared with the knowledge that a highly respected organization established the scoring precedent. These scores

TABLE 4

STRUCTURE SURVEY: APPRAISAL ITEMS EXTRACTABLE FROM MULTIBAND AERIAL PHOTOGRAPHY

Item	Maximum Penalty Score
A. FACILITIES	
1 Structure: Main Access. Access to residences may be from a commercial strip, from a high-volume, high-speed street, from a quiet residential street. Access in these cases are not equal in terms of safety, convenience, comfort.	20
2 Daylight Obstruction. This item measures obstruction by adjacent buildings of the normal amount of sunlight which would enter the dwelling.	45
3 Dual Egress. This item measures a very important safety factor (fire) and also a convenience factor, i.e., all persons would have to go in and out one door, and this could involve considerable movement around the structure. This item more likely occurs in the singular, but is included because it could be very serious in case of fire.	100
4 Building Architecture. This item measures structure style, i.e., unimaginative, assembly-line type apartment buildings or smaller structures versus distinct styles such as high-rise apartment buildings like honey-combed Marina Towers in Chicago, or smaller structures in ranch, colonial or split-level styles.	35
MAXIMUM DWELLING TOTAL	180

TABLE 5

ENVIRONMENT SURVEY: APPRAISAL ITEMS EXTRACTABLE FROM MULTIBAND AERIAL PHOTOGRAPHS

Item		Maximum Penalty Score
A.	LAND CROWDING	
1	Coverage by Structures. The areal incidence of structures on lots is measured and summed over a cluster or the neighborhood. A high rating of necessity implies less free space per area considered.	30
2	Residential Building Density. The number of residential buildings per area is recorded; eg., 80 per block, and penalized according to criteria established by the investigator.	10
3	Residential Yard Areas. The amount of free space per lot is summed over the cluster; this is a combination of 1 and 2, coverage and residential building density.	20
4	Building Frontages. The distance from the building front to the sidewalk is calculated. This is a measure of monotonicity.	10
5	Multiple-Unit Versus Single-Unit Residential Structures. This is a measure of population density and free space available per person per area.	30
		100
B.	NONRESIDENTIAL LAND USES	
1	Areal Incidence of Nonresidential Land Uses. The proportion of the areal extent of the area occupied by other than residential structures (eg., commercial or industrial activity) is calculated.	15
2	Linear Incidence of Nonresidential Land Uses. The proportion of use other than residential located along streets, river banks, railroad tracks, etc., forming frontage is calculated.	20
3	Specific Nonresidential Hazards and Nuisances. Examples of these are wrecked cars, large piles of litter and garbage strewn behind garages, industrial plants, and warehouses.	40

TABLE 5--Continued

Item		Maximum Penalty Score
4	Smoke Incidence. In particular the search is for smoke emanating from industrial plants and garage lots.	10
5	Non-Structure-Supporting Land. This includes vacant lots which are not utilized for an organized purpose, and are frequently found to be strewn with wrecked cars, garbage, litter, cinder from furnaces. This land may be an indication of stagnation or withdrawal in an area.	40
6	Non-Structure-Supporting Organized Land. In particular, unpaved versus paved parking lots is measured.	10
7	On-Street Parking. The number of vehicles utilizing on-street parking facilities may be an indication of population per area, or population per structure (if large). This item may be an indicator of low-value housing; i.e., off-street parking privileges may be a function of rent per area or structure (if large).	15
		150
C.	PRIVATE ORGANIZED FREE SPACE	
1	Landscaping. This item is a measure of shrubbery (hedges), grass, patios, trees, walks or fences found in the lots, clusters, or neighborhoods.	45
2	Condition of Green Spaces. This item measures grassed areas versus bare earth areas, new or old grass, dying or healthy grass, paths worn through grass.	15
3	Litter or Garbage Factor. This is a measure of neatness or cleanliness of areas in terms of old foundations, litter, garbage, wrecked cars, lumber piles found strewn over or occupying free space.	75
		135
D.	HAZARDS AND NUISANCES FROM TRANSPORTATION SYSTEM	
1	Street Traffic. Traffic moving through residential area is determined. This measure may be in terms of type (car versus truck), volume (high versus low), speed (fast versus slow), distribution (lumped or spread out), direction (one-way versus two-way). Danger to children crossing streets or playing in the streets, and nuisances such as glare, noise, and fumes are considered.	20

TABLE 5--Continued

Item		Maximum Penalty Score
2	Railroads (Freight and Passenger) and Switchyards. This item measures danger to persons and vehicles crossing the railroads, and nuisances such as noise and vibration.	15
3	Alleyways. This item measures the condition of the alley with particular reference to cleanliness. Garbage, bits of furniture, litter, etc., constitute a health hazard by providing forage food and sometimes harborage for rats. In addition to composition, capacity of the alley to accommodate garbage trucks and cars is considered.	35
		70
E.	PUBLIC UTILITIES	
1	Streets, Walks, Parkways. The provision and condition of streets, walks, parkways, is determined. Lack of curbing along streets or parkways, organized land without provision of these facilities, condition of the facilities, are included. This item also includes condition of grass on parkways; i.e., grass versus bare earth.	20
		20
F.	PRESENCE OF BASIC COMMUNITY FACILITIES	
1	Elementary Public Schools. This item measures the availability of schools. In order to measure adequacy, age data are necessary. The location of the school is considered here (surrounded by high-speed, high-volume streets) as is the architecture, and landscaping.	10
2	Public Playgrounds. The location and availability of asphalt basketball courts, tennis courts, equipment is determined.	15
3	Public Playfield. This item measures availability of fields for football, baseball.	10
4	Other Public Parks. This is a measure of green free space containing trees, grass, pools, etc., and providing walking, resting, and picnic areas.	10
		45
MAXIMUM ENVIRONMENT TOTAL		520

lose meaning on a relative scale only if the item is marginally extractable from the imagery. That is, an item which is difficult to extract and identify from the imagery will not be as valuable to the form developed here as it would be for the APHA form. Items which are equally extractable but which have been deemed unequal in importance as indicators of housing quality are given here unequal penalty scores, and vice versa. An item may be important, but if it is difficult to extract, then its value is diminished.

It is intended that the penalty scores in Table 5 serve only as qualitative indicators of the relative importance of each feature. Nine representative study areas have been reported on in some detail in Appendix C. However, far more than this number have been analyzed from the imagery. The case studies are included as detailed explication of what can be extracted from the imagery. The utility of attaching scores at even an incipient stage lies in the ease with which the relative importance of each factor can be perceived, as of that time. That is, a penalty score of 50 versus a penalty score of 25 indicates that, based on the procedure of this study, one factor is twice as important (or, twice as serious a deficiency) as another, as a housing quality indicator.

The scope of this paper precludes an attempt to produce an analytical solution to the problem of scoring (e.g., what score levels indicate poor quality housing) and although the literature search did not reveal the application of factor analysis,[35] a mathematical technique which appears to have considerable potential in this area, it did reveal the application of a technique known as scale analysis.[36] The latter approach is outlined in Appendix E of this paper, and

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[35]For a detailed description of factor analysis see: H. Harman, Modern Factor Analysis (Chicago: University of Chicago Press), 1960, and
M.G. Kendall, A Course in Multivariate Analysis (London: Charles Griffin), 1957.

[36]Louis Guttman, "A Basis for Scaling Qualitative Data" in American Sociological Review, April 1944, pp. 139-150.
Louis Guttman, Measurement and Prediction (Princeton University Press), 1950.

several comments are made as to how scale analysis has been utilized by N. E. Green.

The scores were assessed, therefore, not only in terms of frequency of appearance of the item, but upon association. For example, this investigator asserts that on the basis of research carried out, that litter, garbage, and junk are among the outstanding indicators of areas of low quality housing. They have not yet been absent from an area which contained even one deficiency item in sections A, B, C, D, E. As shown by the scores, these factors assume greatest value (75) when they can be traced to structure-supporting land and can be attributed to homeowners or landlords. They could directly account for a maximum of 190 penalty points. (Table 5: B3(40) + B5(40) + C3(75) + D3(35) = 190).

The total score for the housing quality appraisal form generated by this study is summarized in Table 6.

TABLE 6

HOUSING QUALITY APPRAISAL

Category	Total Penalty Score
Structure Appraisal	180
Environment Appraisal	520
HOUSING QUALITY TOTAL	700

The preliminary appraisal forms illustrated in Tables 4 and 5 are claimed to be as objective as those set forth by the APHA. Objective criteria are defined as those which are reproducible. The following tables specify those criteria which, in this study, do not appear to lend themselves to objectivity. All others, it is claimed, either are objective or can be made so through further testing and refinement. Collaboration with the APHA would have proven particularly useful in this part of the study.

TABLE 7

NON-OBJECTIVE CRITERIA IN TABLE 4

Item	Maximum Penalty Score
A1 Structure: Main Access	20
A4 Building Architecture	35
NON-OBJECTIVITY SCORE	55/180 = 20%

TABLE 8

NON-OBJECTIVE CRITERIA IN TABLE 5

Item	Maximum Penalty Score
C1 Landscaping	45
C2 Condition of Green Spaces	15
D1 Street Traffic	20
E1 Streets, Walks, Boulevards	20
NON-OBJECTIVITY SCORE	100/520 = 19%

The determination of threshold levels for the identification of housing quality based on structure and environment appraisal must await further development. It appears at this time that no absolute measures can be offered. The forms illustrated contain suggested housing quality indicators generated from multiband aerial photographs. There is ample room for experimentation here, and interested researchers are limited only by their own imaginations.

Chapter IV

CONCLUSIONS

The preceding chapter explicitly notes that absolute measures have not been generated for evaluating structures or clusters of structures as a result of analysis and interpretation of the case study areas. This does not mean that any attempted resolution of the problems which have beset the sound-deteriorating-dilapidated housing classification will be ignored. On the basis of the present research several general observations have been developed pertaining to this classification problem, as well as to the potential role of the multiband imagery in approaching the problem of housing quality appraisal.

Classification of Housing Quality -- A Compromise Solution

The following observations are offered as possible solutions to criticisms levelled against housing data generated by the Census, and to a lesser degree, that generated as a result of utilizing the APHA appraisal forms in a housing survey:

(1) Census housing data are far too restricted in that the environmental conditions are totally neglected; the approach introduced by the APHA and repeated in this study leads to more meaningful statements about housing quality and affords much more useful data to the large number of interested users. Data are also recorded in block units by the Census, so that at this level of aggregation, inclusion of environmental data should not prove overly cumbersome.

(2) The basic unit of data collection should not be confined to the block. In many situations users require data which must be worked and re-worked, at either higher or lower levels of aggregation in order to overcome artificial restrictions or limitations imposed by present methods of data handling. A new approach which

would permit data collection, storage and presentation at various levels, (to be specified by data users) yet without loss of data sensitivity, would markedly improve the utility of Census housing data.[37]

(3) Provisions should be inherent in the system to accommodate directly information which pertains to hazards to life or health. For example, the system should be able to incorporate characters (numbers, letters of alphabet, symbols) which could signify structural hazards, industrial hazards, sanitation conditions, etc. (plumbing, heating, rats, etc.) which pose such immediate hazards.

(4) The sound-deteriorating-dilapidated controversy may in part arise from attempts to pin down an elusive concept through the application of an all-inclusive descriptive classification. There are any number of critical defects which may cause specific housing facilities to be classified as dilapidated. Aggregation of these defects into a single category makes it difficult, if not impossible, to carry out adequate field checks of such housing. For example, if a housing unit was classified as dilapidated because of several defects, and if the defects were noted, then, if a city authority field checked such a unit, the authority could readily

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[37]The following reports discuss this observation in greater detail.

Evelyn S. Mann, Op. Cit., "Experience in the Development of a Program of Analysis Utilizing 1960 Magnetic Tapes."

W.L. Garrison, A. Rosenfeld, R.H. Alexander, E.N. Thomas, D.F. Marble, and M. Thompson, Five Papers on Remote Sensing and Urban Information Systems. Technological Report No. 1, Urban and Transportation Information Systems, Department of Geography, Northwestern University, Evanston, Illinois. 1966.

W.L. Garrison, R. Alexander, W. Bailey, M.F. Dacey, and D.F. Marble. Data Systems Requirements for Geographic Research. Technical Report No. 2, Geographic Information Systems, Department of Geography, Northwestern University, Evanston, Illinois. 1965.

Kenneth J. Dueker, Spatial Data Systems. Technical Report Nos. 4, 5, 6. Urban and Transportation Information Systems. Department of Geography, Northwestern University, Evanston, Illinois. 1966.

Barry Wellar, "Towards the Development of a Geographic Information System: A Series of Queries Designed to Explicate the Nature of the Demands Which May be Addressed to a Geographic Information System." Department of Geography, Northwestern University, Evanston, Illinois. 1966 (Mimeographed).

R.D. Campbell and H.L. LeBlanc. An Information System for Urban Planning. Maryland--National Park and Planning Commission, Silver Spring, Md. 1962.

discern if the critical defects still remained or if improvements had been made. A possibility here is to key the critical defects and/or to provide a housing appraisal score for the block, which, though not absolute, is relative.

A "cutting edge" may or may not have been developed by this discussion. The onus remains upon the data users to inform the data collectors with respect to the desired composition of the data set. Similarly, data users may wish to impose their own cut-off points, or they may wish that universal cut-off points be established by the data collection and distribution groups. If dissatisfaction is expressed with cut-off points, the source of this dissatisfaction must be located, and if possible, resolved. This paper suggests that defects detected by one organization must be made apparent to other organizations since arguments can only be resolved if the involved parties are aware of the source of disagreement.

(5) There are limitations to the photographic method, particularly (and obviously!) with respect to being able to obtain information regarding the interior of structure. No data can be generated from present imagery dealing with facilities, or space per person per unit. Further, this approach cannot directly determine such items as inadequate fire resistant separations, stairway enclosures, partitions between units, or boiler room enclosures.

Utility of the Multiband Aerial Photographs

The multiband prints have not yet been thoroughly tested, primarily because of severe limitations imposed by the quality of the imagery on hand. That important contributions can be made by both the visible and photographic infra-red portions of the electromagnetic (e-m) spectrum has been demonstrated. The following observations are made only on the basis of what can be determined from a simple dichotomy of the e-m spectrum into the visible (bands 1, 2, 3, 4, 5, 6) and the photographic infra-red (bands 7, 8, 9), as well as on the basis of current levels of resolution

(20 to 30 lines per millimeter).[38] Imagery in the Case Studies illustrates the reference to resolution. The utility of the multiband photographs will obviously be a function of resolution, but imagery with different resolution levels has not yet been made available to this study. Several of the observations pertain to housing quality surveys and conventional aerial photography, whereas others refer specifically to the multiband aerial photographs:

(1) A great variety of housing information is available in terms of numbers, sizes, exterior condition, style.

(2) Land use can be identified with a high degree of reliability and classified as to commercial, industrial, residential, recreational, organized and unorganized.

(3) Motor vehicle facilities can be described in terms of size (width), direction of flow, amount of flow, parking provisions.

(4) Environmental conditions such as green spaces, trees, grass, shrubbery, are readily extractable from prints in the photographic IR bands, and neatness (evidence or lack of litter) is readily extractable from the prints in the visible bands.

(5) Photography captures an area in time and permanently registers the area imaged. This is most valuable in terms of visually observing change through slices of time.

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[38] Resolution levels are further discussed in:
P.N. Slater, R.H. Noble, B.J. Savidge. "Summary Report on Photography Obtained with ALOTS." (Automatic Lightweight Optical Tracking System) Optical Sciences Laboratory of Steward Observatory, University of Arizona, Tucson, Arizona. March 1967. On page 10 of that report it states that the ALOTS system test set photographic range at 40,000 feet. (The Case Study imagery in this report is from 3000 feet) This applied even for some of the oblique photographs because resolution had been found to be relatively insensitive to increase in photographic range. Such a system partially alleviates concern about resolution from high-altitude cameras, because extraction and identification inputs do not seem to differ from the inputs required in the study of the imagery contained in Appendix C of this paper. Furthermore, the ALOTS system was forced to use less-than-optimum film types, suggesting the possibility of even higher quality returns.

(6) The flexibility of handling data units is an important characteristic of photography. Block data, street data, cluster data, slices of block data, are all possible with photography. The archival nature of the images means that changes in the data set can be made long after the initial analysis and interpretation in a far more flexible manner than is possible with Census- or APHA-collected data.

(7) A "screening survey" (Twichell, p. 48) is an example of one way in which multiband photography appears to be of immediate use. A screening survey may be defined as one that roughly outlines the problem areas (blighted or slum), suggests the nature and magnitude of problems to be anticipated there, and helps in the broad shaping of public policy. However, if necessary, the multiband aerial photographs can provide additional detail and accuracy, the level of which is a function of imagery quality, the number of researchers involved, and the requirements of these researchers.

Chapter V

IMPLICATIONS FOR FUTURE RESEARCH

This study has been concerned with the generation of housing quality data from multiband aerial photographs, and the subsequent classification, evaluation, and presentation of such data. There are a number of interesting urban problems, however, which are beyond the scope of the present investigation, but which appear to be at least partially susceptible to solution if subjected to further study. Several of these problems are outlined below as avenues of research which merit serious consideration in the very near future. In addition, several points are made with respect to problems in the utilization of imagery such as that used in this study.

(1) Large urban centers represent a major socioeconomic problem as evidenced by the large body of literature pointing out the existence of slums and blighted residential districts, etc. It appears, however, to repeat a point made earlier, that substandard housing units are more of a problem in the suburbs than in the central cities for both owner- and renter-occupied housing in all areas in the United States except the Northeast. (The other areas being North Central, South, West),[39] Considerable testing in a variety of urban areas will be required to give the procedure suggested here the viability necessary to make it a useful and reliable generator of housing quality data, and very possibly of other components

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[39]Advisory Commission on Intergovernmental Relations, Metropolitan Social and Economic Disparities: Implications for Intergovernmental Relations in Central Cities and Suburbs, pp. 19, 20, 182-193.

of the urban data set.[40]

(2) One suggested use of multiband aerial photography in urban areas is the development of a number of socioeconomic statistics for persons occupying the small areas (or residences) imaged.[41] That is, to provide estimates of the socioeconomic characteristics of persons occupying particular housing units and locations from photographs. This part of the methodology should await on-the-ground estimates by sociologists,[42] geographers, economists, and public health officials. Since this can apparently be done at ground level, it may well be possible to do it from aerial photographs.

(3) It was noted earlier that a number of persons are disenchanted with the content of the Census publications and, to a lesser degree, with APHA data. It is felt that multiband aerial photographs comprise an additional data source that

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[40] Harvey S. Perloff, "Knowledge Needed for Comprehensive Planning" in Needed Urban and Metropolitan Research, Donald J. Bogue (ed.), "Scripps Foundation Studies in Population Distribution," No. 7 (Oxford, Ohio: Scripps Foundation, Miami University), 1953, pp. 12-13.

[41] General statements to this effect were made by several panels of geographers in Spacecraft in Geographic Research, NAS-NRC, Publication 1353 (Washington, D.C.: 1966). See in particular the following sections: Settlement, Population, and Historical Geography; Urban Data and Data Systems; Transportation and Linkages.

[42] F.S. Chapin in his very thorough book, Experimental Designs in Sociological Research (New York: Harper and Brothers, 1947, Rev. 1955), refers to only one effort by sociologists to treat this problem.

William W. Clark and J. Harold Williams in their publication, "A Guide to the Grading of Neighborhoods," Bull. 8, Whittier State School, Whittier, California (1919) propose a five-section scale for rating a neighborhood, town, small city:

(1) neatness, sanitation, improvements
(2) recreational facilities
(3) institutions and establishments
(4) social status of residents
(5) average quality of homes.

F.S. Chapin in The Measurement of Social Status (Minneapolis: University of Minnesota Press, 1933) attempted to generate a socioeconomic status scale by measuring cultural possessions, effective income, material possessions, and participation in the group activities of the community. The first part, cultural possessions, measures the contents of the living room as an indicator of socioeconomic statistics. The present study has suggested that such measurements might be possible by inference from surrogate information extracted from aerial photographs.

could greatly increase the flexibility of current data sources. Supplementation of current Census data sources by aerial photographs could conceivably enhance the quality and/or quantity of housing data (or other urban data) in several ways.

An immediate need, therefore, is involvement of a greater number of persons interested in such data.[43] The case studies have already been evaluated by the author. A logical exercise would be for others to do the same. Such comparisons would obviously strengthen the criteria selected as deficiency items and the penalty scores assessed. A large group of participants might also justify the use of statistical methods such as regression, scale, and factor analysis.

(4) Aerial photographs in general could prove a useful supplement to the 1970 Census. There is a distinct possibility that self-enumeration as a method for the 1970 census of housing could provide serious room for error. Persons renting and persons owning might have quite different views as to the quality of housing facilities. This condition is not unknown to Census persons.[44] Aerial photographs, and particularly multiband photographs, might prove to be a very useful means of checking returns.

(5) The time slice captured on the imagery is very brief; i.e., the dwell or imaging time is expressed in split seconds. It is suggested that although much more work should be expended in treating the daytime imagery, it would be useful to conduct flights at different seasons of the year. The results generated to date are promising, but a more thorough exploration of the various possibilities is required to fully test this procedure.

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[43] Harvey S. Perloff in A National Program of Research in Housing and Urban Development, Resources for the Future, Inc. (Washington, D.C.: 1961) discusses the urban data problem (pp. 1, 9, 10, 14).

[44] U.S., Bureau of the Census, Self-Enumeration as a Method for the 1970 Census of Housing, p. 14, Table 10--Percentage Agreement Between Expert and Respondent Ratings of Condition for Identical Units by Tenure, for Fort Smith, Arkansas, 1962; also, p. 15, subheading "Self Enumeration of Condition in the Louisville SMSA."

Priorities

In terms of priorities, two distinct avenues of research are of prime importance:

(1) Extension of the approach suggested here to imagery of a number of cities or to imagery of a wide variety of neighborhood types in the Chicago area. Data generated will provide a basis for the application of statistical techniques to determine appropriate weights to be attached to statistically derived indicators of poor quality housing. This analysis depends on

(2) development of clear statements of data needs from potential users, e.g., APHA, Census (Housing), local governments, universities, business, etc. Since these users require data for specific problems, they must contribute to the identification of data requirements.

APPENDIX A

FLIGHT PLANS

The imagery utilized in this study has been extracted from that taken on two sets of flights over the Chicago test site #43.[45] The first flight was on Friday, 19 November, 1965, and the second on Thursday, 30 June, 1966. The multiband camera system suffered a series of malfunctions during segments of each flight (stable mount malfunction, repeated magazine malfunctions, accidental exposure of film, mechanical failure of multiband system, etc.), and this has necessitated combining imagery from the two flights to develop a representative sample of the areas covered by the flight line. In addition to failures in the system during the November flight, lighting was only "sufficient" due to a high, thin overcast. Demands made on the Natural Resources Remote Sensing Aircraft, NASA 926, precluded postponing the flight until after a forecast rain and snow storm had passed Chicago.

Four lines were flown for the group at Northwestern University, Department of Geography. Line 4, containing the areas imaged in the Case Studies overlays the Eisenhower Expressway, and runs from the "Loop" to Aurora, Illinois. The November flight was flown at 1300 hours CST, and at an altitude of 3000 feet above datum. The July flight was flown at 1200 hours CST at an altitude of 2000 feet above datum. The imagery in the Case Studies ranges over several streets north

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[45] National Aeronautics and Space Administration. Natural Resources Program Remote Sensing Aircraft. Flight Data Summary Report. NASA 926 CV-240A. Mission No. 14. Flight Research Projects Branch, Manned Spacecraft Center, Houston, Texas. Friday, 19 November, 1965, and,

National Aeronautics and Space Administration. Natural Resources Program Remote Sensing Aircraft. Flight Data Summary Report. NASA 926 CV-240A. Mission No. 25. Flight Research Projects Branch, Manned Spacecraft Center, Houston, Texas. Thursday, 30 June, 1966.

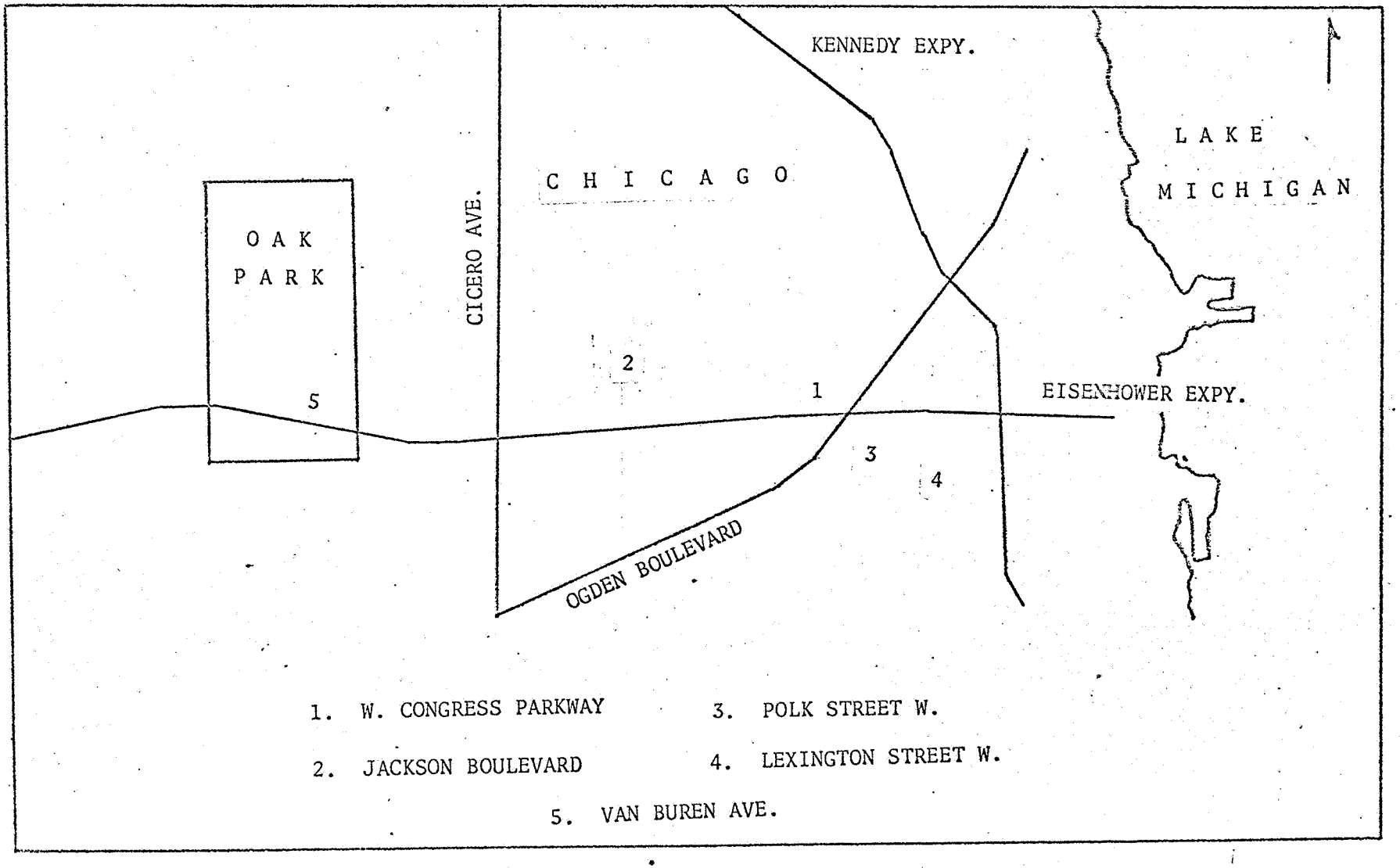

FIGURE 1. LOCATION OF CASE STUDY AREAS

and south of the Eisenhower Expressway. Fourteen prints cover areas in Chicago, and four prints cover areas in the fashionable Chicago suburb of Oak Park, Illinois.

Plans originally called for the filter combinations shown in Table 12, Appendix B. Unfortunately, the filter combinations were changed in the November flight, so that the November imagery is not directly comparable with that obtained the following June.

APPENDIX B

THE ELECTROMAGNETIC SPECTRUM[46] AND MULTIBAND (MULTISPECTRAL AERIAL PHOTOGRAPHY[47]

The electromagnetic spectrum classifies (according to wavelength or frequency) all energy that moves with the constant velocity of light in an harmonic wave pattern. Such energy is harmonic because the energy waves are equally and repetitively spaced in time. The essential character of all electromagnetic (e-m) waves is the same: they differ from each other only in wavelength, frequency, and energy. The effective differences between the components (see Table 9 which follows) of the e-m spectrum are only differences in their interactions with matter.

Energy in its interaction with matter can either be:

(1) transmitted, that is, propagated through the solid matter;

(2) reflected, that is, returned unchanged to the medium;

(3) absorbed, that is, energy given up, largely into heating the matter;

(4) emitted, or more commonly, re-emitted by the matter as a function of temperature and structure, at the same or different wavelength, or

(5) scattered, that is, deflected to one side and lost ultimately to absorption or further scatter.

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[46] For a more complete discussion see R. N. Colwell and others, "Basic Matter and Energy Relationships Involved in Remote Reconnaissance," Photogrammetric Engineering, V. 29, 1963, pp. 761-769, and,

Earl S. Leonardo, "Capabilities and Limitations of Remote Sensors," Photogrammetric Engineering, Vol. 30, No. 6, 1964, pp. 1005-1010.

[47] For a description of the hardware see: "Introduction to NASA 926 and NASA 927 Remote Sensor Aircraft as Applied to the Earth Resources Survey Program," MSC, Houston, Texas, March 1966.

TABLE 9

THE ELECTROMAGNETIC SPECTRUM AND THE OPERATING REGIONS OF REMOTE SENSORS

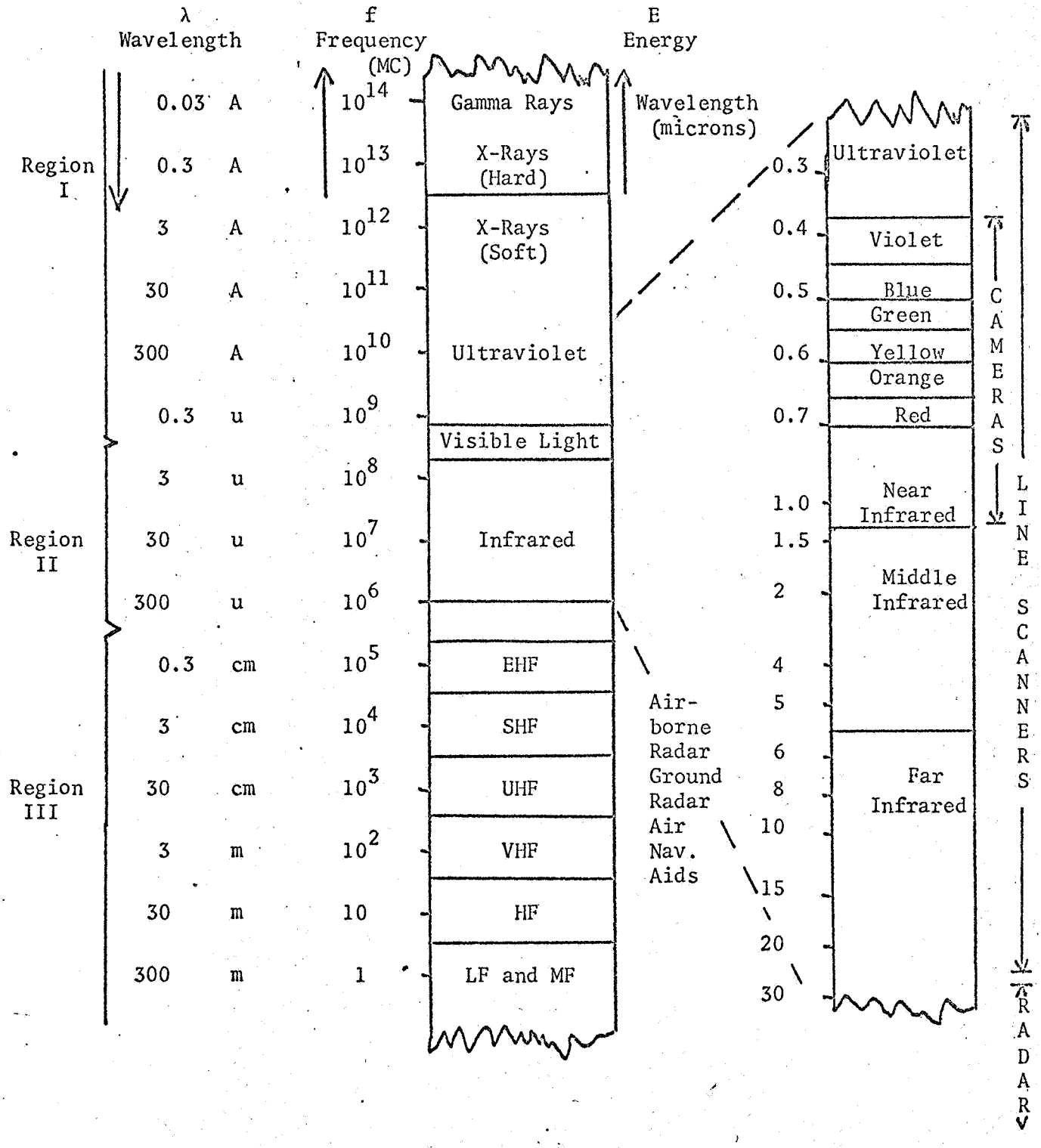

TABLE 9--Continued

DESCRIPTION OF BROAD SPECTRAL REGIONS

Region I

Region of quantum ideas:

Photons (particle-like)

Generation primarily by direct energy input

Material interaction on microscopic levels of:

Nuclei
Plasmas
Atoms
Molecules

Region II

Region of mixed ideas

Temperature correlation strongest

Material interaction on microscopic level

Molecular and atomic thermal properties

Region III

Region of classical ideas

Electric fields E

Magnetic fields H

Generation by oscillation of charges (or close-lying energy levels!) (First and easiest region for coherence.)

Material interaction on microscopic level, primarily.

Electrical and magnetic properties

Source: Lecture notes handed out by Professor G. J. Zissis at 1966 Summer Conference on Remote Sensing of Environment for College Teachers of Natural Sciences, University of Michigan, Ann Arbor, Michigan.

TABLE 10

MULTIBAND CAMERA SPECTRAL BANDS

Frame	Spectral Band (mμ) 11/65	6/66	Film
1	385-500	400-500	Plus X
2	430-560	450-510	"
3	515-605*	520-550	"
4	585-720	550-600	"
5	515-605**	590-640	"
6	645-720	670-720	"
7	685-880	700-810	B&W Infrared
8	730-880	810-900	"
9	740-880	Full film range	"

Note: Flight of 11/65 used special filter configurations.

*Polarized perpendicular to line of flight
**Polarized in line of flight.

Since e-m waves differ from each other only in wavelength, frequency and energy, transmission, reflection, absorption, emission and scattering of e-m energy by any kind of matter are selective with regard to wavelength (different wavelengths of e-m energy interact differently with matter), and are specific for that kind of matter (the interaction is invariable), depending primarily upon the atomic and molecular structure of the matter.

Multiband Aerial Photography

The ITEK nine-lens 70-mm. multiband camera obtains photographic coverage from 0.4 to 0.9 microns. The coverage is subdivided into nine frames by the use of nine 6-inch Leighty High-Resolution lenses with a 21° square field of view. Gelatin filters are employed with each lens to take nine simultaneous exposures of the same ground area. Resolution is from 20 to 30 lines per millimeter. Six of the exposures are on two rolls of 70-mm. panchromatic film and three exposures are on one roll of 70-mm. infrared film. Eight of the exposures represent signatures in eight different narrowband portions of the e-m spectrum. The ninth exposure is the full sensitivity range of the IR film. The format and filter combinations are shown in Table 10.

Image Motion Compensation (IMC) is provided in this system to reduce the effect of smear due to aircraft forward motion. In the ITEK camera, slit direction during exposure is opposite to the film advance during IMC, resulting in a slightly elongated frame. V/H information (velocity in feet per second/height of aircraft above datum in feet) manually set in by the operator establishes the IMC rate. This control is calibrated for ranges of 150 to 300 knots and 1,000 to 30,000 feet altitude.

The most serious factors affecting image resolution are flight conditions and the accuracy with which IMC is matched to true ground speed and absolute

altitude. For these reasons, gyro-stabilized camera mounts as well as Doppler radar ground speed and radar altitude information are essential to high quality imagery. Random and momentary aircraft motions--pitching, yawing, lateral movement--may be encountered in rough air at the instant of exposure, and may be of a magnitude which cannot be completely suppressed by the stable platform. Some degradation of image resolution is unavoidable in this case.

APPENDIX C

CASE STUDIES

This part of the study is essentially exploratory. In involves analysis and interpretation of selected examples of available imagery, and a field check report of the inferential statements made about the quality of housing in the study areas.

Selected Study Areas

The imagery utilized in this study is from an ITEK corporation nine-lens 70 mm. multiband camera (Appendix B). The negatives frequently are not of good quality and this factor has a definite bearing on the type and extent of housing quality characteristics that can be observed in the prints. This is particularly true in bands 1, 2, 3 and bands 7, 8, 9. Bands 4, 5, 6 are also affected, but the result does not appear to be quite so deleterious. In an exploratory paper such as this, it is not possible to consider the contribution of each frame to the analysis and interpretation of the imagery. Instead, frames 1, 2, 3, 4, 5, 6 of the visible part of the spectrum will be used as a unit, as will frames 7, 8, 9 within the infrared.

The procedure has been to study the prints and make observations as to what can be seen at the grossest level of detail and working down towards smaller detail. This involves studying a print and noting any characteristics about the

print which are indicative of low quality housing.[48] The study at present is not overly concerned with labelling individual houses, but the content of the entire prints. The prints could be subdivided into arbitrary sizes, but will not be here because of accounting problems. (This approach becomes a serious deficiency only when variegated clusters are found in a frame.) Both the houses as a group, and the environment, therefore, are under study. The final result using this approach is an inferential statement about quality of housing after summing the housing and environment observations. The environment observations are essentially surrogates for housing quality and are not, at this stage, important in themselves.

Ground truth operations have been carried out by comparing the features extracted from the aerial photographs against observations made from the car, and on foot. Ground truth at this stage is concerned only with verification of the results of analysis and interpretation, that is, concern is with correct identification of features, and not with verification of definitions or whether or not appraisal form content is complete. Photographs have been taken of backs of houses, alleys, open areas, and commercial-residential intermixtures to verify ground truth observations, and to file for future testing certain identificatory characters which are observable at ground level, but were not readily apparent

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[48] As a preliminary move towards determination of what constitutes low quality, the following observations are designated as characteristic, and have greatest reliability when used in combination:
- dirt yards versus grass yards
- yards covered with litter versus clean yards
- dirty, ill-defined alleys versus clean, well-defined alleys
- yards with small per cent free space versus yards with high per cent free space
- houses close to street versus houses set back
- high volume streets versus restricted movement or cul-de-sac streets
- bare earth parkways versus grassy parkways
- highly integrated residential-business districts where a number of buildings are aggregated versus separated residential-business districts
- houses without garages versus houses with garages
- littered non-structure-supporting land versus clean non-structure-supporting land
- single access structures versus dual access structures.

at the photo interpretation stage.

I Negative 735--Frames 1, 2, 3, 4, 5, 6--
W. Congress Parkway, Chicago
(See Figure 2)

Prints of negative 735 contain the following:

8 city blocks

111 multiple-unit dwelling structures

5 commercial or industrial structures

Land use intermingling.--In addition to residential land use there is a large bus depot, an industrial plant covering one-half a block, and its parking lot which covers another one-sixth of a block. The parking lot is only two-thirds used and it appears that several former building foundations are still outlined. The lot is not paved.

Lot crowding.--The houses occupy most of the lots and leave only small amounts of yard space for recreational use. This situation is particularly serious since most of the dwellings are multiple-unit.

Building frontages.--Almost all of the houses are within several feet of the sidewalk, leaving little or no room for front lawns.

Non-structure-supporting land.--There are several large vacant lots or unused sections of land in the study area. Particularly noticeable in the lots are contrasts in tone between dirt and grass, and the large amount of litter strewn over such land.

Thoroughfares.--Litter is noticeable on the parkway (strip between sidewalk and street) near the vacant lots and in front of houses on the east-west running street, and also on the parkway which parallels the bus depot. One parkway and several streets are void of trees. One alley exhibits large cracks in the road-surfacing material.

Parking.--All streets in the study area are utilized for parking purposes, several

Figure 2. Multiband Imagery: Negative 735, .55-.60 microns
W. Congress Parkway, Chicago, November 1965

heavily. Even houses with garages in the rear have cars parked in front, suggesting multiple-dwelling units, or overflow from business or some other employment agency (e.g., street near bus depot).

Recreation facilities.--Private facilities are sorely limited due to lack of yard space. Public facilities consist of a small park with no provision for shelter, shade trees, or benches.

Nuisance factors.--In this area the movement of cars poses a definite hazard, since the one-way streets constitute a large portion of non-covered land. Numerous turnings from the bus depot lot have left an imprint on the street indicating movement away from the study area. The street crossing the expressway is a high-volume street, and this area also has an off-ramp from the expressway. Fire might be disastrous in this area where the houses are so close together. Smoke can be seen billowing from one plant.

Buildings.--The buildings are quite similar in terms of street alignment, proximity to the street, proximity to one another, flat roofs, general similarity of shape and size. Inherent in such architecture are characteristics of monotonicity of surroundings, land crowding, lack of light and air, and the serious hazard of fire spreading quickly once started. The flat roofs and large cornices suggest brick construction. The tone of the roofs suggests a similar composition of roofing materials for most of the buildings, probably asphaltic.

Negative 735--Frames 7, 8, 9--
W. Congress Parkway, Chicago
(See Figure 3)

The infrared prints reveal that many of the yards have patches of bare earth, as does much of the parkway. These prints aid in identification of objects (cars, paths, etc.) but the poor quality of the prints precludes intensive study of the prints for quality of housing evaluation.

Figure 3. Multiband Imagery: Negative 735, .70-.81 microns
W. Congress Parkway, Chicago, November 1965

Summary of Analysis and Interpretation

This area appears to contain poor quality houses on the basis of the features just noted. Although the buildings appear structurally sound, the environment is highly suggestive of conditions not conducive to good health, safety, and amenities. In terms of condition of housing, the buildings themselves do not directly reveal interior quality, but exterior conditions are suggestive of substandard housing.

Ground Truth

A field check of the area verified most of the characteristics noted above, and a traverse through the area led to the same conclusion; namely, that the buildings are structurally sound for the most part, but interior conditions are deemed substandard by inference from the environmental conditions. Field checking revealed that litter in the alleys and along sidewalks is more extensive than was determined by photo interpretation. Three houses are out of plumb by as much as six inches, but this could not be determined from the prints. These three houses would be classified as dilapidated in that they cannot be rehabilitated and should be demolished. Bus traffic does not affect this area, but the other nuisance factors (hazards in two cases) of traffic, fire, and smoke are present.

II Negative 736--Frames 1, 2, 3, 4, 5, 6-- W. Congress Parkway, Chicago (See Figure 4)

Prints of negative 736 contain the following:

7 city blocks

1 of the 7 blocks used for institutional purposes

105 multiple-unit dwelling structures

20 commercial-residential structures

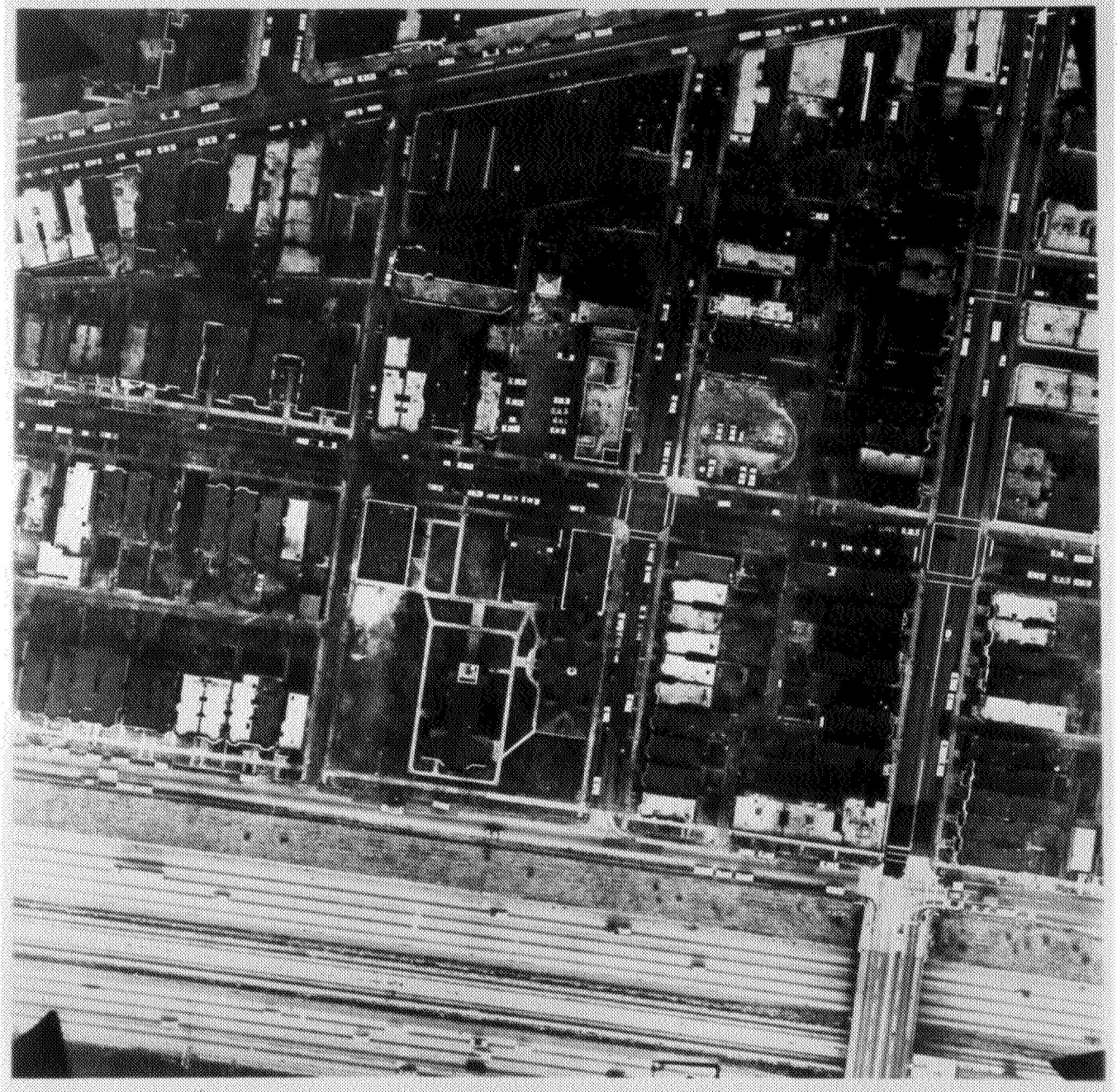

Figure 4. Multiband Imagery: Negative 736, .55-.60 microns
W. Congress Parkway, Chicago, June 1966

Land use intermingling.--In addition to residential land use there is considerable commercial land use, and one block is occupied entirely by a school. The areal incidence of commercial land use is high for several blocks as is the linear incidence. The commercial street is evidenced by lack of entranceways, double width sidewalks, and lack of parkways. Residential structures are of both the several- and multiple-unit type.

Lot crowding.--As in the prints from negative 735 the structures in 736 occupy most of the lot and leave only small amounts of yard space for recreational use. Again, in an area of multiple-unit dwellings, the amount of space allocated for recreation in the yard is minimal. The smaller buildings are usually accompanied by a garage, leading to a further reduction of recreational space in the yard.

Building frontages.--The rule here, as in 735, is for the buildings to be close to the streets, suggesting again either maximum land occupance per lot, or an attempt to aggregate free space in one section of the lot.

Non-structure-supporting land.--There are several small sections which appear to have been cleared of pre-existing structures, and several lot-size properties which are void of structures. One of the properties is strewn with litter.

Thoroughfares.--One lengthy parkway is completely void of curbing and is therefore subject to being driven on by cars and trucks when they park. Litter is strewn along several streets and in several alleys garbage appears to have spilled. Much of the parkways are void of trees.

Parking.--Parked cars are found in all streets in the study area as well as in one narrow alley. Of the two parking lots in the study area, one is paved and the other is dirt.

Recreation facilities.--Private facilities are sorely limited due to land crowding by structures. Public facilities are connected to a small school and

consist of a dirt yard approximately 15 by 60 yards in area, with a large sand-pile located at one end. The playground is bounded on three sides by busy streets, streets with obstructed view to children and motorists due to parked cars.

Nuisance factors.--Traffic is the major nuisance factor in this area due to proximity to the expressway, and two large streets which go over the expressway. All streets run through the area, several of them one-way, leading to faster-moving and hence more dangerous traffic with respect to safety for children. The three streets which pass the school are all one-way.

Buildings.--There are two types of residential buildings in this area, small and large multiple-unit dwellings. The smaller buildings are similar in terms of street alignment, proximity to the street, proximity to one another, flat roofs, and general similarity of shape and size, as shown by the cornices. The larger buildings with their courtyards serve to break up the monotony which the smaller buildings tend to produce, and provide on some streets the only extensive amount of grass and shrubbery to be seen. The large, flat roofs and cornices suggest brick structures with composition of the roofing materials being asphaltic. The only disjointed (gabled) roofs in the study area are those of the school complex.

Negative 736--Frames 7, 8, 9--
W. Congress Parkway, Chicago
(See Figure 5)

The prints clearly reveal dirt yards and lawns having large patches of bare earth. Although object identification is aided, the quality of the negatives precludes detailed study of structures.

Summary of Analysis and Interpretation

This area appears to contain a large proportion of poor quality houses on the basis of the observations noted. Features such as lot crowding, litter, repetition of building style, heavy traffic, and land use intermingling in combination are characteristic of areas of low quality housing.

Ground Truth

Ground truth verifies the overall evaluation of the area as one of poor quality. The buildings are structurally sound, but by inference it is hypothesized that the interiors of most of the buildings are substandard. Field checking further revealed that a large number of the residences have old, dilapidated stairs behind them leading down from the second or third floor, that many of the garages are dilapidated and out of plumb, and that almost all back yards contain litter.

III Negative 752--Frames 1, 2, 3, 4, 5, 6--
Jackson Blvd., Chicago
(See Figure 6)

Prints of negative 752 contain the following:

3.5 city blocks

.5 of the 3.5 blocks are used for commercial purposes

76 multiple-unit dwelling structures

47 single-unit dwelling structures

12 commercial or industrial structures

Land use intermingling.--In addition to two distinctly different housing types (discussed below) there is commercial intermingling on at least one street, and the area is bounded on the south by large commercial buildings. Several residences are located on the street which is dominated by commercial land use. Two large parking lots (one paved, one unpaved) and several smaller ones can be observed, as can a large vacant lot and several smaller strips of unused land. The areal and linear incidence of non-residential land use is very high in the bottom part of the negative.

Lot crowding.--The majority of structures in this area occupy a large percentage of the lot which they occupy, leaving only a narrow strip of land for the front lawn and a slightly larger strip for a back yard. There are several clusters of a different housing type, however, where there is both a large front lawn and a

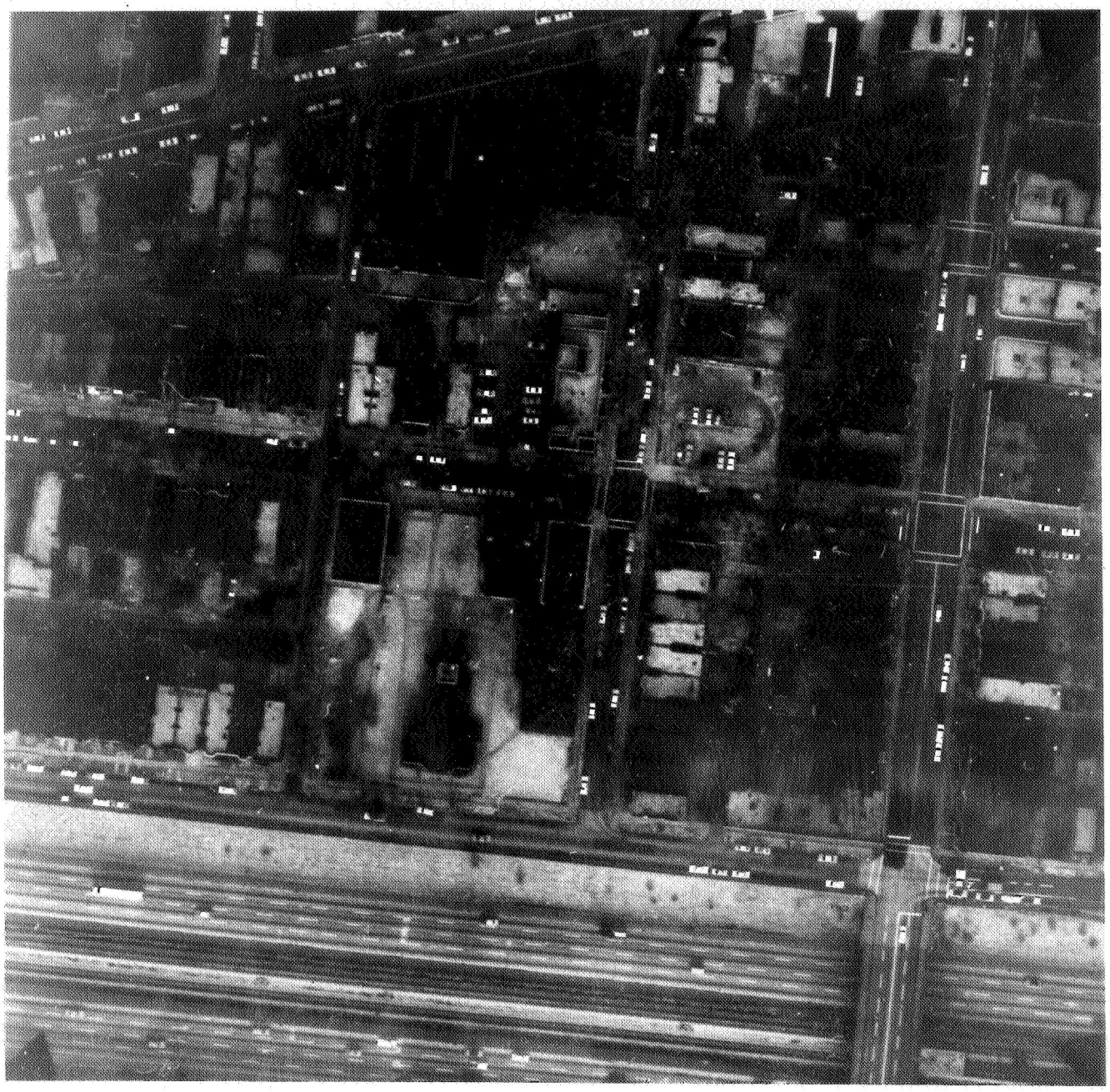

Figure 5. Multiband Imagery: Negative 736, .71-.80 microns
W. Congress Parkway, Chicago, June 1966

Figure 6. Multiband Imagery: Negative 752, .55-.60 microns
Jackson Boulevard, Chicago, November 1965

much larger back yard. The lots occupied by multiple-family structures afford even less yard area per capita, and since most structures here are multiple-unit, lot crowding is serious.

Building frontages.--As just noted, frontages vary. On some streets the buildings are set back several feet from the sidewalk, and there is variation only at those places where structures of a different type have been erected. The multiple-unit dwellings show almost total uniformity in off-set from the street. The newer, generally smaller, dwellings offer some variation.

Non-structure-supporting land.--As noted previously, there is one very large plot of vacant land (could support four multiple-unit structures) and several smaller plots. There is a minimal amount of litter on the vacant land.

Thoroughfares.--One street is a commercial street. The other streets are residential streets of medium volume. The alleys and streets are clean, all streets are curbed and have clean, grass-covered parkways. The alleys appear to be uniform in width and composition.

Parking.--Off-street parking facilities in this area of multiple-unit dwellings is limited since there is only one single-car garage per lot. Imagery taken at night would be more revealing in this area. The heavy on-street parking at the bottom is the overflow from the non-residential land use.

Recreation facilities.--There are no public recreation facilities, and private facilities are limited due to land crowding and lot crowding. The vacant lot does not indicate recreational land use.

Building.--This area exhibits two distinct housing types, large and small multiple-dwelling units, and single-family dwelling units. The multiple-dwelling structures are flat-roofed, have large cornices, are almost uniform in length and width for each size respectively, are close to the street, close together (little light and air for apartments located along sides, especially those on lower levels). The

single-family dwellings (and occasional duplex) have peaked gabled roofs, cement walks around the house, more yard space, are set back further from the road, and the distance between structures is greater.

Negative 752--Frames 7, 8, 9--
Jackson Blvd., Chicago
(See Figure 7)

The poor quality of the imagery makes interpretation difficult. It appears that lawns throughout the area are in good condition, and no bare earth can be detected with certainty. The infrared imagery also reveals that there are a large number of trees distributed throughout the residential area, and that trees are almost nonexistent in the non-residential area.

Summary of Analysis and Interpretation

This area has many of the characteristics which previously pointed to poor quality housing. However, there are other factors in this area which have an ameliorating effect. There are a number of single-family houses in the area, the boulevards and streets are clean, the yards, vacant lots, and alleys are not strewn with litter, there is no apparent immediate source of smoke or noise. There appears to be a relatively clear-cut demarcation between residential and non-residential land use, and the intermingling will pose a problem of a serious nature only if the large vacant lot centered in the residential block is allocated to business use. Invasion of this type would detract from the overall quality because of the extra-vehicular movement that a now-residential street would have to bear. This area appears to have undergone either a conservation or a rehabilitation program, or both.

Ground Truth

Ground truth verifies the overall evaluation of the area as having a number of characteristics associated with poor quality housing, but being rather an area

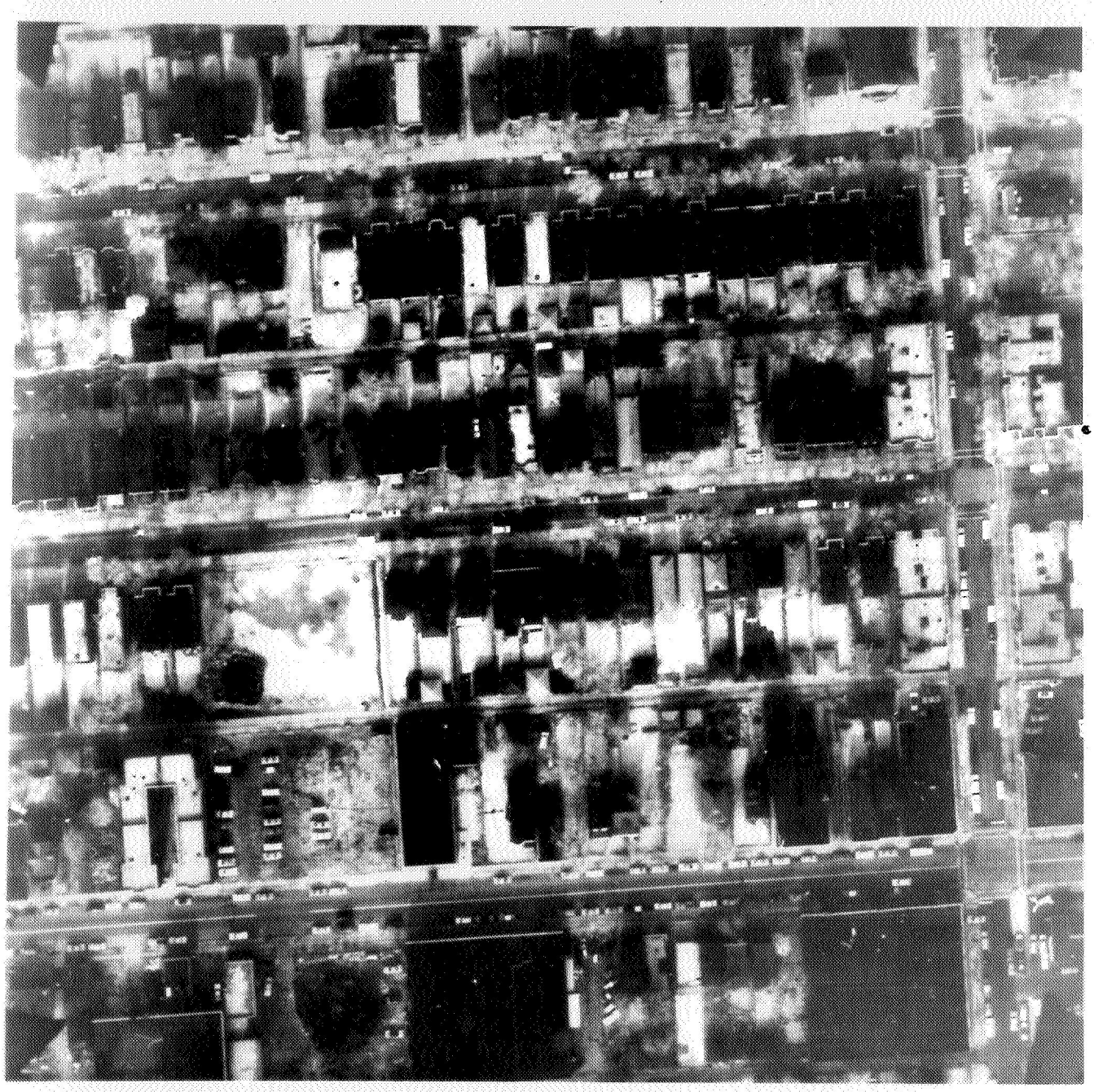

Figure 7. Multiband Imagery: Negative 752, .70-.81 microns
Jackson Boulevard, Chicago, November 1965

of apparent conservation or rehabilitation. Living conditions are strained due to overcrowding of land by buildings and buildings by dwelling units, but environmental conditions point to good quality in the interior of the buildings. Almost all exteriors are brick, and appear to be sound.

IV Negative 202--Frames 1, 2, 3, 4, 5, 6--
Polk Street W., Chicago
(See Figure 8)

Prints of negative 202 contain the following:

6 city blocks

193 multiple-unit dwelling structures

27 single-unit dwelling structures

Land use intermingling.--The area imaged is almost completely residential. What appears to be a large institutional or business complex bounds the area to the southeast. In addition to a highway island, there is sufficient vacant land in the area to support an additional 21 average-size multiple-unit dwelling structures.

Lot crowding.--There is extreme crowding on lots supporting a multiple-unit structure and a garage as well. Single-unit dwellings leave a noticeably larger amount of land free, as do what appear to be two-family dwellings.

Building frontages.--There is considerable variation in street frontages in this study area. On the three higher volume streets all structures, both single- and multiple-unit, are between 8 and 10 feet from the sidewalks. On the lower volume, more residential street, both single- and multiple-unit dwellings are about 20 feet from the sidewalk. In this area the variation is markedly different from areas considered thus far. The single-unit dwellings are aligned with the multiple-unit dwellings on each street, but the street alignments are different from one another.

Non-structure-supporting land.--As noted previously there is sufficient vacant land

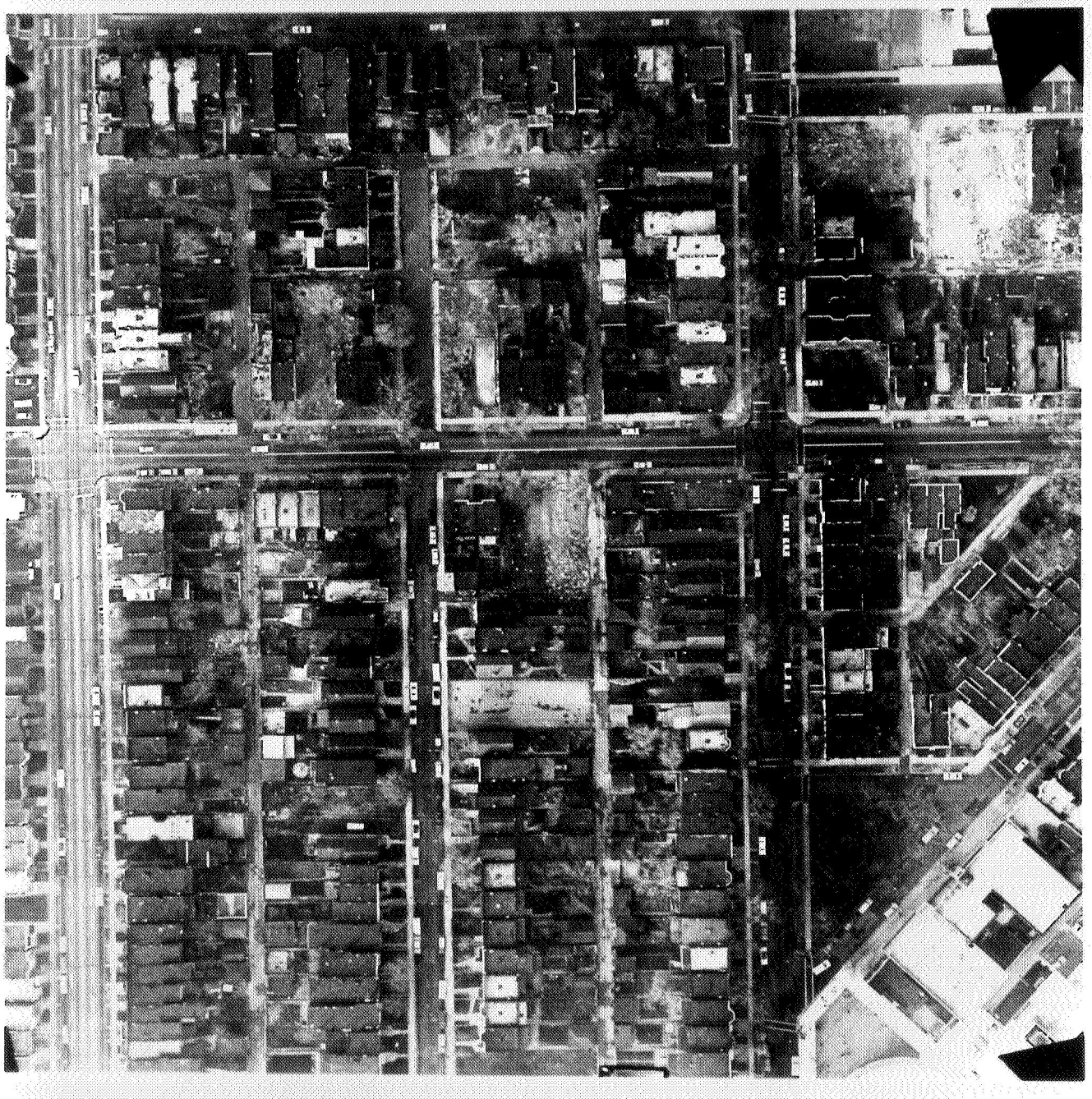

Figure 8. Multiband Imagery: Negative 202, .55-.60 microns
Polk Street W., Chicago, June 1966

in the study area to support at least a score of the average-size multiple-unit dwelling structures. The larger lots are strewn with litter, as are several of the smaller vacant lots. The amount and dimensions of the refuse suggests a demolition program which has left remnants of the demolition lying about. There is one paved parking lot in the area.

Thoroughfares.--In this area there is one high-volume street, two relatively high-volume streets, and one residential street which does not join up directly with another street; i.e., it forms the stem for a " ⊤ " with an alley. All the streets are curbed, and two of the higher volume streets are separated from the sidewalks by a grass strip (parkway). The alleys without exception are lined with litter or refuse and are very narrow. They are not uniform in dimension, or in surfacing. Hence, there may be combinations of dirt, concrete, and asphalt alleys.

Parking.--All streets in the study area are utilized for on-street parking, particularly the smaller residential street. Not every dwelling structure (both single- and multiple-unit) has a garage, and this factor may account for some on-street parking. However, the high proportion of multiple-unit dwelling structures probably generates an abundance of cars which simply cannot be accommodated by the small garage located to the rear of each apartment building.

Recreation facilities.--Private facilities are a function of lot crowding, a serious problem in this area. The smaller structures have, as a rule, about one-third of total land space available as free land. The larger structures, on the other hand, have only from about one-third to one-eighth of total land available as free space. This condition is exacerbated where structures are two stories or more high. A plot of land covering two lots and apparently paved, may provide public recreation facilities.

Nuisance factors.--Traffic hazards exist here, as in many areas. The refuse in this area might prove to be dangerous to children playing, and it might also provide

harborage for vermin. It is scattered over vacant lots, alleys, and yards.

Buildings.--Although the buildings are quite similar in terms of street alignment, and clusters of styles are evident throughout the study area, there is not overwhelming monotony in the study area. There are at least five different housing designs. The arrangement of the houses is one of mixture; i.e., although the styles are clustered, there is a mixture of structures on four different streets. On four streets one single style prevails. Characteristics such as cornices, flat versus peaked roofs, tone of roofing materials, size and shape of buildings, help determine structure style and composition. Several structures which measure approximately 20 by 30 feet appear to have sheds attached to the rear. This may be an indication of conversion of houses which originally were probably designed to shelter one family.

Negative 202--Frames 7, 8, 9--
Polk St. W., Chicago
(See Figure 9)

The infrared imagery in this area suggests differences in grass, e.g., new versus old, healthy versus diseased. This is suggested by the fact that the darkest lawns in the visible imagery are not the most reflective imagery in the IR (infrared). From this very important fact it can be deduced that the vacant lots are unorganized land, i.e., they are not cared for but are simply overrun by weeds, and a strain of grass which appears to survive to a degree without care. The IR clearly indicates cared-for versus uncared-for lawns. Finally, the IR reveals bare earth over most of the parkway area.

Summary of Analysis and Interpretation

There are several anomalies in this area. For example, at the time of the flight there was possibly one recreation area, and only very limited private recreation facilities. There is heavy on-street parking; there is considerable vacant land strewn with rubbish; lot crowding is prevalent (i.e., one-third to one-

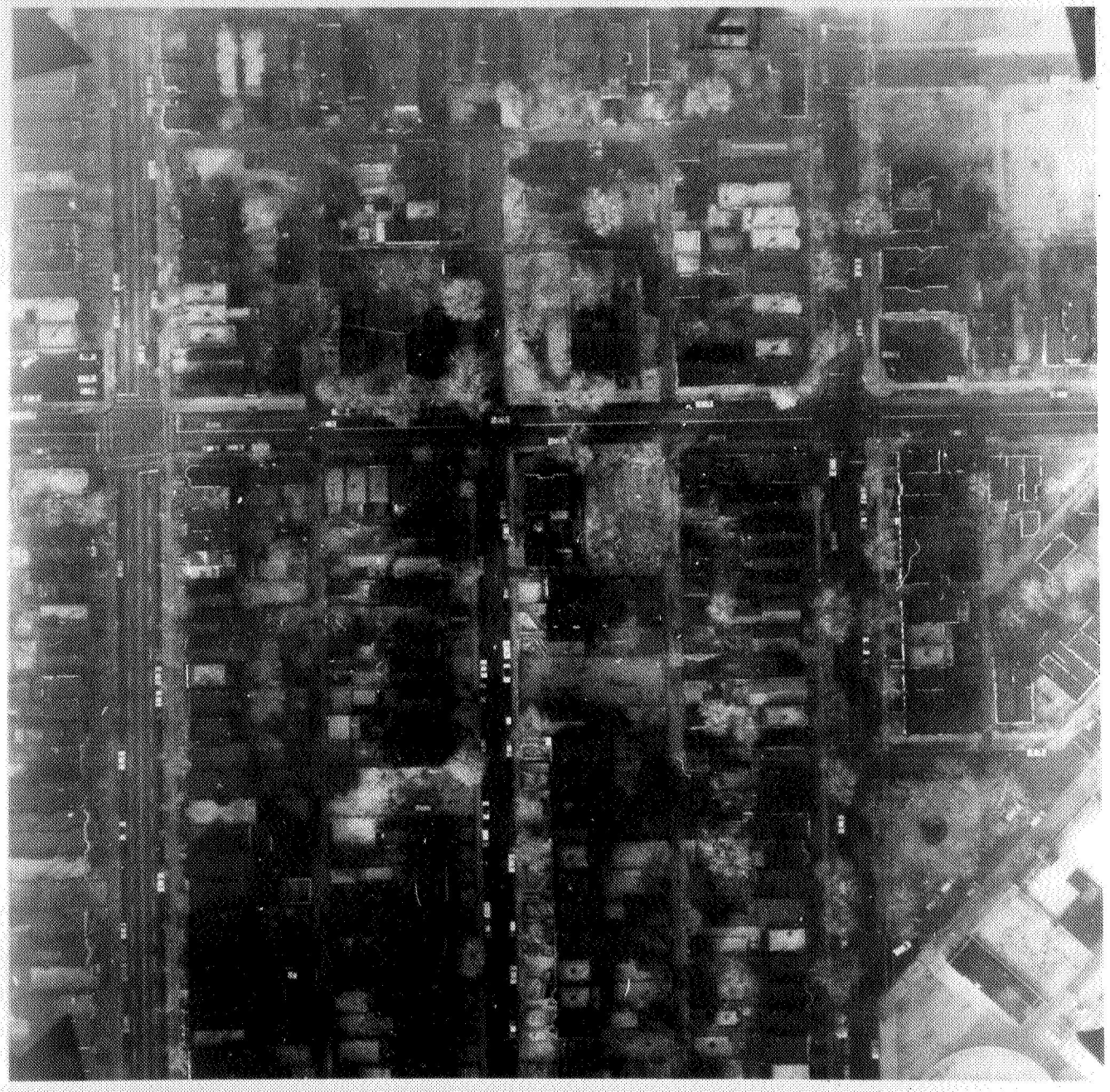

Figure 9. Multiband Imagery: Negative 202, .70-.81 microns
Polk Street W., Chicago, June 1966

eighth of lot space free); houses are aligned to the street in clusters. On the other hand, new housing designs appear to be making inroads on what at one time may have been an area entirely covered by high-density multiple-unit dwelling structures. As well as the different housing designs there is some variety in locating houses away from the street. This area would therefore appear to contain indications of the very early stages of a rehabilitation and/or renewal scheme. Clusters of substandard housing persist, but indications are that they are to be removed. Patches of lawn in yards of the smaller structures are in great contrast to the small amount of free space available in yards supporting multiple-family structures. All in all, the area appears to be one which provides very poor living conditions but may be undergoing a renewal program.

Ground Truth

The outstanding characteristic in the area imaged in negative 202 is the litter and garbage which is strewn over the area. It is found over all the vacant lots, in the alleys, on the parkways, on the sidewalks, and in the back yards. A large number of houses are in disrepair, having broken stairs, shingles and boards missing, and lean-to type sheds attached to the rear of houses. Parkways and lawns are void of grass, cement floors in back yards are the remnants of garages, many "garages" have doors so small that a standard-size car could not enter. The alleys are narrow, and are made narrower by the refuse and garbage barrels which are distributed throughout the alley. Most of the vacant lots are covered with cinder from furnaces, as well as bicycle frames, parts of cars, etc. Some yards have cinder instead of grass cover.

V

Negative 208--Frames 1, 2, 3, 4, 5, 6--
Lexington Street W., Chicago
(See Figure 10)

Prints of negative 208 contain the following:

4 city blocks

Figure 10. Multiband Imagery: Negative 208, .55-.60 microns
Lexington Street W., Chicago, June 1966

13 single-dwelling structures

101 multiple-dwelling unit structures

8 apartment buildings (more than 6 households)

22 commercial-residential structures

2 institutional buildings

1 service station and lot

Land use intermingling.--The amount of land use intermingling is apparent from the above list. The commercial establishments are generally confined to corners, except in the case of one street covering three blocks where there are indications of 21 commercial structures. The residential structures are bounded by commercial or institutional enterprise on the corners, and some dwelling units are probably located on the second floor of buildings which have commercial activity at street level. The small industrial shops are located primarily along one street, sharing the street with 20 residential structures.

Lot crowding.--Lot crowding is evident here, but it is not serious, i.e., in many lots one-half the lot is free space. This occurs primarily where the lot does not support a garage. The buildings are almost touching, but on several streets there is considerable free space both in front of and behind the structure. Lots supporting industrial buildings (warehouses, possibly) are completely covered.

Building frontages.--In the area imaged there is considerable variation, both within and among streets. The best indicators are the peak-roofed structures in comparison to the flat-roofed structures. The latter are usually aligned the same distance from the sidewalk, whether it be 6 feet for all or 20 feet for all, whereas the peak roofed structures vary from lot to lot, and they may be 6 feet or 20 feet from the sidewalk.

Non-structure-supporting land.--There are two vacant lots, one in the residential area, and one in the small industries area. Five parking lots are closely associated to the commercial area, and none are in the residential area. One of

the parking lots and both vacant lots are strewn with litter. In the case of the residential lot, indications are that rubble of the former structure remains.

Thoroughfares.--There are three relatively high-volume streets, and two lesser-volume streets in the area imaged. The latter two are one-way streets. All streets are curbed, and all but one are separated from the sidewalk by a curb. The alleys are not of regular dimension, but are infringed upon by fences and refuse piles. All the alleys are strewn with litter. In terms of composition they appear to consist of combinations of dirt, asphalt, concrete.

Parking.--In addition to the parking lots utilized in the business areas, the streets are vehicle-supporting. Most residential properties contain a garage, or open space designed to provide parking area.

Recreation facilities.--There are no public recreation facilities of an open area type. Private free space is considerable, but is affected by the large amount of litter strewn over both front and back yards.

Nuisance factors.--Traffic poses a hazard here. Streets constitute the largest segments of non-structure-supporting land, thereby creating a dangerous "recreation" area. The most obvious hazard, however, is refuse. It is widespread, found in vacant lots, alleys and yards. It is a potential source of disease, and provides a harborage for rodents. Noise (from traffic) and glare (from business streets) might also be present here.

Buildings.--The predominant structure type is the two- or three-floor multiple-dwelling-unit structure measuring about 25 feet in width by 50 to 60 feet in length. They are flat-roofed, and their dimensions are usually clearly outlined by the cornices. A number of smaller, peak-roofed structures are interspersed throughout the area. There is a third housing type, measuring about 25 by 50 feet, and these buildings are flat-roofed. There are stairs leading into almost all structures. Access to the structures from the sidewalk is usually by means

of one small segment of sidewalk. There are only a few cases where a sidewalk runs alongside the structure leading to a side or rear entrance.

Negative 208--Frames 7, 8, 9--
Lexington St. W., Chicago
(See Figure 11)

The infrared imagery clearly reveals the differences between free space covered with grass and that covered with bare earth. The peak-roofed houses are usually accompanied by grass-covered land, both in the rear yard, the front yard, and the parkways. On the other hand, the multiple-dwelling-unit structures are highly correlated with dirt yards and bare earth in the parkways in front of the structures. The grass areas associated with the larger structures are obviously poorly cared for in comparison to the smaller, and apparently, single-family units. The quality of the imagery is not good, but the contrast in free space characteristics is so great, that even poor quality imagery is useful.

Summary of Analysis and Interpretation

This area is one which is extremely deficient in terms of providing safe, healthy, and amenable living conditions. There is not a clear separation of business and residential land use, there is widespread evidence of litter, no public, open residential land, buildings have been demolished and the rubble still remains, and much of the free space is uncared-for by local residents. There are a minority of houses and properties which exhibit cleanliness.

Ground Truth

The summation and preceding statements were in the main substantiated by the field check. There are several buildings which are uninhabited and appear to be awaiting demolition. Several structures exhibiting "For Rent" signs are in about the same outward condition. A number of structures have had windows replaced by boards. A large number of garages remain standing only because they are leaning

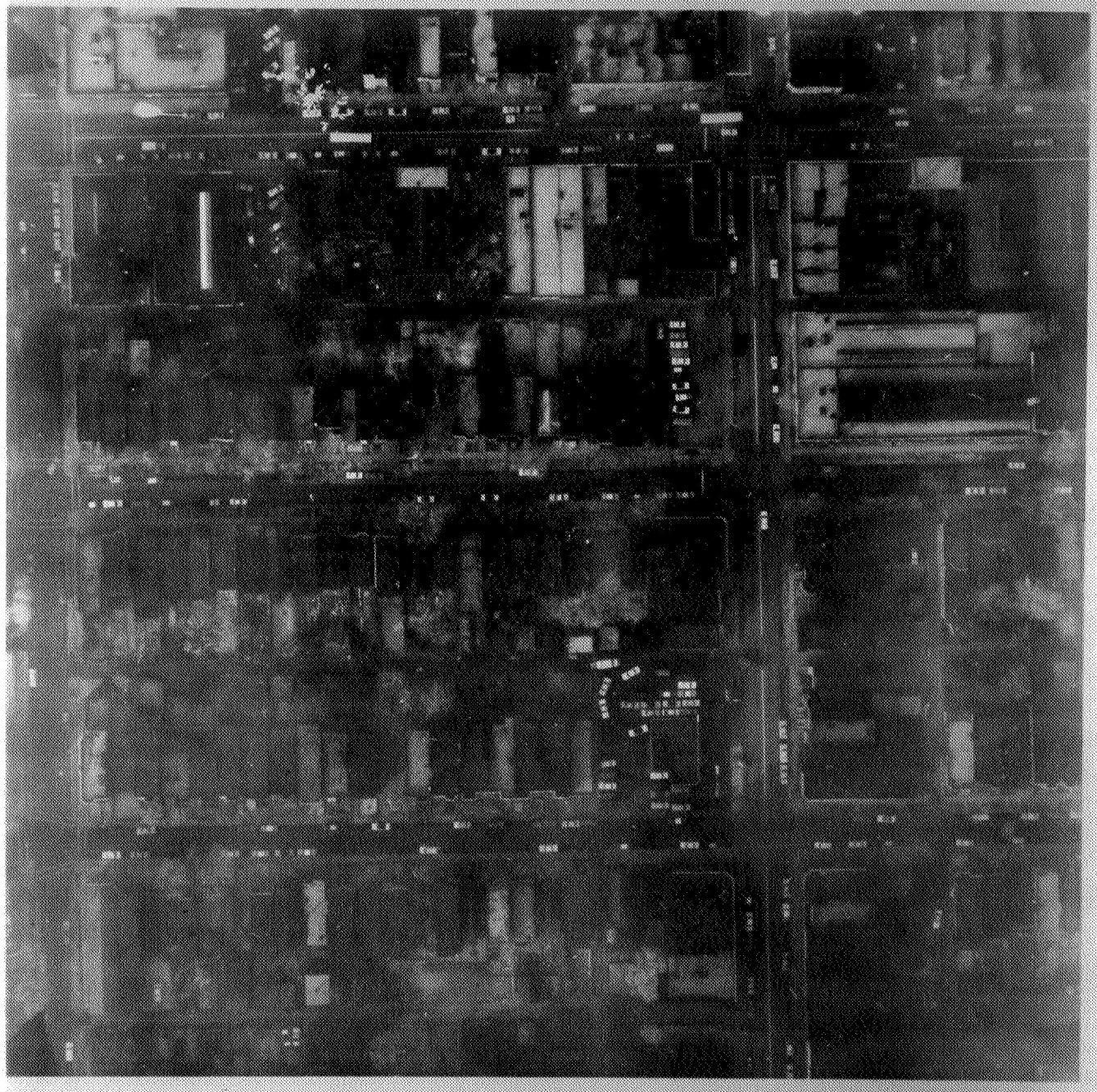

Figure 11. Multiband Imagery: Negative 208, .70-.81 microns
Lexington Street W., Chicago, June 1966

against another. The filth of the area appears great from the imagery, but is even worse when seen in the field. Building counts when checked out were found to be very close, as were the evaluations of structure condition. The peak-roofed structures are neater than the flat-roofed buildings almost without exception. Some business activities were hard to check out even in the field; that is, some buildings combined retailing, warehousing and industrial production, but the separation of business and residential use was accurate. This area, then, offers even worse living conditions from the ground than from the imagery, which was designated as substandard throughout much of the area imaged.

VI Negative 758--Frames 1, 2, 3, 4, 5, 6--
Van Buren Ave., Oak Park, Illinois
(See Figure 12)

Prints of negative 758 contain the following:

5 city blocks

160 peak-roofed, single- or two-family structures

5 apartment buildings

5 commercial buildings

Land use intermingling.--There is one commercial street on the periphery of the residential area. Three large apartment buildings are intermingled with the business activities, while the other two structures are separated from the business area and located within the single-family structure area.

Lot crowding.--The multiple-dwelling unit structures occupy almost the complete lot. On the other hand, the single- or two-family structures leave, on the average, about forty per cent of the lot as free space. In some cases free space is greater than fifty per cent, and as much as 66 per cent.

Building frontages.--Frontages vary almost from house to house. On the average, houses are set back from the sidewalk between 12 and 15 feet, but the range is 6 and about 80 feet.

Figure 12. Multiband Imagery: Negative 758, .55-.60 microns
Van Buren Ave., Oak Park, Ill., November 1965

Non-structure-supporting land.--There are two lots which are vacant. Both are grass-covered, and both are litter-free. The single, paved parking lot is in the rear of a business establishment and could support about 18 automobiles.

Thoroughfares.--There are four residential streets and one commercial street. One residential street is currently undergoing repair. The streets are clean, as are the alleys. The alleys are paved with concrete. All parkways are curbed, and all are grassed. There does not appear to be one patch of bare earth on the parkways.

Parking.--Only one of four streets supports more than six autos. This is a street which is currently undergoing repair. There are both trucks and cars parked, so that they may in fact belong to the workers. The small concentration of cars on one street is just off the commercial street, and may be overflow. Almost every lot has provision for off-street parking.

Recreation facilities.--There are no open, public recreation facilities imaged, but the amount of privately-owned free space is considerable, in every yard. In quantitative terms, total free space per lot averages about 800 square feet. No yard appears to have less than 500 square feet of free space, and one has about 1600 square feet of free space.

Nuisance factors.--Traffic may be a hazard here, particularly if trips to and from the commercial area travel over the imaged streets.

Buildings.--The majority of residential structures are colonial style. Other styles present include ranch, and split-level. There is great variety in styles created by dormers, cement walks, patios, awnings, etc. There is an impression of "newness" or "cleanness" about the area, as there are no splotches of tar, or patches of roofing materials to be seen. The apartment buildings with flat roofs and white cornices stand out in contrast, as do the commercial buildings.

Negative 758--Frames 7, 8, 9--
Van Buren Ave., Oak Park, Ill.
(See Figure 13)

The infrared imagery makes obvious the care which has been exercised by

Figure 13. Multiband Imagery: Negative 758, .70-.81 microns
Van Buren Ave., Oak Park, Ill., November 1965

property owners to produce or preserve shrubbery and grass-covered plots and parkways. There is not one yard or section of parkway which is shown as bare earth by the IR imagery. The large number of trees is also apparent.

Summary of Analysis and Interpretation

This area contains modern houses, there is ample private yard space, yards are grass-covered in front and back, all houses have dual egress, and streets, parkways, and alleys are clean. This is a residential area separated from commercial and industrial activity. There is variety in house alignment, trees are numerous, all lots have provision for vehicle accommodation. There is a minimum of non-structure-supporting land, a possible indicator of the desirability of land in this area. The free land and the parking lot are void of litter. This area then, is modern in housing style, and clean and verdant in the surroundings.

Ground Truth

The summation is verified by field checking. The area contains neat colonial, ranch, and split-level houses. Only one house in the area appeared ready for a new coat of paint when compared to the others. Yards are grass-covered, clean, and spacious. Streets, alleys, parkways are clean. The building count was accurate. One relative difficulty might be to attempt a structure count of each style.

VII Negative 203--Frames 1, 2, 3, 4, 5, 6, 7, 8, 9-- Polk Street W., Chicago (See Figure 14 and Figure 15)

The area imaged in prints of negative 203 is contiguous to the area imaged in prints of negative 202. The two areas are almost identical in terms of classifications such as land use intermingling, lot crowding, building frontages, etc. The summary statement is the same, i.e., housing and surroundings are very similar.

Figure 14. Multiband Imagery: Negative 203, .55-.60 microns
Polk Street W., Chicago, June 1966

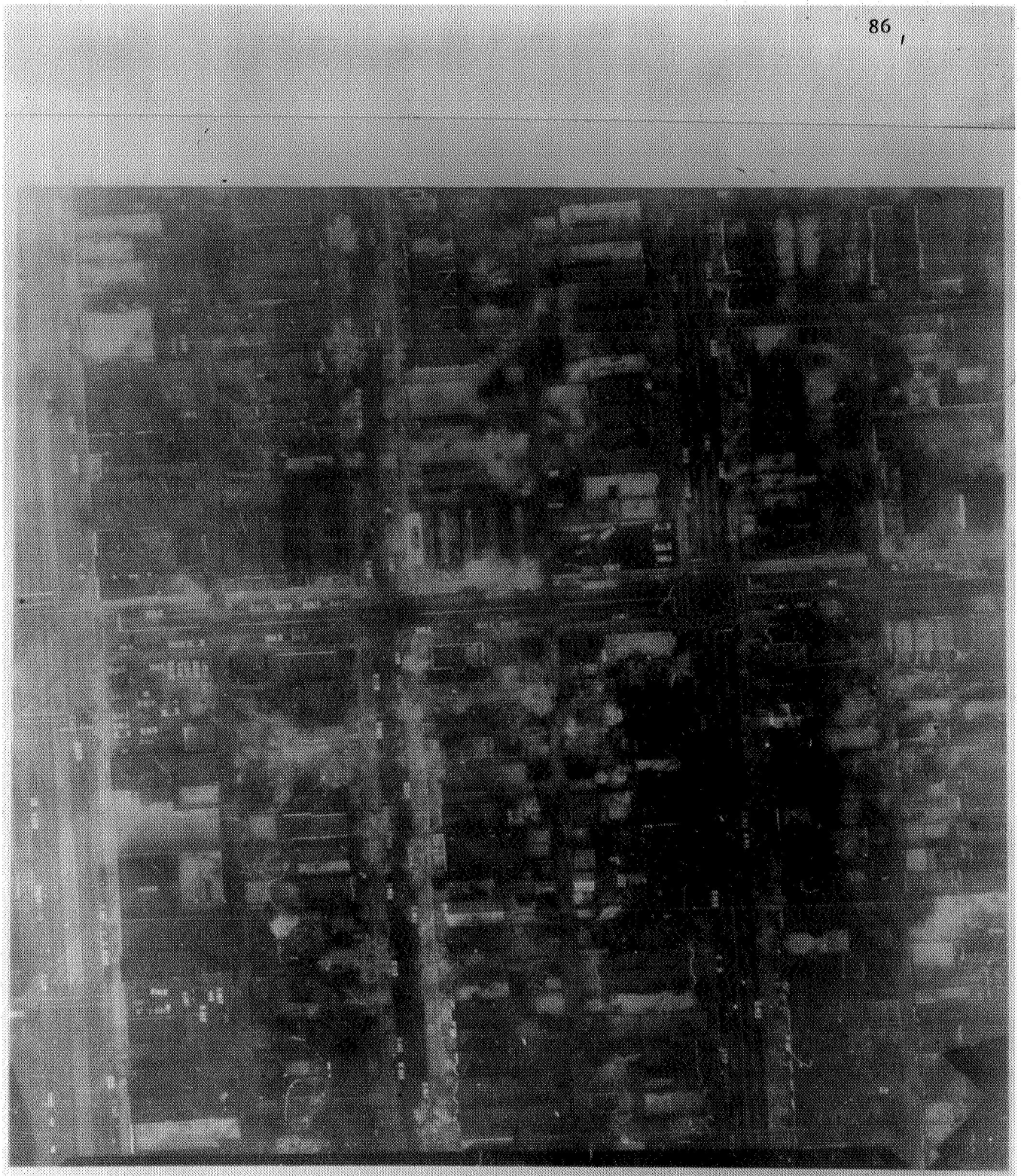

Figure 15. Multiband Imagery: Negative 203, .70-.81 microns
Polk Street W., Chicago, June 1966

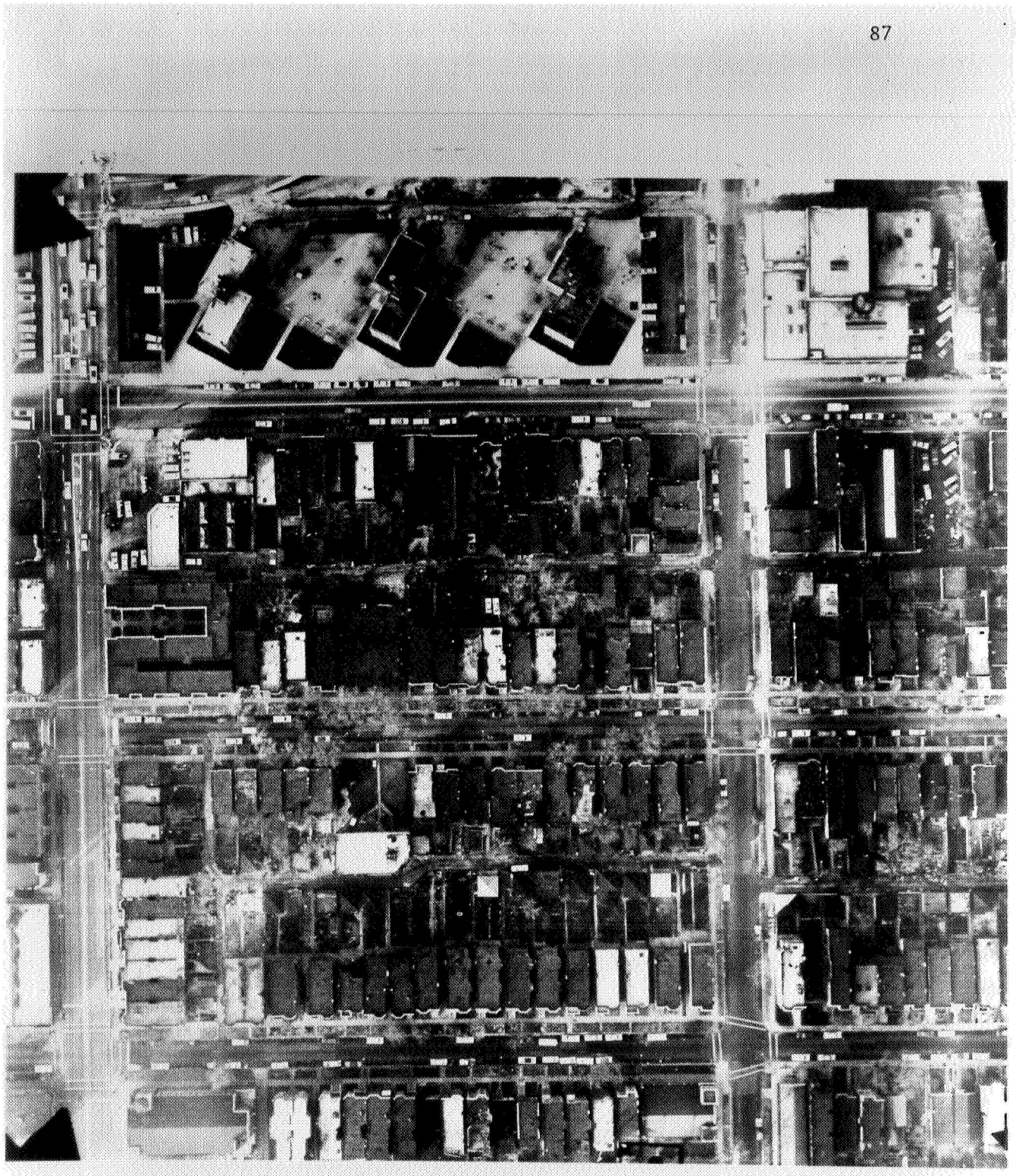

Figure 16. Multiband Imagery: Negative 209, .59-.64 microns
Lexington Street W., Chicago, June 1966

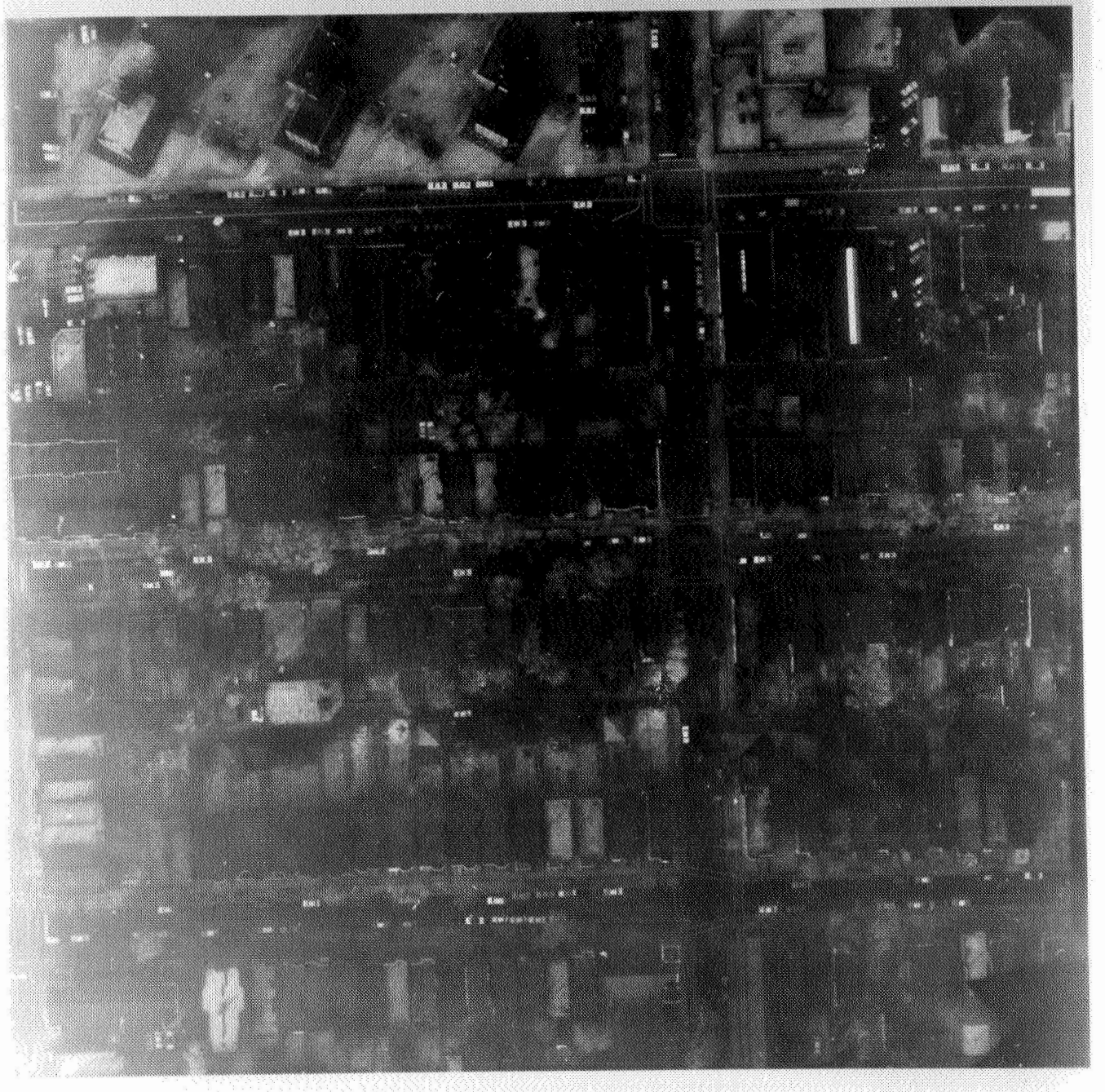

Figure 17. Multiband Imagery: Negative 209, .81-.90 microns
Lexington Street W., Chicago, June 1966

Figure 18. Multiband Imagery: Negative 759, 550-600 microns
Van Buren St., Oak Park, Ill., November 1965

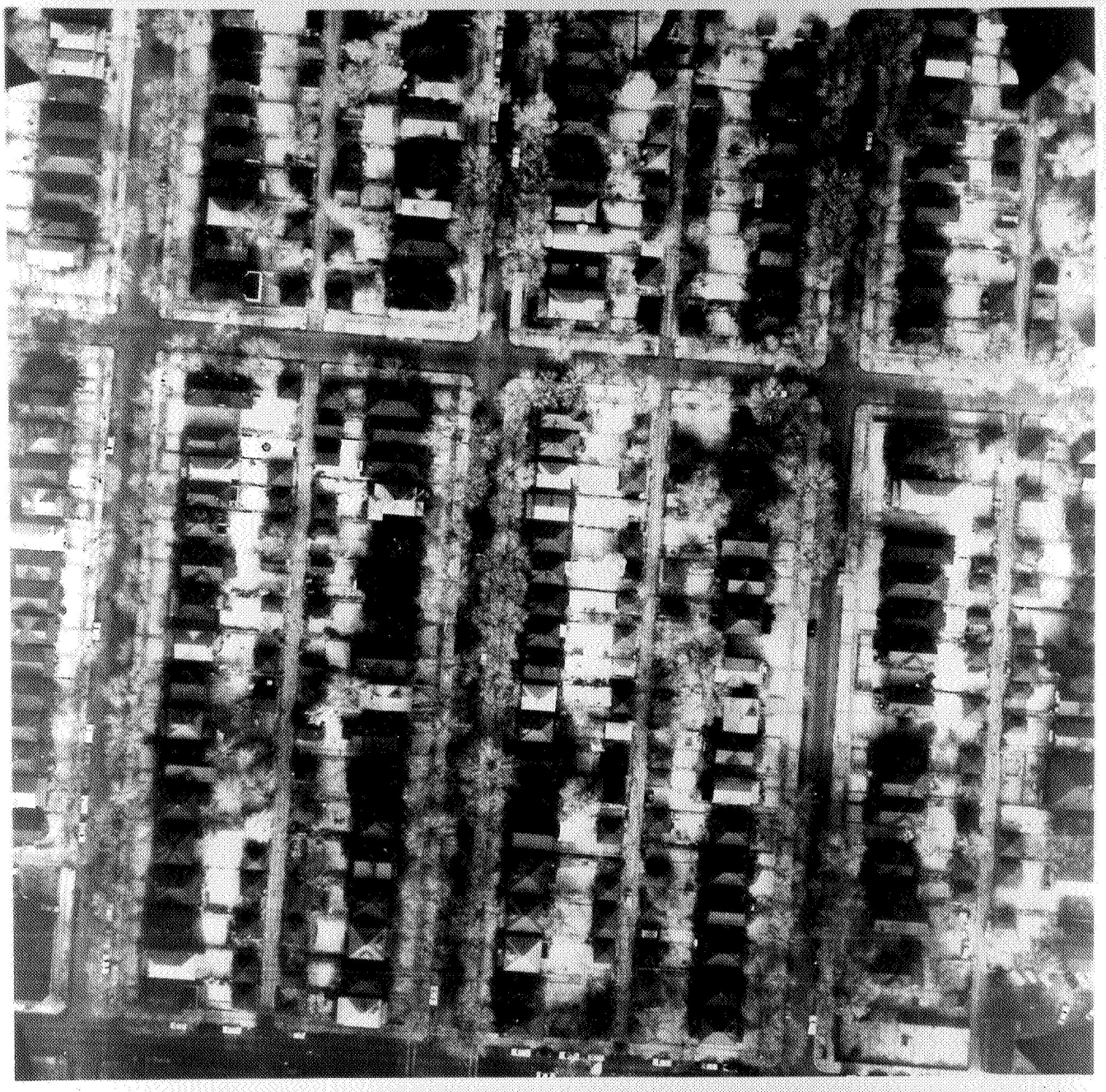

Figure 19. Multiband Imagery: Negative 759, .700-.810 microns
Van Buren St., Oak Park, Ill., November 1965

VIII Negative 209--Frames 1, 2, 3, 4, 5, 6, 7, 8, 9--
Lexington Street W., Chicago
(See Figure 16 and Figure 17)

Areas imaged in prints of negatives 208 and 209 are contiguous. There is no distinct or even notable difference between the two areas, either with respect to housing or surroundings.

IX Negative 759--Frames 1, 2, 3, 4, 5, 6, 7, 8, 9--
Van Buren Street, Oak Park, Ill.
(See Figure 18 and Figure 19)

Areas imaged in prints of negatives 758 and 759 are contiguous. There is no distinct or even notable difference between the two areas, either with respect to housing or surroundings.

Conclusion

Nine negatives or eighty-one frames of multiband imagery have been used as sources of housing quality data. At least, nine negatives have been reported. Six more have been analyzed and interpreted and field checked. However, to complete this report which is essentially exploratory, an arbitrary cut-off point was imposed on data collection. The meaning of the case studies is developed by comparing them with what the APHA and the Census have done in housing quality determination and presentation of data.

APPENDIX D

SIGNATURES

It has been established (Appendix C) that certain features or characteristics of features can be extracted from multiband aerial photographs. This appendix is included to note the signatures of some features considered in the study. Among the more prominent factors used in identifying features are (1) shape, (2) size, (3) tone (color), (4) pattern, (5) shadow, (6) site (topographic location), and (7) texture.

This portion of the study is again exploratory. Some time has been spent by photo-interpreters in developing keys, but considerably less time appears to have been spent towards developing a signature key. This is an operation which obviously merits serious consideration if scanning operations by machine are to be effective. In Chapter II and Appendix C it is noted that analysis and interpretation were based on association, i.e., features were not studied per se, but in combination with other features. The stress here is not upon identifying the signatures of features in general, but rather upon those features which have been previously noted as important for housing quality studies. Some of these features and a partial list of their signatures (identificatory characters) are noted below:

residential structure--

shape (roofs, cornices)

size (longer than wide, occupies 50% to 100% of lot)

pattern (alignment along street, sidewalk)

tone (constancy of roof material results in regular tone which differs from surroundings; tone of cornices outlines buildings)

industrial structure--

size (larger than single-unit dwellings, but may be smaller than multiple-unit dwellings)

shape (rectangular, almost flat roof, cylindrical smokestack)

association (trucks in loading area)

tone (variation in yard area, e.g., litter, garbage, junk varies with dirt, asphalt)

commercial structure--

association (wide sidewalks, no distinct entranceways into buildings, awnings, parked cars on street, lack of boulevards)

one-way streets--

pattern (vehicles pointing in the same direction on both sides of the street; turning marks left by buses leaving depot; both traffic lanes facing red light occupied, no vehicles waiting in lanes on line with stopped vehicles)

smoke--

shape (of cloud

tone (light or dark cloud, contrasts with surroundings)

lawns--

shape (outlined by fences)

tone (if lawn all grass, tone constant, if lawn partly bare, tone varies; best shown by IR--bare earth has different reflectivity than grass)

association (along streets, between houses and streets, behind houses)

litter--

tone (both light and dark flecks spread over area)

association (industrial land vacant lots, alleys, low quality housing)

parking lots--

tone (uniformly dark tone if asphalt paved, uniformly light tone if concrete paved, irregular tone if not paved, e.g., dirt or cinder)

association (adjacent to large apartment buildings, commercial or industrial land use)

shape (usually rectangular, but if not paved, area of greatest usage usually outlined by grass fringe)

The importance of developing such keys is made evident when the process of urbanization is considered. In 1960 there were 212 metropolitan areas in the United States (Metropolitan areas are, by definition, made up of one or more central cities and an amorphous group of suburbs beyond the central city limits which includes cities, towns, villages, and rural or semirural areas within the same or adjacent county. Population must be equal to or greater than 50,000). In 1960 nearly two-thirds of the entire population of the United States resided within these 212 metropolitan areas--113 million persons of the nationwide total of 179 million.[49]

Indications are that the urbanization process will continue, and estimates call for 75 per cent or more of all residents of the United States living in metropolitan areas by 1980. Pressures for information about cities is already being experienced, and indications are that they are going to be exacerbated in years to come. Clearly more time and thought must be expended towards increasing the efficiency and comprehensiveness of methods of generating urban data. Aerial photography (and particularly the multiband variety) may offer a partial solution to the problem.

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[49] Advisory Commission on Intergovernmental Relations, Metropolitan Social and Economic Disparities: Implications for Intergovernmental Relations in Central Cities and Suburbs, p. 1.

APPENDIX E

SCALE ANALYSIS

This section is concerned with the application of an analytical technique to housing quality data. To facilitate matters, N. E. Green's efforts will again be examined (as they were in Chapter II). Readers interested in the criticisms levelled against Green may find it worthwhile to read "Scale Analysis of Urban Structures: A Study of Birmingham, Alabama," in its entirety.

The scale analysis method hypothesizes that certain categories of data constitute a scalable continuum. Green's paper considered a continuum of housing quality. The four items upon which Green based his paper on scale analysis have already been subjected to critical examination in Chapter II. They are recalled here in tabular form

TABLE 11

ITEM AND CATEGORY DEFINITIONS FOR SCALE OF RESIDENTIAL DESIRABILITY

		Category Definitions		
Item No.	Subject	Negative (A)	Neutral (B)	Positive (C)
1	Zonal location	Inner	Middle	Outer
2	Prevalence of single-family homes	30%	30-60%	60%
3	Dwelling-unit density	30	19-30	=18
4	General land use characteristics	Unfavorable		Favorable

The four items selected by Green as indicators of residential desirability yielded a total of eleven response categories (three trichotomous items and one dichotomous item) which in turn generated eight scale types on the hypothetical

continuum of residential desirability (see Table 12). That is,

TABLE 12

SCALE OF RESIDENTIAL DESIRABILITY FOR TWENTY-EIGHT CENSUS TRACTS IN BIRMINGHAM, ALABAMA

Scale Type	Tract No.	Item Number and Response Category C 3	C 2	C 1	C 4	B 3	B 2	B 1	A 4	A 3	A 2	A 1	Scale Score	
I		X	X	X	X								14	
I		X	X	X	X								14	
I		X	X	X	X								14	
II			X	X	X	X							12	
II			X	X	X	X							12	
II			X	X	X	X							12	
II			X	X	X	**				* X			12	*** (10)
III					X	X	X	X					10	
III					X	X	X	X					10	
III					X	X	X	X					10	
III			X		X	_	_	X	X				10	
IV			X		X	X	_	X					8	(10)
IV		X			X	_	X	X					8	(10)
IV					X	X	X	X					8	
IV					X	X	X	X					8	
IV					X	X	X	X					8	
V			X			X	_	X	X				6	(8)
VI					X		X	X	_	X			4	(6)
VI							X	X	X	X			4	
VI							X	X	X	X			4	
VII								X	X	X	X		2	
VIII						X			X	_	X	X	0	(2)
VIII									X	X	X	X	0	
VIII									X	X	X	X	0	
VIII									X	X	X	X	0	

Scale Type	Tract No.	Item Number and Response Category C				B			A				Scale Score
		3	2	1	4	3	2	1	4	3	2	1	
VIII									X	X	X	X	0
VIII									X	X	X	X	0
VIII									X	X	X	X	0
Frequency		5	9	11	16	12	11	10	12	11	8	7	(112)
Errors		2	2	0	1	1	0	0	1	1	0	0	

* "Incorrect" response to scale analysis.
** "Correct" location of response according to scale analysis.
*** Actual score resulting from "incorrect" response to scale analysis.

the scale scores are a continuum, with consecutive scale types differing by a score of two.

The scale scores were obtained by Green in his study by assigning weights of 4, 2, and 0 respectively to the positive, neutral, and negative categories of the trichotomous items and weights of 2 and 0 respectively to the favorable and unfavorable categories of the dichotomous item. Therefore, the values under C are 4, 4, 4, and 2; under B, 2, 2, 2, and under A, 0, and 0, 0, 0 in the second table.

The assignment of such weights is a very important element of the scalogram. According to Green, the first three items, zonal location, prevalence of single-family homes, and dwelling-unit density per block are equally important indicators of housing quality (residential desirability), and general land use characteristics is only half as important as the other three items. There is no indication that such weights have been statistically derived, a serious omission.

SELECTED BIBLIOGRAPHY

Advisory Commission on Intergovernmental Relations. Building Codes: A Program for Intergovernmental Reform. Report A-28. Washington: U.S. Government Printing Office, January, 1966.

Advisory Commission on Intergovernmental Relations. Metropolitan Social and Economic Disparities: Implications for Intergovernmental Relations in Central Cities and Suburbs. Report A-25. Washington: U.S. Government Printing Office, January, 1965.

Advisory Commission on Intergovernmental Relations. Performance of Urban Functions: Local and Areawide. Report M-21-Revised. Washington: U.S. Government Printing Office, September, 1963.

Alexander, Robert H. "Geographic Research Potentials of Earth-Satellites," Proceedings of the Third Symposium on Remote Sensing of Environment, The University of Michigan, Ann Arbor, Michigan, 1965.

_____. "Multispectral Sensing of Urban Environments," Technical Report No. 1, Office of Naval Research Task No. 389-143. Washington, 1966.

American Public Health Association. An Appraisal Method for Measuring the Quality of Housing, Part 1, Nature and Uses of the Method. New York: The Association, 1945.

_____. Planning the Neighborhoods. Public Administration Service. Chicago, 1948.

American Society of Photogrammetry. Manual of Photographic Interpretation. Menasha, Wis.: The George Banta Co. Inc., 1960.

American Society of Planning Officials. Urban Mapping, Aerial Photography, and Duplicating: Some Basic Elements. Information Report No. 29, 1951.

Aronovici, Carol. Housing the Masses. John Wiley and Sons, Inc. New York, 1939.

Badgley, Peter C. "Current Status of NASA's Natural Resources Program," Proceedings of the Fourth Symposium on Remote Sensing of Environment, The Institute of Science and Technology. Ann Arbor: University of Michigan, 1966.

Barraclough, Robert E., and Paul Rosenberg. "The AULT System," Photogrammetric Engineering, XXXII, 1966.

Binsell, R. E. Dwelling Unit Estimation from Aerial Photographs, unpublished B.A. Thesis, Department of Geography, University of Toronto, 1967.

Bogue, Donald J. (ed.) Needed Urban and Metropolitan Research. "Scripps Foundation Studies in Population Distribution," No. 7. Oxford, Ohio: Scripps Foundation, Miami University, 1953.

Branch, M. C. Aerial Photography in Urban Planning and Research. Harvard City Planning Studies, No. 14. Cambridge, Mass.: Harvard University Press, 1948.

Calhoun County Health Department. Housing Survey of Battle Creek, Mich. and Surrounding Townships. 1948.

Campbell, R. D., and H. L. Leblanc. An Information System for Urban Planning. Maryland--National Capitol Park and Planning Commission, Silver Spring, Md., 1962.

Cantwell, R. C. "The Appraisal Process--Outline and Diagram," The Appraisal Journal. April, 1961.

Carls, Norman. "How to Read Aerial Photos for Census Work." Washington: U.S. Government Printing Office, date unknown.

Case, Fred E. "Prediction of the Incidence of Urban Residential Blight," Papers, Regional Science Association, Vol. XI, 1963.

Chamberlain, Katherine. An Introduction to the Science of Photography. New York: The MacMillan Co., 1951.

Chapin, F. S. Experimental Designs in Sociological Research. New York: Harper and Brothers, 1947 (Rev. 1955).

_____. The Measurement of Social Status. Minneapolis: The University of Minnesota Press, 1933.

Churchill, E. D., and R. L. Stitt. "Association Analysis Applied to the Interpretation of Aerial Photographs," Photogrammetric Engineering, XXI, 1955.

City of Chicago. Classification of Structures as Dilapidated and Substandard Warranting Clearance Because of Structural Deterioration. Chicago: By Department of Urban Renewal (date unknown).

_____. Comparative Census Tract 670, Block 9. Chicago: By Department of Buildings, May, 1962.

_____. Enumerator's Manual for Basic Structure Surveys. Chicago: By Department of Urban Renewal, Sept., 1963.

_____. Inspection Procedures, Manual 4. Chicago: By Department of Buildings, May, 1965.

_____. Memorandum from A. H. Zimmerman to G. L. Ramsay, Commissioner, Department of Buildings: "U.S, Department of Commerce, Bureau of Census Criteria for Determining the Quality of Housing." Chicago, May 10, 1962.

City of Chicago. Report to the Department of Urban Renewal on the Designation of Slum & Blighted Area. Redevelopment Project Roosevelt-Halsted. Chicago: By Department of Urban Renewal, July, 1966.

City of Evanston. Population and Housing. Evanston: By Planning Department, 1961.

City of Philadelphia. Philadelphia Housing Quality Survey. Philadelphia: Joint report by City Planning Commission, Redevelopment Authority, and Housing Authority, 1951.

City of St. Louis. St. Louis Housing Survey Report. St. Louis, Mo.: Joint Report by City Plan Commission, Division of Building and Inspection, and Division of Health, August, 1953 (reprinted Feb. 1955).

Clark, Willis W., and J. H. Williams. "A Guide to the Grading of Neighborhoods." Bulletin 8. California: Whittier State School, 1919.

Colwell, R. N., and others. "Basic Matter and Energy Relationships Involved in Remote Reconnaissance," Photogrammetric Engineering, V. 29, 1963.

Craig, D. R. "Billions of Bits/Minute," Photogrammetric Engineering, XXVII, 1961.

Dacey, M. F. and D. F. Marble. Some Comments on Certain Technical Aspects of Geographic Information Systems. Technical Report No. 2. Geographic Information Systems, Department of Geography, Northwestern University, Evanston, Illinois, 1965.

Dawe, H. G. "How Accurate is Aerial Survey," Photogrammetric Engineering, XXV, 1959.

Dueker, Kenneth J. Spatial Data Systems. Technical Reports 4, 5, 6. Department of Geography, Northwestern University, Evanston, Illinois, 1966.

Fiser, Webb S. Mastery of the Metropolis. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1962.

Frost, R. E. "Discussion of Photo Recognition, Analysis, and Interpretation and Photo Keys," Photogrammetric Engineering, XVIII, 1952.

Garrison, W. L., A. Rosenfeld, R. H. Alexander, E. N. Thomas, D. F. Marble, and M. Thompson. "Five Papers on Remote Sensing and Urban Information Systems," Urban and Transportation Information Systems, Technical Report No. 1, Department of Geography, Northwestern University, Evanston, Illinois, 1966.

Garrison, W. L., R. Alexander, W. Bailey, M. F. Dacey, and D. F. Marble. "Data Systems Requirements for Geographic Research," Technical Report No. 1. Geographic Information Systems, Department of Geography, Northwestern University, Evanston, Illinois, 1965.

Green, N. E. Aerial Photography in the Analysis of Urban Structures, Ecological and Social. Unpublished Ph.D. dissertation. Chapel Hill: University of North Carolina, 1955.

Green, N. E. "Comments on Mr. Witenstein's Review of 'Aerial Photographic Interpretation and the Social Structure of the City,'" Photogrammetric Engineering, XXII, 1956.

_____. "Scale Analysis of Urban Structures: A Study of Birmingham, Alabama," American Sociological Review, Feb. 1956.

Grey, George Herbert. Housing and Citizenship: A Study of Low-Cost Housing. Reinhold Publishing Corporation, New York, 1946.

Guttman, L. "A Basis for Scaling Qualitative Data," American Sociological Review, April 1944.

_____. Measurement and Prediction. Princeton: Princeton University Press, 1950.

Hadfield, Samuel H. An Evaluation of Land Use and Dwelling Unit Data Derived from Aerial Photography. A report prepared for Chicago Area Transportation Study, Chicago, 1963.

Harman, H. Modern Factor Analysis. Chicago: University of Chicago Press, 1960.

Hartman, George W., and John C. Hook. "Substandard Urban Housing in the United States: A Quantitative Analysis," Economic Geography, XXXII. Clark University, Worcester, Mass, April 1956, pp. 95-114.

Introduction to NASA 926 and NASA 927 Remote Sensor Aircraft As Applied to the Earth Resources Survey Program. Flight Research Projects Branch, Aircraft Operations Office, Manned Spacecraft Center (MSC) Houston, Texas, March 1966.

Kain, John F. "The Development of Urban Transportation Models," Regional Science Association Papers, Volume XIV, 1965. European Congress, Ghent, 1964.

Kendall, M. G. A Course in Multivariate Analysis. London: Charles Griffin, 1957.

Kesseli, J. E. "Use of Air Photographs by Geographers," Photogrammetric Engineering, XVIII, 1952.

King, George D., Jr. "Aerial Photography and Municipal Engineering," Photogrammetric Engineering, XXIV, 1954.

Lancaster, Charles W., and Allen M. Feder, "The Multisensor Mission," Photogrammetric Engineering, XXXII, 1966.

Landen, David. "Photomaps for Urban Planning," Photogrammetric Engineering, XXXII, 1966.

Latham, James P. "Electronic Measurement and Analysis of Geographic Phenomena." Final Report Nonr 3004(01). Bowling Green State University, 1964.

Leonardo, Earl S. "Capabilities and Limitations of Remote Sensors," Photogrammetric Engineering, Vol. 30, No. 6, Nov. 1964.

Lewis, G. K. "The Concept of Analogous Area Photo Interpretation Keys," Photogrammetric Engineering, XXIII, 1957.

Lueder, Donald R. Aerial Photographic Interpretation. McGraw-Hill Book Co., Inc., 1959.

MacFadden, C. H. "The Uses of Aerial Photographs in Geographic Research," Photogrammetric Engineering, XVIII, 1952.

Marble, D. F., and E. N. Thomas. "Some Observations on the Utility of Multispectral Photography for Urban Research," Proceedings of the Fourth Symposium on Remote Sensing of Environment, The Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan, 1966.

May, Arthur A. "Appraising the Home: IV," The Appraisal Journal, Oct. 1951.

Molineux, Carlton E. "Multiband Spectral System for Reconnaissance," Photogrammetric Engineering, XXXI, 1965.

Moore, R. T., Stark, M. C., and Cahn, L. "Digitizing Pictorial Information with a Precision Optical Scanner," Photogrammetric Engineering, Vol. XXX, No 6, 1964.

Morgan, Joseph O., and Virginia L. Prentice. "Third Symposium on Remote Sensing," Photogrammetric Engineering, XXXII, 1966.

Mumbower, L. E., and T. W. Richards. "Image Information Processing for Photo-Interpretation Operations," Photogrammetric Engineering XXVIII, 1962.

National Association of Real Estate Boards. Housing Quality and Income. Washington, D.C., 1964.

Northeastern Illinois Planning Commission. Metropolitan Planning Guidelines/ Housing Quality, Phase One: Background Documents. Chicago, April 1965.

Olds, Edward B. "The City Block as a Unit for Recording and Analyzing Urban Data," American Statistical Association Journal, Dec. 1949.

Pavlich, A. L., and R. I. Coltrane. "Quality of Rural and Urban Housing in the Appalachian Region," Agricultural Economics Report No. 52, Economic Research Service, U.S. Department of Agriculture, 1964.

Perloff, Harvey S. A National Program of Research in Housing and Urban Development. Washington, D.C.: Resources for the Future, Inc., 1961.

"Photogrammetry and Aerial Surveys," 7 Reports, Highway Research Record, Number 109, Highway Research Board of the National Academy of Sciences--National Research Council, Publication 1327. Washington, D.C., 1966.

"Photogrammetry and Aerial Surveys," 7 Reports, Highway Research Record, Number 142, Highway Research Board of the National Academy of Sciences--National Research Council, Publication 1386. Washington, D.C., 1966.

Quam, L. "The Application of Photo Interpretation to Geographic Research," Photogrammetric Engineering, XVIII, 1952.

Rall, Lloyd L. "Geographic Data Processing," Photogrammetric Engineering, XXXII, 1966.

Rosenberg, Paul. "Earth Satellite Photogrammetry," Photogrammetric Engineering, XXIV, 1958.

Rosenfeld, Azriel, and John L. Pfaltz. "Sequential Operations in Digital Picture Processing," Journal of the Association for Computing Machinery, Vol. 13, No. 4, 1966.

Simon, Ivan. Infrared Radiation. Princeton, N.J.: D. Van Nostrand Co., Inc., 1966.

Simonett, D. S. "Present and Future Needs of Remote Sensing in Geography," Proceedings of the Fourth Symposium on Remote Sensing of Environment, The Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan, 1966.

Slater, P. N., R. H. Noble, B. J. Savidge. "Summary Report on Photography Obtained with ALOTS." (Automatic Lightweight Optical Tracking System) Optical Sciences Laboratory of Steward Observatory, University of Arizona. Tucson, Arizona. March, 1967.

Spacecraft in Geographic Research. Publication 1353, National Academy of Sciences National Research Council, Washington, D.C., 1966.

Spurr, Stephen H. Photogrammetry and Photo-Interpretation. New York: Ronald Press Co., 1960.

Twichell, Allan A. "Measuring the Quality of Housing in Planning for Urban Redevelopment," in Coleman Woodbury (ed.) Urban Redevelopment, Problems and Practices. Chicago: University of Chicago Press, 1953.

U.S., Bureau of the Census. An Evaluation Study of the 1950 Censuses of Population and Housing.

_____. Evaluation and Research Program of the U.S. Censuses of Population and Housing, 1960: Accuracy of Data on Housing Characteristics. Series ER60, No. 3. Washington, D.C.: by Department of Commerce, 1964.

_____. How to Establish Enumeration Districts. Geography Division Instructional Manual, Part III, Washington, D.C.

_____. National Housing Inventory Enumerators Manual. U.S. Department of Commerce, Form 8B-15, House Division, Field Division, Nov. 1956.

_____. Papers Presented at the Census Tract Conference on September 10, 1965 at Philadelphia, Pa. U.S. Department of Commerce, Census Tract Papers GE-40, No. 1. Washington, D.C., 1966.

_____. Papers Presented at the Census Tract Conference December 28, 1961. U.S. Department of Commerce, Working Paper No. 12. Washington, D.C., 1962.

U.S., Bureau of the Census. Papers Presented at the Census Tract Conference December 29, 1958. U.S. Department of Commerce, Working Paper No. 7. Washington, D.C., 1959.

_____. Planning Notes for 1970 Decennial Census. U.S. Department of Commerce, No. 2. Washington, D.C., 1966.

_____. Sampling Applications in Censuses of Population and Housing. U.S. Department of Commerce, Technical Paper No. 13. Washington, D.C., 1965.

_____. Sampling in the 1950 Census of Population and Housing. U.S. Department of Commerce, Working Paper No. 4. Washington, D.C., 1956.

_____. Self-Enumeration as a Method for the 1970 Census of Housing. U.S. Department of Commerce, Working Paper No. 24. Washington, D.C., 1966.

_____. The Post Enumeration Survey--An Evaluation Study of the 1950 Censuses of Population and Housing. U.S. Department of Commerce, Washington, D.C., 1960.

_____. Tract Data Compared for a 25-Percent Sample and a Complete Census. U.S. Department of Commerce, Working Paper No. 3. Washington, D.C., 1956.

_____. U.S. Census of Housing: 1960. Vol. III, City Blocks, Evanston, Ill. U.S. Department of Commerce, Series HC(3), No. 138. Washington, D.C., 1961.

Wagner, Percy E. "Appraisal of Single-Family Homes," The Appraisal Journal, Jan. 1958.

Wellar, Barry. "Towards the Development of a Geographic Information System: A Series of Queries Designed to Explicate the Nature of the Demands Which May be Addressed to a Geographic Information System," Department of Geography, Northwestern University, Evanston, Ill., 1966 (mimeographed).

Wendt, Paul F. Real Estate Appraisal--A Critical Analysis of Theory and Practice. New York: Holt and Co., 1956.

Winnick, Louis, and Ned Shilling. American Housing and Its Use, the Demand for Shelter Space. Social Science Research Council in cooperation with the U.S. Department of Commerce, Bureau of the Census. New York, 1957.

Wirth, Louis. "Housing as a Field of Sociological Research," American Sociological Review, Vol. 12, No. 2, April 1947.

Witenstein, Matthew M. "A Report on Application of Aerial Photography to Urban Land-Use Inventory, Analysis and Planning," Photogrammetric Engineering, XXIV, 1954.

_____. "A Review of 'Aerial Photographic Interpretation and the Social Structure of the City'" by N. E. Green, Photogrammetric Engineering, XXII, 1956.

_____. "Uses and Limitations of Aerial Photography in Urban Analysis and Planning," Photogrammetric Engineering, XXV, 1955.