*Measurements from the Principal Parallel*

It is often more convenient to measure from the principal parallel rather than from the horizon or the nadir parallel. If the quantities ($f \tan \theta$) and ($f \cot \theta$) are determined as constants for a given oblique photograph, then

$$d = f \tan \theta - y$$

$$e = f \cot \theta + y$$

where $y$ is measured from the principal parallel. If the point is above (that is, toward the horizon the principal parallel) $y$ is plus (+); if below, $y$ is minus (−).

It should also be noted that all the elements of the formulae, except the measured distances, are constants which need be determined only once for a given photograph.

# AERIAL PHOTOGRAPHIC INTERPRETATION OF URBAN LAND USE IN MADISON, WISCONSIN*

*L. L. Pownall, Dept. of Geography, Auckland University College, Auckland, New Zealand*

THE technique of aerial photographic interpretation has much to contribute to the mapping of land use in urban areas.[1] Nine basic steps for the interpretation of aerial photographs have already been suggested.[2] The present paper is a description of this technique as applied to the study of urban land use in Madison, Wisconsin. Through the use of this technique, approximately 80% of the mapping of this city was carried out in the office (Figure 1). The task of interpretation was simple. The inventory was made rapidly and efficiently as comparative field checking revealed. By the use of similar techniques, urban studies can be made as simply, efficiently, and rapidly, wherever aerial photographic coverage is available throughout the world.

The field and office work on which this paper is based was carried out in the Madison area from December, 1947 to March, 1948. All identification keys developed for this study, therefore, apply particularly to that city, although they are applicable to many urban areas in the United States, and to some degree to all cities of the western world.[3]

## STAGES IN AERIAL PHOTOGRAPHIC INTERPRETATION OF MADISON

The seven stages used in this study were a modification of a technique already published.[4]

* Appreciation is expressed to Professor Kirk H. Stone in the Department of Geography at the University of Wisconsin for his helpful suggestions in conducting this study and in the preparation of the present paper.

[1] Aerial photographic interpretation is a research technique by which aerial photographs are studied with the naked eye and with a stereoscope in order to locate and to identify natural and cultural features of the landscape. By this means, recognition characteristics and distribution patterns are determined and identification keys are established.

[2] Stone, Kirk H., "Aerial Photographic Interpretation of Natural Vegetation in the Anchorage Area, Alaska," *Geographical Review*, July 1948, p. 466.

[3] General interpretational keys relating to urban areas in the north-eastern part of the United States have already been published. See Russell, J. A., Foster, F. W., and McMurray, K. C., "Some Applications of Aerial Photographs to Geographic Inventory," *Papers Michigan Acad. of Sci., Arts, and Letters*, Vol. 29, 1943, Ann Arbor, Mich., 1944, pp. 315–341.

[4] Stone, K. H., *op. cit.*

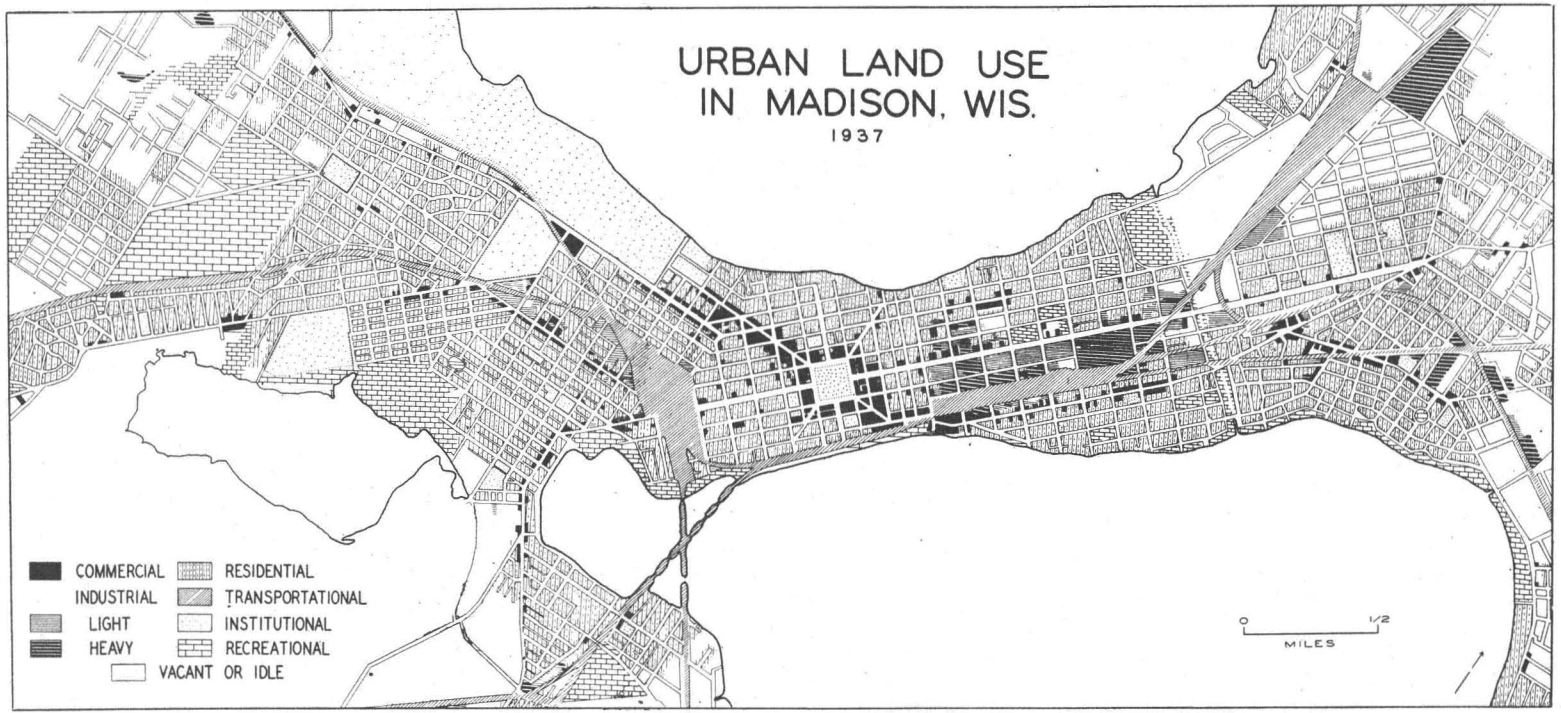


FIG. 1. Urban Land Use Map compiled with the aid of aerial photographs.

1. *Documentary, Cartographic, and Photographic Research.* All of the available material on the area was studied.[5]

2. *Determination of Photographic Scale.* The scale of the photography was calculated. (The representative fraction of vertical aerial photographs equals the focal length of the camera, divided by the altitude of the plane at the moment of photography.)[6]

3. *Plotting and Indexing Photography.* The outline of each photograph was plotted and its number marked on a base map.[7]

4. *Preliminary Examination of Photography.* A mosaic of the photographic cover of the area was prepared, and the photography studied as a whole. On this mosaic the general form of the city and of the shape and location of some of the land use areas was apparent.

5. *Preliminary Stereoscopic Study of Photography.* The preliminary identification of buildings and areas was made with a stereoscope.[8] The known, or positively identifiable urban features, were located and marked on the photographs by means of a grease pencil.[10] The detail was then studied stereoscopically, and recorded on the base map. Identification keys were written in the office in as much detail as possible for known urban features. Unidentifiable areas and buildings were marked as "problem" areas for field checking.

6. *Field Work and Stereoscopic Study in the Field.* Field work was done to map the areas and buildings not identified in the previous stage. In addition, the completed identification keys were checked and some incomplete keys were finished.

7. *Post-field-Work Stereoscopic Study.* The land use areas were again studied stereoscopically in the office and the identification keys were elaborated. The detail recorded directly or indirectly on the photographs was transferred to the base map with the degree of generalization required.[9]

In the initial identification of urban land use areas, the compact commercial core or the industrial areas which parallel main lines of transportation were suitable starting points. Interpretation was then concentrated upon the identification of buildings or blocks of like function. Areas which were multi-functional were studied after the completion of the mapping of single-function areas. It is suggested, therefore, that the photo-interpreter should make himself familiar with one type of urban land use before commencing the analysis of another functional type.

Identification keys are established to allow rapid mapping of the land use structure of an urban area, and thus, to permit much of the field time to be spent on other geographic aspects. Such keys do not make photo interpretation solely

[5] Basic references were the "Sanborn Atlas" for 1945, miscellaneous maps and publications of the Planning Commission of the City of Madison, and Production and Marketing Administration (Agricultural Adjustment Administration) vertical photography at a scale of 1:20,000. Information about the total aerial photographic coverage of the United States, and the cost and availability of prints, may be obtained from the Map Information Office, U. S. Geological Survey, Dept. of Interior, Washington, D. C.

[6] The photography was taken on June 6, 1937, and the study was confined to mapping the land use of Madison at that time. The population of Madison was then approximately 66,000.

[7] The base map of a scale of 1:13,300 was obtained from the Engineer's Office of the City of Madison, and upon it the outline and numbers of each photograph were plotted.

[8] The instrument was a five inch, folding, pocket stereoscope with two-power lenses.

[9] A photographic interpreter's scale was used for measuring features which were difficult to identify. The size of these features was then compared with that of known buildings or structures which might have a similar appearance and location.

[10] The grease penciling was later removed from the photographs by wiping the sufaces with paper tissues moistened with lighter fluid.

an office procedure; they simply make field work more productive for analysis rather than for descriptive mapping.

## IDENTIFICATION KEYS IN THE URBAN LAND USE OF MADISON

Seven major functional areas comprise the urban structure of Madison—commercial, industrial, residential, transportational, institutional, recreational, and vacant or idle areas. Such areas can be recognized by certain distinguishing characteristics which are set-out for each area in the following identification keys. These recognition characteristics are based primarily upon tone (the shade of whiteness or blackness), texture (the evenness of tone), appearance when seen in stereovision (third dimension), pattern, distribution, and associative characteristics. In any one key, the relative importance of individual factors may vary considerably, for example, tone is of greater significance as a recognition characteristic for schools than in the differentiation between large apartment and commercial buildings. Identification is made by a combination of characteristics and seldom by merely one factor (Figure 2).

### Commercial Buildings and Associated Areas (Figure 3)

*Tone.* Changes in tone from building to building may be observed due to the use of different types of roofing materials.

*Texture.* The texture of individual roofs is even; blocks of contiguous commercial buildings are much more uneven than contiguous residential areas.

*Stereoscopic Appearance*

A. Down-town Commercial Core

The height of tall buildings is exaggerated. Shadows cast by buildings are particularly noticeable, and occasionally overlap adjacent buildings.

Small water or aeration tanks are frequently observed on roofs.

B. Decentralized Neighborhood Areas

Commercial buildings are often one or two stories higher than surrounding buildings. They may be identified by their flat fronts and nearness to the curb. Some houses, however, are used in these areas for commercial purposes, the second floor being occupied by professional offices, or as residences. These can be determined only by field checking.

*Pattern*

A. Down-town Commercial Core

The commercial core forms a clearly differentiated cluster of tall buildings. There is an abrupt change in roof heights from the surrounding, lower residential and industrial buildings.

The pattern is a modified square with linear extensions paralleling major thoroughfares.

The whole core in Madison is largely a solidly built-up area, excepting for parks.

Commercial buildings are next to the sidewalk.

The area is multi-functional with public and semi-public buildings, for example, public utilities, local governmental offices, and churches. Field checking is necessary for delimitation.

Roofs tend to be flat with some ridge or arch types, for example, the auditoriums of theaters.

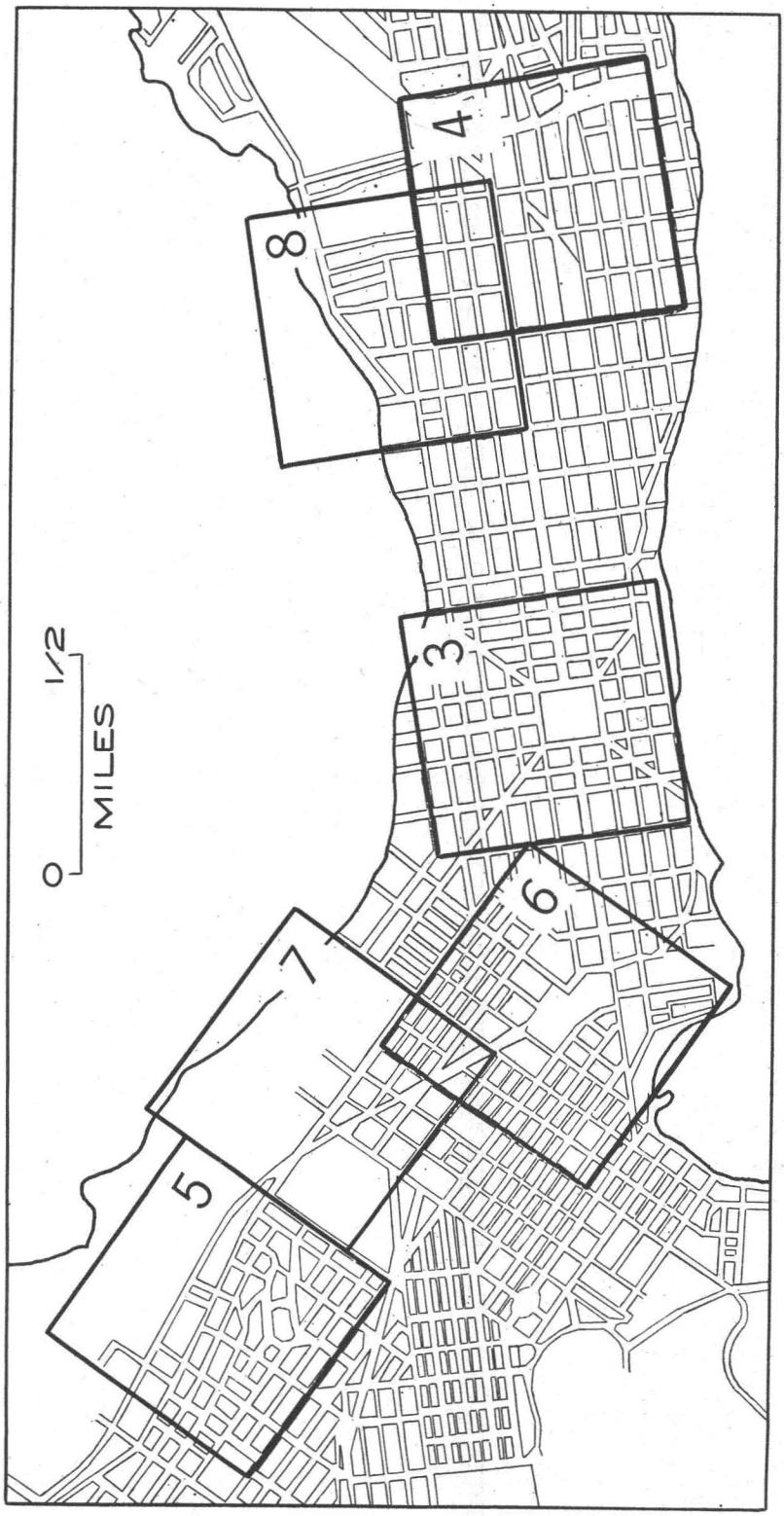


FIG. 2. Index map of illustrative aerial photographs.

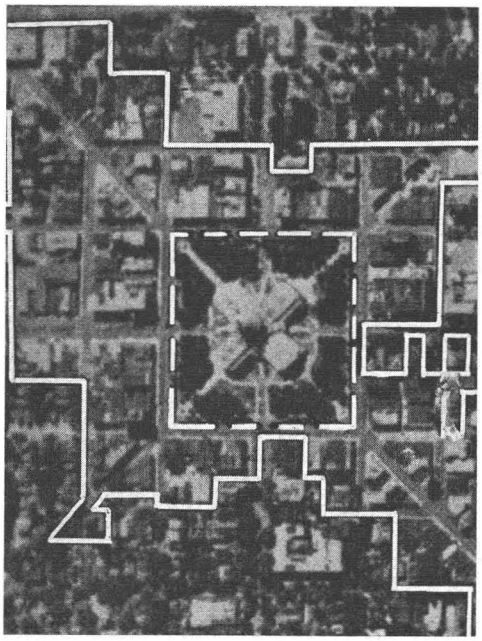

FIG. 3. Commercial Buildings. The continuous lines separate the commercial buildings in the central core of Madison from adjacent land use areas. The broken lines enclose the state capitol. Scale—1:10,000.

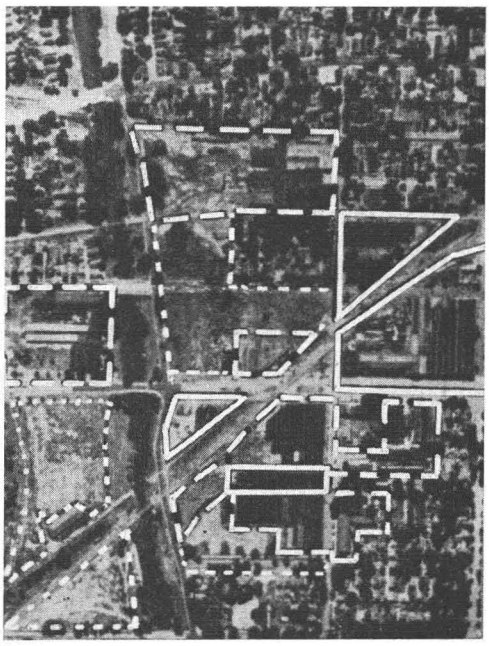

FIG. 4. Industrial Buildings, and Vacant or Idle Areas. The continuous lines separate heavy industrial buildings from adjacent land use areas. The broken lines enclose light industrial buildings. The dotted lines separate areas of vacant or idle land from adjacent land use areas. Note the land use of adjacent areas (Figs. 1 and 2). Scale—1:10,000.

B. Decentralized Neighborhood Areas

Neighborhood commercial buildings tend to be unevenly distributed throughout residential areas, in small clusters. The roofs of these buildings are generally flatter and larger than those of surrounding residences. These buildings are generally built next to the sidewalk. Where houses have been converted to commercial uses, field checking is necessary.

*Distribution*

A. Down-town Commercial Core

The core is at the principal focus of main streets and extends outward along major thoroughfares.

B. Decentralised Neighborhood Areas.—Neighborhood commercial area buildings are located:

Along a major thoroughfare and at the junction of a major thoroughfare and a side street;

In the vicinity of schools, decentralized industry, and city bus terminals.

*Associative Characteristics*

Cars are parked parallel or at an angle to the curb, or in adjacent parking lots. Such parking lots may be associated with an individual light industry or with super markets.

Trees between curbing and sidewalk are less common in the central core than in the neighborhood commercial areas, except in open areas, as around the Capitol Square in the heart of Madison.

### Industrial Buildings and Associated Areas (Figure 4)

*Tone.* The roofs of industrial buildings are generally darker in tone than neighboring buildings. Associated areas may have patches of light tone where there are waste piles, assembled end-products, raw materials, or bare ground. Storage tanks, in general, are light in tone.

*Texture.* The texture of the roofs of buildings is more even than the mottled appearance of adjacent areas. Halation (light reflection) may be observed on some processing buildings in a specific plant.

*Stereoscopic Appearance.* Buildings for heavy industry appear lower than adjacent buildings used for light industrial purposes.

A. Heavy and Noxious Industry

The height of the buildings is not as pronounced as in light industrial plants.

Smoke stacks have an exaggerated height with some appearing to be split when seen in stereovision.

Frequently numerous small tanks, pipes, open skylights, and ventilators on the roofs of buildings appear in stereovision.

When seen in stereovision, ridges, monitors, or flat roofs predominate on the basic, heavy-construction buildings, with a predominance of the saw-tooth type on assembly buildings or structures occupying comparably extensive areas.

B. Light Industry

The height of tall buildings is exaggerated although many light industries are unidentifiable on the basis of height.

Small tanks, pipes, open skylights, and ventilators may be found singly or in combination on the roofs of light industrial buildings. They are less characteristic of this type of industry, however, than of heavy and noxious industries.

Roofs are generally saw-tooth or ridge type on buildings of low elevation, and flat on high buildings.

*Pattern*

A. Heavy and Noxious Industry

Either clustered or strung-out along streets and railroads.

Associated groups of buildings frequently occupy large areas.

There is frequently a cluster of buildings of various sizes and of different roof types.

Heavy industry tends to be clustered together and segregated from other functional areas.

B. Light Industry

Buildings frequently occupy less area than in heavy industries.

Buildings are often several stories in height.

*Distribution*

A. Heavy and Noxious Industry

Located along a railroad or within one or two blocks where spur lines make access possible; particular reference to power supply and heavy or bulky raw materials or products.

B. Light Industry

Light industry may fringe or be within heavy industrial areas. At the same time it invades the commercial core of the down-town area and thus becomes mixed with stores. This can only be accurately revealed by checking in the field or by use of the Sanborn Atlas of Madison.[11]

Located frequently with reference to road rather than rail transportation, and to labor rather than bulky, raw materials.

*Associative Characteristics*

A. Heavy and Noxious Industry

Large, open spaces for the storage of raw materials, end-products, or waste.

Power houses (smokestacks or transformer stations) with coal piles of dark tone, enclosed conveyors, or travelling cranes may be seen directly, or interpreted by the shape and position of shadows. The "step" appearance of the power house buildings with boiler house, generator hall, and transformer and switching station may be seen in stereovision.

Railroad sidings parallel or enter buildings.

Frequently a larger supply of water is required than in light industry, hence water towers are separate structures or are on roofs of buildings.

Tanks for oil, gas or by-products storage may be associated with the plant and connected to buildings by overhead pipe lines.

B. Light Industry

Light industry often lacks open spaces for storage.

Small water tanks are frequently located on the roofs.

RESIDENTIAL BUILDINGS AND ASSOCIATED AREAS (FIGURE 5)

*Tone.* Tone varies from gray to dark gray and is generally darker than buildings in the commercial core.

*Texture.* Texture tends to be even in the older residential areas, and uneven in areas of recent housing development.

*Stereoscopic Appearance*

Most Madison residences, being two-story structures, appear to be lower than buildings in other land use areas.

Large apartment houses and multiple family residences are similar to commercial buildings in size, height, roof types, and roof features except for skylights and tall pipes. Differentiation between these functional areas may be aided by the presence of washing on the roofs of residential buildings of this type, but accurate differentiation is possible only by field checking or by the use of the Sanborn Map.

*Pattern*

Residences, in general, uniformly parallel the street.

Residences are set back from the street, or

Backyards can be observed in the rear of residences as areas with clearly defined boundary lines and frequently patches of halation.

[11] The Sanborn Map Company has surveyed most American urban areas for insurance purposes. Sanborn maps are corrected annually by surveyors of the company, and show water facilities, constructional details, and utilization of individual buildings.

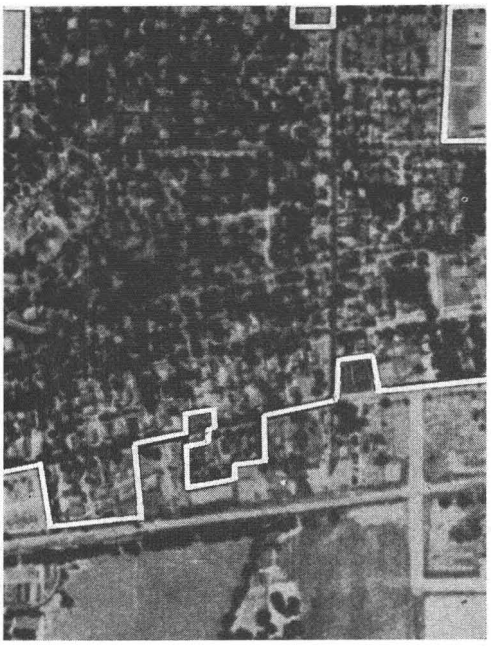

FIG. 5. Residential Buildings. The lines separate residental buildings in the upper part of the picture from adjacent land use areas. Refer to Figs. 2 and 3. Scale—1:10,000.

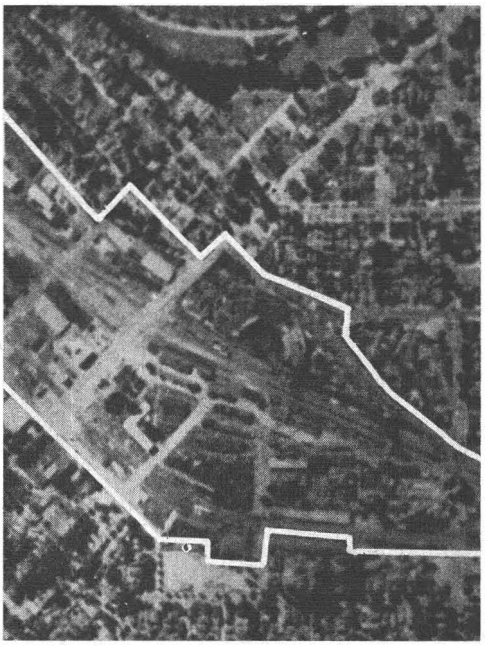

FIG. 6. Transportational Areas. The lines separate railroad areas from adjacent land use areas. Refer to Figs. 2 and 3. Scale—1:10,000.

*Distribution.* Residences form the bulk of urban structures and are found in all land use areas in Madison, excluding the central, commercial core.

*Associative Characteristics*

Roofs are generally ridged.

Trees are more common than in commercial or industrial areas.

Individual residences are small by comparison with other urban structures.

Modern apartment buildings occupy less area than decentralized institutions, and appear higher than surrounding residences.

The grounds of apartment buildings, in general, are small.

Roofs of apartment buildings are generally flat. Elevator houses may be observed on roofs.

House types[12]

a. Superior residences
   Lots are large, and generally outlined by hedge or fence.
   Drives curve, and entrance may be at any point along front or side of lot.
   Houses are large, ridge-top system complex.
   Large driveway areas and large backyards, often with summerhouse and tennis courts, are common.

b. Ordinary residences
   Houses are fairly close together and lots are small.
   Over a considerable distance garages, drives, and entrance walks are in same position with respect to lot.

[12] This section is a modified extract from the paper by Russell, *et al.*, *op. cit.* In the present study, only a statement of general characteristics of house types was undertaken.

Houses seldom have more than two ridge lines; roofs are stereotyped.
Backyards are small and houses occupy most of width of lot.
Houses are regimented with respect to street.

c. Inferior residences
Houses are small, with single roof forms.
Lots are small, even when buildings are scattered.

## Transportational Areas (Figure 6)

### A. STREETS AND ROADS

*Tone.* In general, streets are light in tone, ranging from the whiteness of concrete to the gray and dark gray of asphalt. Macadam is intermediate in tone.

*Texture.* Streets are generally of uniform texture.

*Stereoscopic Appearance.* Bridges and overpasses appear to go over other features and usually cast shadows.

*Pattern.* The number of major thoroughfares is relatively restricted. Streets appear as narrow lines with sidewalks as fine lines of lighter tone.

*Major Thoroughfares*

1. Frequently wider than other streets and often tree lined.
2. Because of the physical structure of the site of Madison, the major thoroughfares pass through the central core.
3. Railroad overpasses and underpasses may be observed. Grade crossings in Madison are more common than overpasses and underpasses. Grade crossings may be located by the lack of stereo appearance and by the visible intersection of roadway and rail lines.
4. Tributary thoroughfares join in suburban areas.
5. Major thoroughfares have smoother and broader changes in direction than have other streets.
6. The volume of traffic may be detected. (Note that such traffic will not appear in stereovision as vehicles will have moved between consecutive camera exposures.)

*Other Streets*

1. Streets frequently divide the urban area into small, rectangular, city blocks.
2. Street corners are generally right angles.
3. Superior residential streets may be curved. (Compare with identification keys for cemeteries and parks.)
4. Trees may prevent direct identification of streets on the photography. These can be checked by tracing to a junction with a clear street.

*Distribution.* Streets form a complete network throughout the whole urban area.

*Associative Characteristics*

Buildings, in general, are built parallel to the street.

Alleys and driveways join the streets.

Parked vehicular traffic may line the streets, particularly in down-town areas, and/or occupy adjacent parking lots. (Note that such areas may be confused with used-car lots. In the latter, however, cars are generally parked in widely spaced rows parallel to the street for display and inspection purposes. This is in contrast to the arrangement of cars and the intensive use of all available space in a parking area.)

Neighborhood commercial areas tend to be found along major thoroughfares.

B. RAILROADS

*Tone.* Railroad tracks frequently appear darker in tone than neighboring streets, particularly where the latter are of concrete or gravel construction.
*Texture.* Railroads are of even texture.
*Stereoscopic Appearance.* Underpasses and overpasses appear to go over or under other features and if the latter to cast shadows.

*Pattern*

Changes in direction are by long, smooth curves.
Branch lines join with sweeping curves.
Single track lines are narrower than streets.
Lines divide into yards for classification purposes—a network of parallel tracks.
Distributary sidings or spur lines are frequently dead-ends.
Tracks cut across the normal street pattern at varying angles.
Railroad tracks may cross one another at an acute angle.
*Distribution.* Railroad tracks go around the commercial core of Madison.

*Associative Characteristics*

Structures may be identified on either side of the tracks
a. Roundhouse—semi-circular in shape.
b. Coal piles—loading towers or cranes with marked stereo appearance, dark tone, and shadows.
c. Station buildings—vehicular parking and shipping areas with ready access to the street.
d. Signals and water towers—marked stereo appearance and shadows.
e. Repair shops—sidings enter buildings (located frequently close to the roundhouse).
f. Freight warehouses.
g. Sanding towers—white tone around tracks.

Freight cars may be observed on lines, particularly in classification yards.
Complete trains may be seen on sections of the line but will be blurred if photographed when moving.

INSTITUTIONAL BUILDINGS AND ASSOCIATED AREAS (FIGURE 7)

*Tone*

The tone of associated open spaces generally differentiates between hospitals and schools, for example, halation from the sports fields adjoining the latter.
Buildings themselves tend to be lighter in tone frequently than others of comparable size.
*Texture.* The texture of roofs of institutional buildings is uneven, varying from building to building and from individual building to its associated area.
*Stereoscopic Appearance.* The stereoscopic appearance is particularly high on churches (with spires), and buildings of similar construction, for example, the State Capitol, and the University of Wisconsin Armory.
*Pattern.* Institutional buildings, in general, follow no orderly pattern except that:
Buildings are frequently set in extensive grounds back from the street.
Vehicles are either absent, few in number, or parked in delimited areas within the grounds.
Buildings tend to have one or more wings, or to be constructed around a relatively large court, for example, the Wisconsin General Hospital.

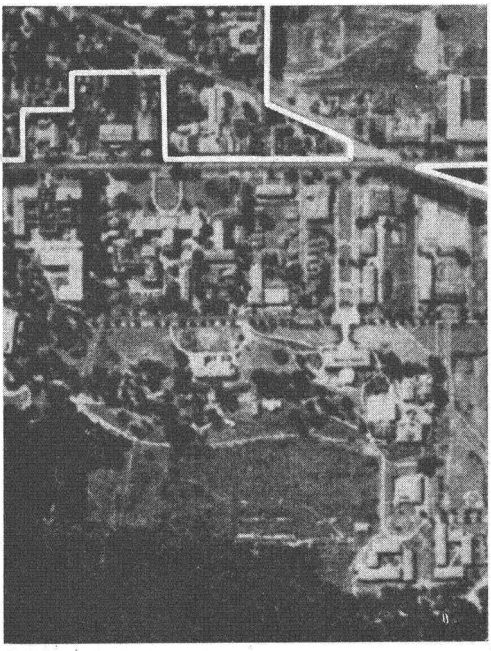

FIG. 7. Institutional Buildings. The lines separate buildings of the University of Wisconsin campus in the bottom of the picture from adjacent land use areas. Compare with buildings of similar function in Figs. 3, 5, and 6. Refer to Figs. 1 and 2. Scale—1:10,000.

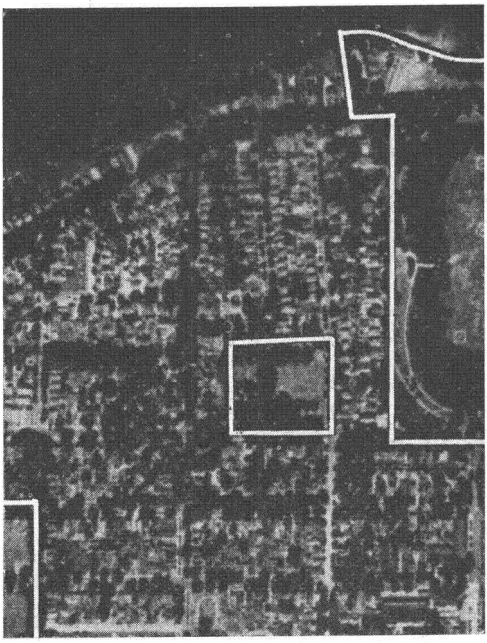

FIG. 8. Recreational Areas. The lines separate recreational areas and parks from adjacent land use areas. Compare with areas of similar function in Fig. 4. Refer to Figs .1 and 2. Scale—1:10,000.

Decentralized institutions stand out among the surrounding buildings because of their greater size, distinctive shape, and high stereoscopic appearance.

Roofs are often ridged or flat.

*Distribution.* Institutional buildings tend to be located near, or as part of the down-town area and decentralized neighborhood areas. Branches of the same institution may be found in both areas, for example, libraries, schools, and utilities.

Schools and churches tend to be distributed evenly throughout Madison, frequently in association with neighborhood commercial areas. However, this is less true of churches, many of which have a central urban location in this city.

Main libraries, and government and utility offices, tend to be located near or within the central core. Hence, decentralized branch buildings may be too small to be characteristically distinctive. Field checking is necessary to differentiate clearly between such buildings and decentralized commercial buildings.

*Associative Characteristics.* Playing fields with recreational facilities, for example, baseball diamonds (diamond-shaped areas with much halation in vicinity) may be identified. Tennis courts, similarly are white in tone.

### RECREATIONAL AREAS, PARKS, CEMETERIES, AND ASSOCIATED BUILDINGS (FIGURE 8)

*Tone.* The light tone of large parts of recreational areas contrasts with the grayer tones of lawns in parks and cemeteries. Some bare patches may give considerable halation around baseball diamonds, on golf-course tees, or in sand traps. Tennis courts and swimming pools generally give a lighter tone to that of their surroundings.

*Texture*

Recreational areas are mottled and of extremely uneven texture, with frequent patches of halation.

The texture of parks and cemeteries is more even than recreational areas, although small areas of halation can be observed.

*Stereoscopic Appearance.* Associated buildings can be recognized by their stereoscopic appearance which will generally elevate them above the surrounding areas.

*Pattern*

The curved driveways of parks and cemeteries possibly could be confused with superior residential areas. The lack of buildings suggests the former land use.

Trees are planted extensively in these areas in Madison.

Grandstands occupy a large part of one side or end of recreational fields.

*Distribution*

Parks and smaller recreational areas as football fields, tend to be located throughout the city, and particularly near the lakes in Madison.

Cemeteries tend to have a peripheral location as do the larger recreational facilities, for example, the golf course on the western fringe of the city.

*Associative Characteristics.* Club houses, pavilions, and crematoriums generally can be seen near the entrances to the parks, recreational areas, and cemeteries.

### Vacant or Idle Areas (Figure 4)

*Tone.* The tone varies from white to dark gray.

*Texture.* Texture is uneven between vacant or idle areas, and within individual areas.

*Stereoscopic Appearance.* There is no stereoscopic appearance.

*Pattern.* Vacant or idle areas have no definite pattern.

*Distribution.* Vacant or idle land is found in all parts of the urban area excluding the commercial core.

The proportion of vacant land increases towards the edge of the city, for example, around the small southern lakes.

Within the built-up area, vacant or idle land is found:

a. paralleling or near the railraods:
b. contiguous to the industrial areas, particularly on the north-east side of the city.

*Associative Characteristics*

Heavy industrial plants and noxious industries, for example, the meat packing plant, and coal gas installation.

Railroad lines, yards, and buildings.

Areas of recent building development, evidenced by halation in vicinity and scattered distribution.

It is often difficult to differentiate clearly between vacant land and areas which are being used. Field checking of "problem" areas is frequently the only reliable way of deciding. Adjacent areas and their functions may give a lead to possible land use, for example, an open space in a built-up residential area (non-suburban area) can be possibly either a park-recreational area, or vacant-land.