# Determining Urban Growth and Change from Aerial Photograph Comparisons

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• THE UTILITY of employing aerial photograph comparisons as a principal means for determining changes in the location and quantity of urban land uses over a period of years is discussed in this paper. It was prepared as an outgrowth of studies undertaken by the Puget Sound Regional Transportation Study as preparation for a regional land use forecast. The purpose is to examine the quantitative and structural growth of land uses over a period of time with the intent of ascertaining whether any persistent patterns occur which could be used in predicting the shape of the future growth of a metropolitan region. Aerial photographs, together with other geographic information sources, form a basis for the determination of these land use patterns.

## PUGET SOUND REGIONAL TRANSPORTATION STUDY

The Puget Sound Regional Transportation Study (PSRTS) is a joint effort of the Puget Sound Governmental Conference and the Washington State Highway Commission, in cooperation with the U. S. Housing and Home Finance Agency, the U. S. Department of Commerce (Bureau of Public Roads), and the Washington State Department of Commerce and Economic Development. The Puget Sound Governmental Conference was the originator of the project and represents the cities of Bremerton, Everett, Seattle, and Tacoma, and the counties of King, Kitsap, Pierce, and Snohomish.

The objective of PSRTS is to formulate a transportation plan as part of a regional development plan to serve twice today's population. The area of study is the most developed 1,700-sq mi urbanized portion of the Pacific Northwest, with a present population of 1.5 million. This objective, as well as the extent and content PSRTS, and a fixed budget limit were all defined in the Prospectus (1) prepared by a technical committee prior to the beginning of the study.

Land use information is essential to a transportation study for two reasons: (a) because the number of trips which leave or arrive at a place within an urban complex is closely linked to the kind of land use found there, and (b) because the travel patterns within the study area depend on the desires of people to travel from one kind of land use area to another for a particular purpose. If it is possible to predict the future location of different land use configurations in an area, it is then possible to estimate the number of trips which may be forthcoming from these areas, together with an estimate of their distribution to other areas. Such travel forecasts can tell where the transportation network will be overloaded much in advance of its actual occurrence and plans can be prepared to avoid such conditions.

## URBAN GROWTH AND LAND USE FORECASTING

### The Land Use Forecast

The land use forecast is the first of two primary activities undertaken by the Land Planning Division of PSRTS. The second is the preparation of a land use plan, not discussed as part of this paper.

A land use forecast is a relatively precise image of how land will be used in the future, based on the premise that present urban development trends will continue and

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that land use controls will be much the same in the future as they are today. A land use plan, on the other hand, would be a consciously-directed arrangement of urban land uses designed to maximize a set of community goals. In this particular study, the object is to forecast the quantitative and locational structure of land uses in the Puget Sound region for 1985 in areas ranging from as small as four blocks in extent in a central business district (CBD) to as large as several square miles in outlying areas. The land use forecast is derived by integrating detailed analyses and forecasts of specific land uses with the findings from studies of other elements which are felt to influence the land use locational pattern. These other elements are direct influences on the ultimate distribution of specific land uses and are therefore considered as parameters, allowing much more precise specification of location. These studies are three in number:

1. A physical limitation study, depicting the location of areas of various degrees of slope and soil type which will restrict or influence the emerging pattern of urbanization.
2. A local plans and program study which evaluates all zoning, plans, and progress of planning agencies in terms of their record of effectiveness and dependability in determining land use locations and intensities.
3. A historical growth study in which the past evolution of urban growth patterns and specific land uses is determined. Location trends, quantities of land per capita and other indices are derived from this study which, if persistence is shown over a period of time, may aid in forecasting the structure of land use locations in the future.

Although these studies are considered to be very directly influential in land use allocations, others derived from sociological, demographic, economic, and political influences can also be undertaken. Population and economic base studies and projections were undertaken to provide bases for determining the total amount of land in different uses in the future regional area.

### Historical Growth Study

The study of historical land use patterns is basically one of map research. In as clear and precise a manner as possible the uses of land in past periods must be identified from whatever sources are available, then entered and measured on maps of a suitable scale for specific dates in the past. Normally, it is impossible to obtain data for a specific date or even a specific year. In general, the researcher must be content to specify a period ranging from one to two years on each side of a target year, particularly for periods 30 to 40 years or more in the past. The degree of land use detail which is sought becomes more restricted the farther back in time the research goes and has a direct bearing on the precision of land use comparability and quantification over time.

## AERIAL PHOTOGRAPHS AND HISTORICAL GROWTH

### Sources of Information

Old maps are the first source of information, whether locally prepared or prepared by some Federal or State agency. Works Projects Administration maps are useful. Books, newspapers, and "old timers" are likely sources if the researcher knows just what to look for or what to ask about. Often these sources are resorted to in filling out data on an incomplete map. Old city directories are useful and the local library is often a fruitful source. Old photographs aid in identifying specific uses. Aerial photographs are valuable if they are available at scales sufficient for accurate interpretations of urban land uses through study of structural differences, ground markings, etc. They can be secured in some areas for periods dating back to the 1930's or before. Some oblique views can be found in some cities for periods before the turn of the century. These photographs, when compared to recent flights form a secure foundation for historical growth comparisons.

## Available Aerial Photographs

A search for historical data in the Puget Sound region uncovered a complete set of aerial photographs which were flown over the most populous part of the area in 1936. These photographs were prepared as part of a county program and were available, if required, at a scale of 100 ft to 1 in. They formed a sound basis for comparison with the complete aerial photography coverage obtained by PSRTS for its own purposes in the summer of 1961. It was determined that the negatives were still in stock and prints could be obtained at any desired scale from the aerial survey company that had taken the aerial photographs in 1936.

A few prints of such photography were obtained for use in preparing this paper. The original prints, available in the vaults of the county which originally had the photography taken, were used in the actual preparation of historical data used by the Transportation Study.

Other aerial photography coverage was also available for various dates in the past and was utilized in preparing historical study data. The example presented here is one which depicts extraordinarily good coverage at a very satisfactory scale.

## Comparison of 1936 and 1961 Photographs

The first photographic pair (Fig. 1) shows a suburban area of Seattle. The 1936 photograph (A) shows a major highway through the center. Two crossroads appear one at the top and one in the middle. By photographic interpretation, a few scattered commercial structures along the highway right-of-way, a railroad right-of-way, a school, the beginnings of residential development on a block pattern, and large areas of open land, some in orchards, some in small gardens, but mostly unused, can be identified. The accuracy of the interpretation can be increased by reference to old city directories, USGS topographic maps published on a quadrangle basis, when available, Sanborn maps, and old W. P. A. maps.

By 1961 (B), the area has shown substantial residential and commercial growth. The road pattern is the same although virtually all roads are paved. The area is about 100 percent developed. Commercial uses are strung out in profusion along the highway, and each of the crossroads has attracted a supermarket. The school to the left has expanded considerably, and a new site has been established at the lower middle right edge of the photograph. Land uses were first identified by photographic interpretation and then checked in the field as part of the basic land use inventory for PSRTS.

Figure 2 shows several different types of uses in the same general area. To the right in the older photograph (A) is a residential area. In the upper right corner it is fully developed, in the lower right, the streets and sidewalks are laid out but there is very little development. The middle right of the photograph contains a steep slope area, evident by the switchback road in the lower part of the photograph and the curving road in the upper portion. The mining of the bank seems to indicate a clay deposit used for brick production. A major road passes through the area with some scattered wholesale or industrial properties along each side. The residential area in the center, although somewhat scantily developed, is being invaded by industrial uses. Other industries appear on the upper left. A roundhouse is in the upper left corner. Again, exact uses can be determined from old directories if finer detail is required.

By 1961 (B), considerable infilling has occurred. The residential area is fully developed and the streets are paved. A power line cuts a swath through the residential area ending at a substation in the industrial district. The industrial area along the road has expanded and the intrusion into the residential area continued. In the area along the left part of the photograph considerable industrial growth is evident. A fully developed industrial district has emerged.

Figure 3 is included not so much to indicate the extent to which an area can change but to show the hazards possible in predicting land use patterns.

A study of this type is undertaken to formulate some indication of trends and persistent patterns of location found in each land use type. Essentially, this is the same as taking old aerial photographs and predicting the land use pattern seen on the new ones. Figure 3 shows an area in 1936 (A) laid out in city blocks but very sparsely

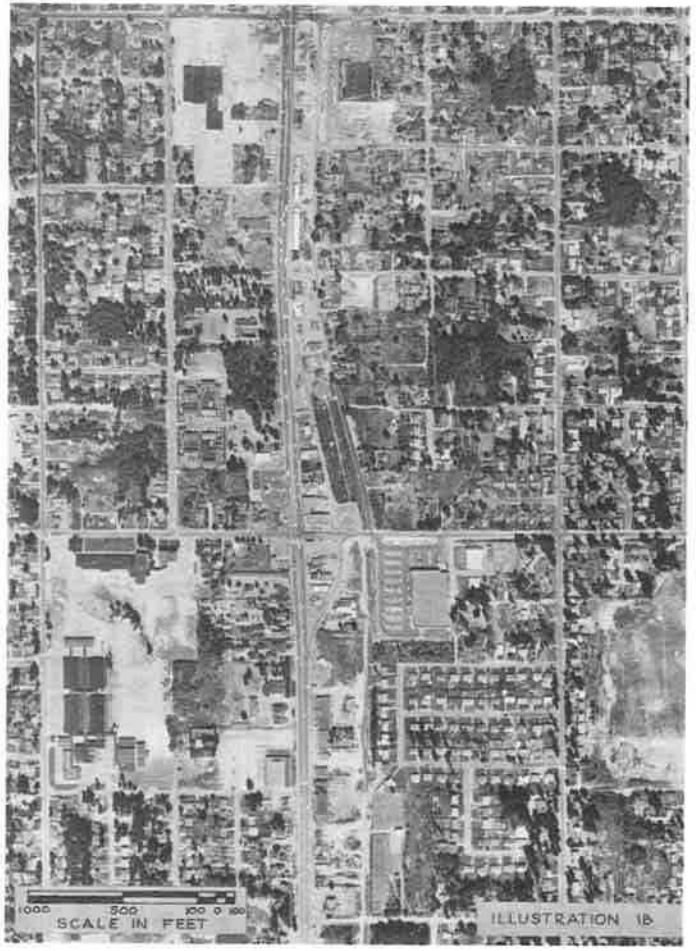




Figure 1. Photographic comparison: (A) 1936; (B) 1961.

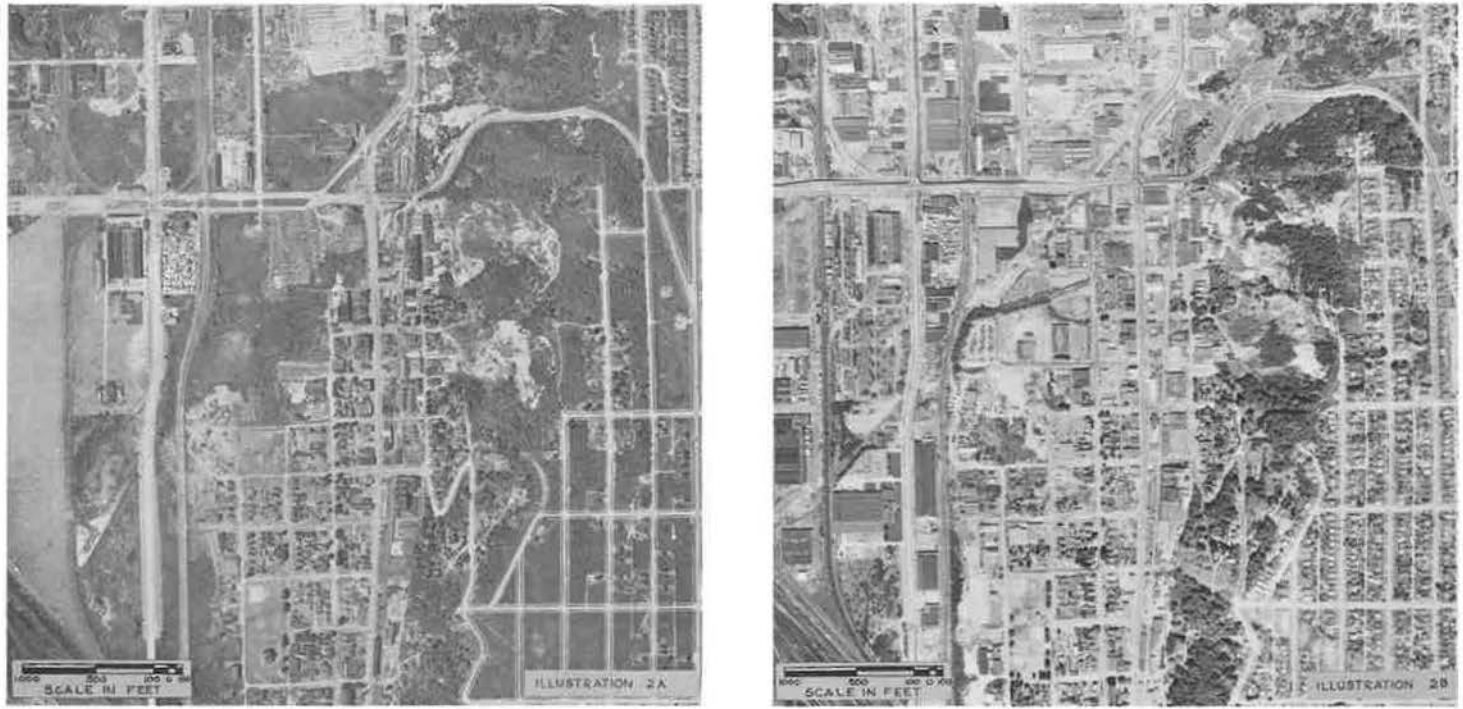



Figure 2. Photographic comparison: (A) 1936; (B) 1961.


Figure 3. Photographic comparison: (A) 1936; (B) 1961.

developed. There is a large block in the lower center of the photograph. By 1961 (B), this block had become the site of a shopping center, evident by the unified arrangement of the buildings and the large parking areas surrounding them. Trying to predict this type of land use at the time the old photograph was taken would probably have led to a wrong conclusion, because such shopping centers were completely unknown at that time. What new types of land development may occur 20 to 25 years from the present day are also unknown. It is assumed that for the most part existing patterns and types of development will persist, but as this example indicates, it is possible to err.

Figure 4 also shows the hazards of prediction. In this area some land has been created over the past 25 years. In the 1936 photograph (A), a dockside area covered partly with structures is shown. The central and upper left indicate a lumber mill. By 1962 (B), although the lumber mill remains the same, considerable increase in land use has occurred in other parts of the area. In addition, substantial quantities of new land have been created and structures are beginning to appear in these locations.

Figure 5 shows a pattern which has now become familiar, an extensive growth over an area which was largely undeveloped in 1936 (A). However, in the area in the lower right there is a crossroads clustering of stores. By 1961 (B), this complex has expanded considerably and ribbon growth extends along the main road to the north. This type of growth is reasonably easy to predict, and even the structure of retail store types found here can be predicted with satisfactory accuracy. The data obtained from analyses of changes revealed by these photographs are of considerable assistance in this task.

Although some commercial uses could not have been predicted as to location in 1936 (as indicated in the shopping center example), "strip" commercial development could likely have been successfully predicted as to location. The utility of a study of this kind is in determining how and where patterns do change. By further research, it is possible to determine why changes have occurred and whether further changes might occur in the future.

## PREPARING ANALYSIS MAPS

Once land use data have been ascertained by interpretation of the aerial photographs, it must be transferred to maps for analysis of time trends.

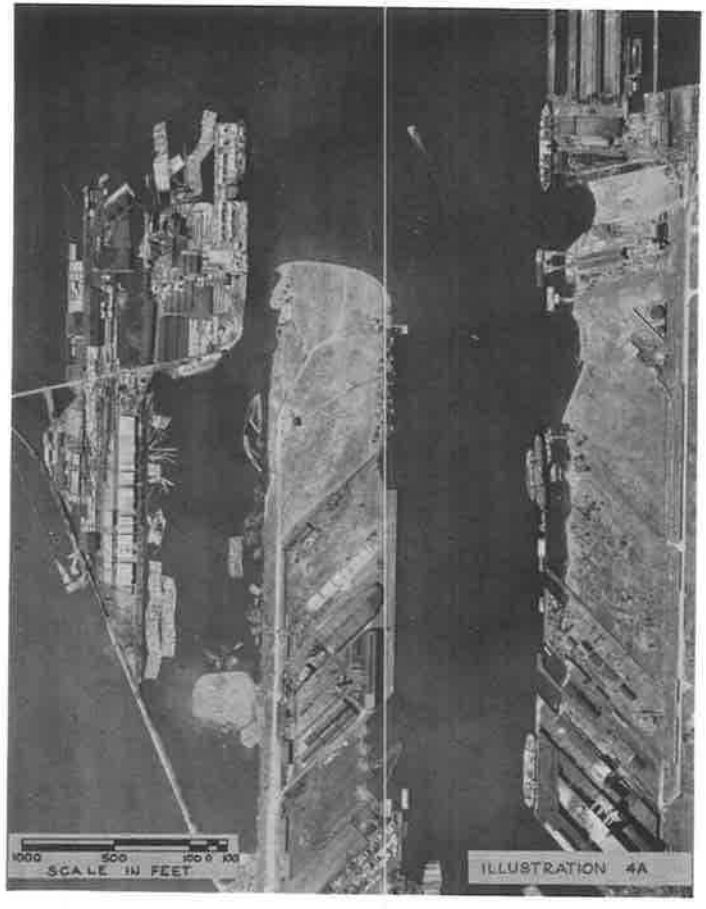
### Mapping by Decades

For analytical purposes, the 1936 photographic coverage in the Puget Sound region was checked against other data sources. It was determined that, in most cases, changes and increases in land use had been so slack after 1930 that these photographs could safely be interpreted as representing conditions quite close to 1930.

The techniques employed in interpreting land uses from aerial photographs were referred to previously. Historical uses can be interpreted directly from the photographs in generalized categories. More precise delineations are obtainable through supplementary means such as old city directories, old Sanborn or other maps, and similar sources. Unfortunately, in the Puget Sound region, aerial photographs were not available for all the decades studied or for the total area surveyed. Had they been more generally available, they would have been unsurpassed as a data source.

When interpretations are completed, they must be transferred to an analysis map of satisfactory scale. At PSRTS a scale 1 mi to 1 in. was used, and, although resorting to scales of ½ mi to 1 in. and larger will permit more precise mapping, the choice of scale depends directly on the accuracy and degree of detail obtained in the historical research. The more refined the detail (which must be consistent over general target dates), the larger the scale may be, and more land use categories can be shown.

One map is prepared for each decade (or for intermediate years, if desired) showing all the land uses in a color code system. Residential uses are shown in yellow (with shadings through brown to indicate duplex and apartment uses, if desired), commercial in red, industrial in purple, etc. (2). At PSRTS, only urban uses were interpreted and recorded, although open uses such as agriculture, timber, mines, quarries, and similar categories can be shown, if desired. Figure 6 shows the generalized result



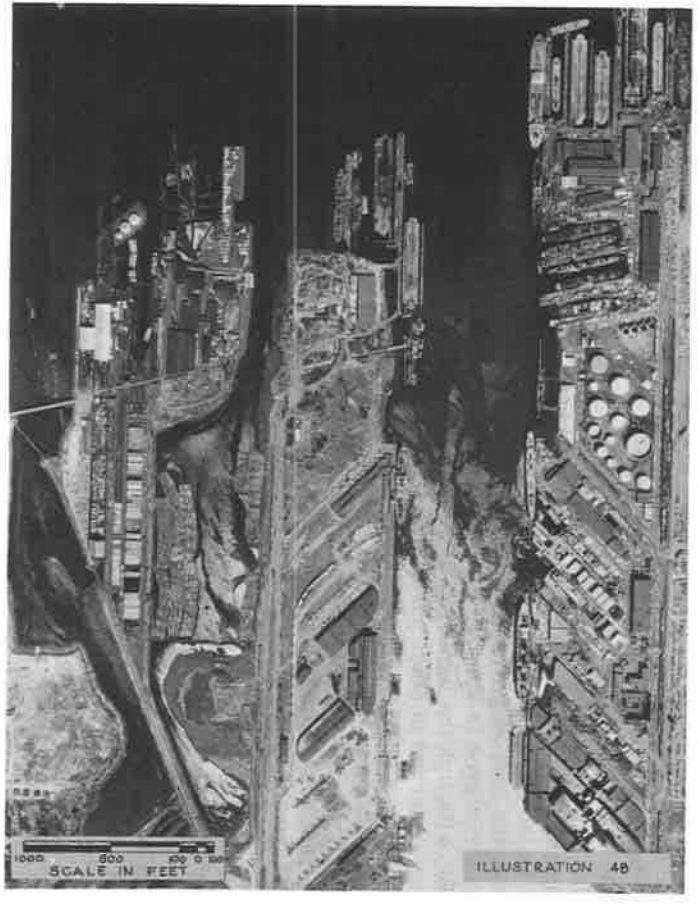




Figure 4. Photographic comparison: (A) 1936; (B) 1962.



Figure 5. Photographic comparison: (A) 1936; (B) 1961.

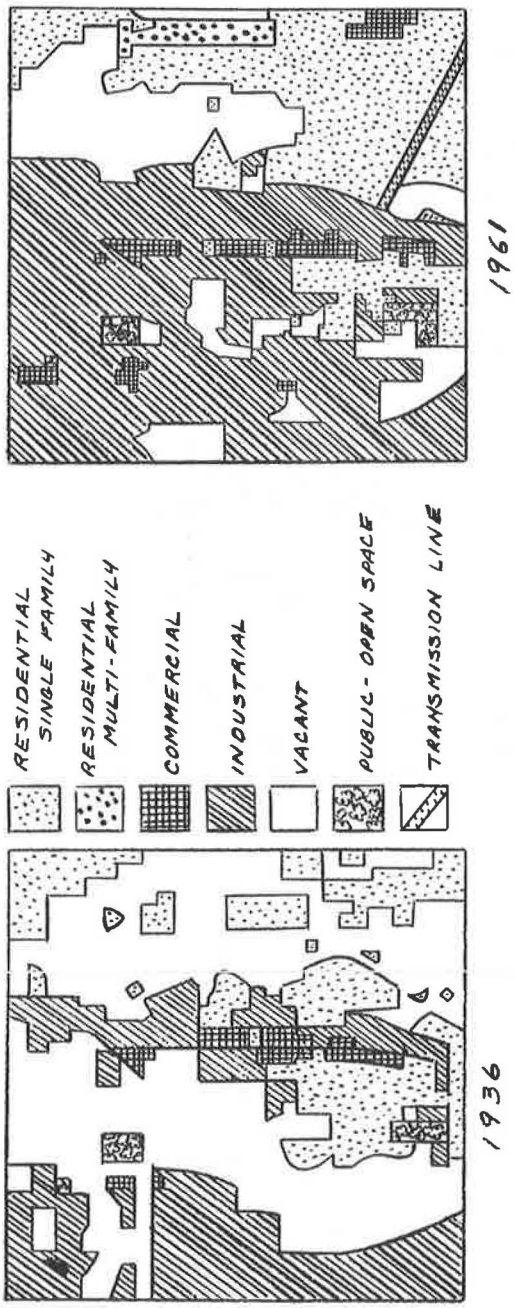



Figure 6. Land use comparison.

of interpreting the 1936 photograph (Fig. 2A) and the 1961 photograph (Fig. 2B) utilizing symbols rather than color.

### Total Urban Growth

The land use maps which have been prepared depict the total growth of the urban complex over a given period of time. If all the uses were colored black, urban growth would look something like a creeping ink spill when viewed decade by decade. An example of this is shown in Figure 7. The amount of land which has been urbanized is measured at this stage to provide a basis for correlation with other indices. Measurement can be made by conventional means such as a transparent overlay grid with standard units of area, or by means of a planimeter.

### Separate Land Uses

Relying on the separate color designations for each type of land use, analytical maps which show the changing structure of distinct land use classes can be prepared. Utilizing a matte finish transparent overlay material, one sheet for each land use, a time series of changes can be shown by successively tracing the extent of the particular land use on the overlay, decade by decade. Figure 8 shows the growth of industrial land uses over a 40-yr period, and Figure 9 shows the growth pattern of commercial land for the same period.

Measurements of the amount of land in each category are also made from the overlay sheets for later correlation and are added together to check the measurements obtained in preparing the map of total urban growth.

## HISTORICAL GROWTH ANALYSIS

Correlations with independent indices, analysis of locational trends, and determinations of the influence of physical and man-made features form the basis of the growth analysis.

### Analysis of Total Urban Growth Map

After the map of total urban growth is completed and the areas measured for each decade, an analysis is undertaken to determine if there are any

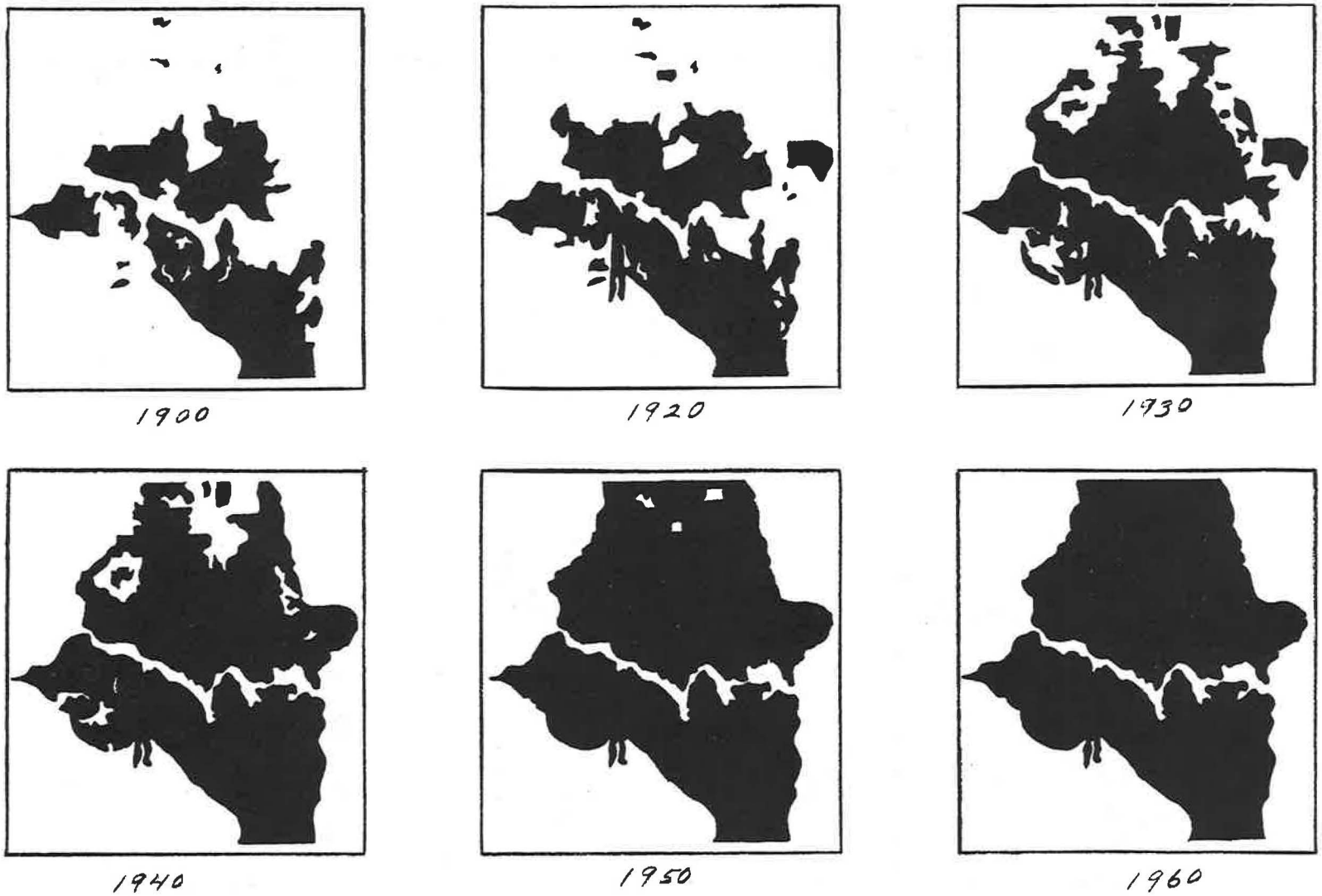



Figure 7. Total urban growth.


Figure 8. Industrial growth.

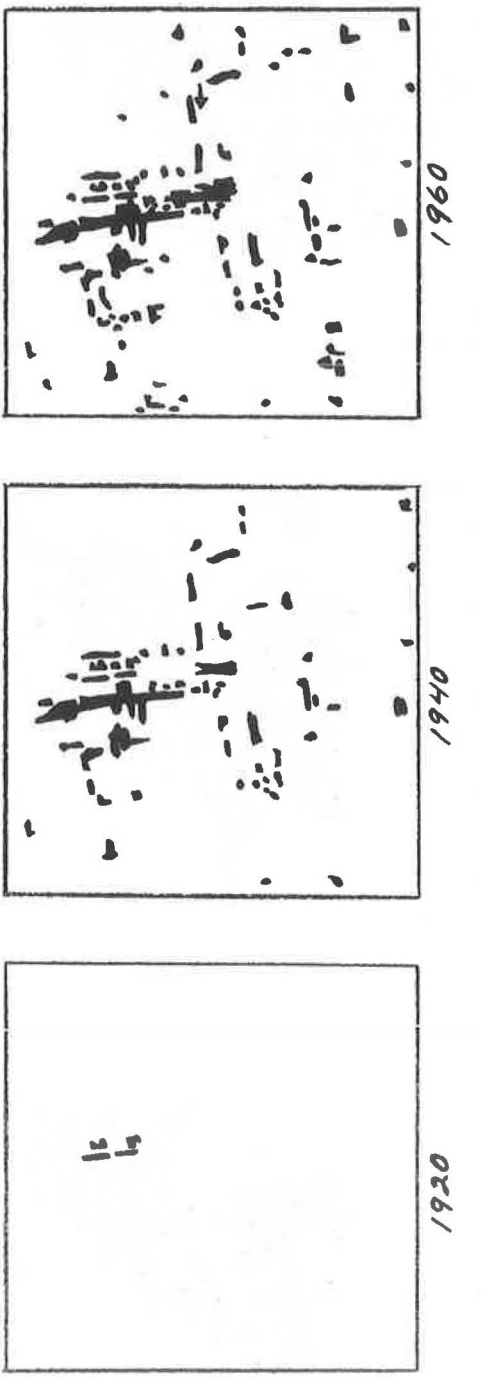



Figure 9. Commercial growth.

persistent trends. The total urban area measured by decades is first correlated with population by decades. If there is a long-term stability in the relationships obtained, there may be a valid basis for implying a persistence in the supply of urban land related to population.

## Locational Patterns

A study of the locational pattern of urban growth is next undertaken. In this analysis the growth pattern is examined for persistence in directional trends. This can be done by selecting base lines running through the center of early settlements and measuring the quantities of growth in each direction by decade. The shape and structure of growth is also observed to determine if it has proceeded in an agglomerated or fragmented manner.

## Influence of Physical Features

The influence of physical features is next considered in an attempt to understand whether they have a direct or indirect relationship to growth. Areas of steep topography, bogs, swamps, rocky areas, etc., are correlated with the growth pattern to determine if they have channeled, restrained, or otherwise influenced the emerging urban structure over a given period of time. If a physical barrier is at first seen to deter or channel the growth pattern and later to succumb to growth pressures, it may indicate that the potential value of the land had reached a point where some modification of the physical features became economically feasible. On the other hand, some features such as slide areas, extremely steep and rocky topography may never be overcome.

## Influence of Man-Made Features

Man-made features are considered to determine if they also influence the pattern of growth. In this analysis, particular attention is focused on the provision and improvement of key roads or highways, the installation of bridges, ferries, and other factors related to the transportation pattern. In past decades, the influence of streetcar, interurban, and railroad service is usually very evident. In more recent times the provision of major high-speed arterial highways is usually influential in affecting the growth pattern.

## Analysis of Separate Land Uses

The methods used in analyzing each separate land use are essentially the same as those for total urban growth. Close attention is paid to each distinct land use growth pattern and to the links with man-made features. Some uses are also highly sensitive to physical features. For example, industrial lands grow by agglomeration, adding to basic locations each decade with very few new sites being established over time. Industry is highly sensitive to slope and generally demands a complex of transportation facilities such as highway, rail, and water, although some more recent sites are not so dependent on rail. Retail-commercial areas, on the other hand, generally grow by fragmenting, the only key growth area in the past being the CBD (which is now declining). Commercial land is never very large in area, even new shopping centers being small in comparison with industrial lands. Orientation to the key modes of personal travel is the primary single link to man-made features. Relatively level land is required, but, because of the high value of a good commercial location (such as a major crossroad), physical impediments can be economically overcome. Figures 8 and 9 show the growth pattern of industrial and commercial lands in a part of the Puget Sound region.

## Analytical Findings

In addition to the distributional pattern previously outlined, some more general relationships relate to land use quantities.

In the Puget Sound region, the historical growth study indicates a changing relationship between total urban land in use and population growth. Figure 10 shows this

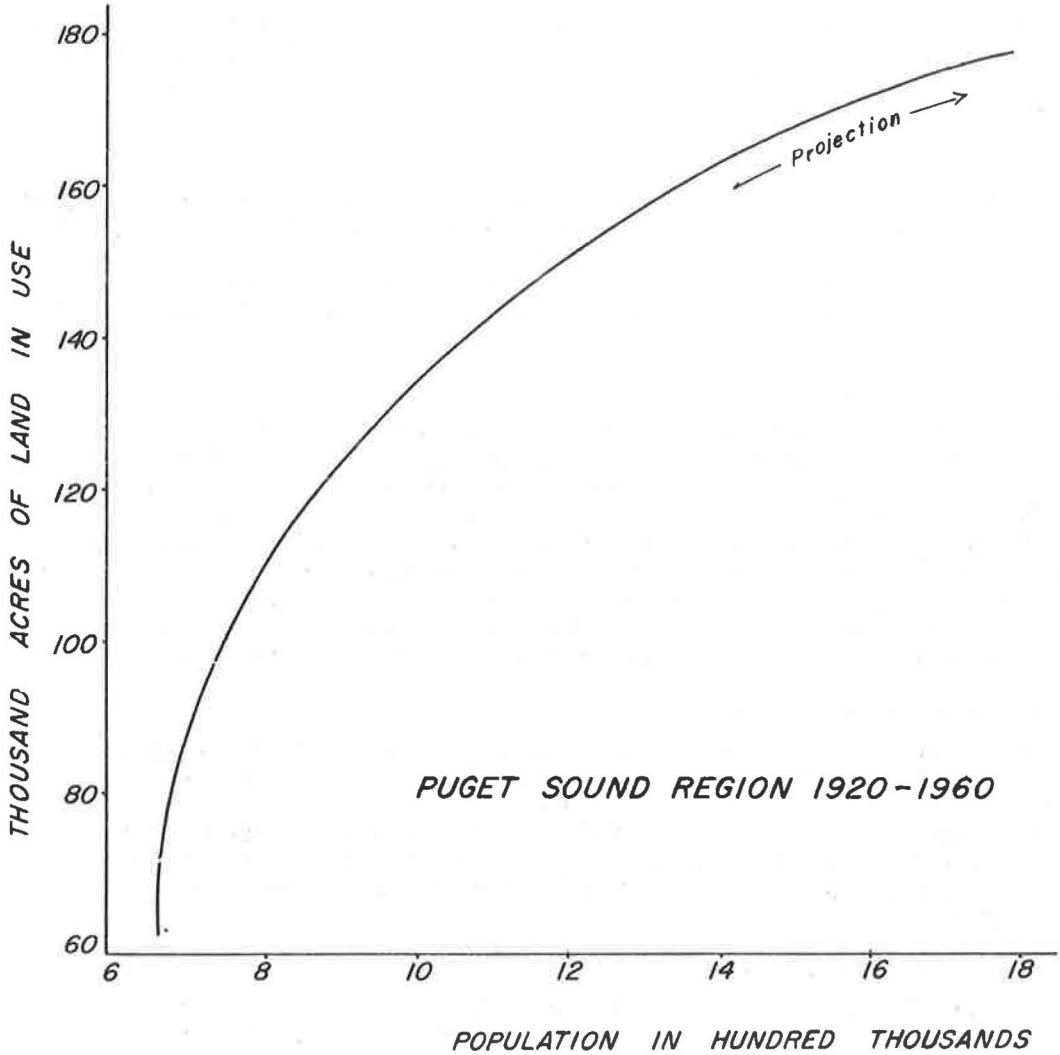



Figure 10. Land in urban use.

TABLE 1

URBAN LAND USES IN THE PUGET SOUND REGION, 1920-1960[1]

| Land Use | Year | | | | |
|---|---|---|---|---|---|
| | 1920 | 1930 | 1940 | 1950 | 1960 |
| Residential | 1,712 | 1,950 | 2,243 | 2,286 | 2,320 |
| Commercial | 73 | 188 | 222 | 212 | 209 |
| Industrial | 446 | 603 | 700 | 567 | 533 |
| Govt. and public | 1,571 | 1,892 | 2,449 | 1,789 | 1,503 |
| Public open space | 261 | 588 | 807 | 624 | 601 |
| Total | 4,063 | 5,221 | 6,421 | 5,478 | 5,166 |

[1] Square feet of land per capita, including streets.

relationship over five census dates. It is evident that as population increases the amount of land in urban use increases at a decreasing rate. This is due in part to increases in density which occur as the population base expands.

Table 1 shows some of the results of the per capita analysis, indicating gross areas and including streets. Residential lands occupy the largest single use area with a per capita rate indicating a steady increase over time. Government and public lands are large space users primarily because of the relatively large number of military establishments occupying extensive land areas in the region. Variations in the rate of provision of government land and public open space depend largely on the policies and financial abilities of the different levels of government. Commercial uses occupy the smallest land area and appear to be relatively stable in rate when compared over time.

### Reliability for Prediction

A historical growth analysis can provide a useful and reliable tool for land use predictions provided it must not be too detailed and is used in conjunction with a series of other analyses. Very recent trends in land use location are also valuable knowledge as a check on the persistence of past growth patterns.

The two components of the prediction are the amount of land and the location. Amounts are derived from the previously derived correlations. For example, if there is a clear, persistent relationship between amounts of land and population, then when a population forecast has been prepared, the amount of land to be urbanized can be predicted with general reliability. The location pattern can be determined by applying the findings of the location analysis to the predicted amounts of land. The impact of physical features and proposals for man-made changes (such as new freeways and bridges) must be noted and the potential influence in the future land use pattern assessed before the final structure can be determined.

Such general forecasts must be evaluated in terms of other analytical sources and adjustments made in allocations. In essence, they form the first approximation of the image of the future urban area—a general understanding of predominant growth movements and location patterns.

### Aerial Photographs for Analysis and Prediction

The most important aspect of any historical analysis, on which a future forecast is based, is the reliability of the source data. Where aerial photographic coverage is available and adequate interpretations and measurements have been made, there is no question about the reliability of the data. In the case of the Puget Sound region, there was not sufficient aerial coverage, and it was necessary to resort to other sources of information. If there had been a regular program of aerial surveys, perhaps once every decade or preferably every half decade, a firmer basis for analysis of growth would have been obtained. In addition, forecasts of urban growth could have been entered on copies of the aerial photographs and checked for accuracy of prediction at a later date. This type of analysis emphasizes the need for periodic aerial surveys of the urban area. By making such periodic taking of suitable scale aerial photography a joint undertaking of several governmental agencies and by making it possible to obtain inexpensive copies, it should be possible to achieve this goal.

## SUMMARY AND CONCLUSIONS

In this paper an exploration has been made of the utility of aerial photographic interpretation, measurement, and analysis as a means for determining urban growth and change in past periods. As a working tool for this purpose, aerial photography is unexcelled. When photographic interpretation is supplemented with secondary source data, the accuracy of urban land use interpretations can be as detailed as required and can accurately portray changing locational tendencies of land use over time. From land use measurements the quantitative aspects of land use changes can be determined and compared with changes in other key growth indices. Aerial photographs provide

a firm basis for allocating land use forecasts and for checking their accuracy through periodic aerial resurveys. Essentially, this inventory and analysis adds an important function to the growing number of uses which are made of aerial photographs in examining the problems of contemporary urban society.

## REFERENCES

1. Prospectus—Puget Sound Regional Transportation Study, approved by Technical Committee, 7/9/60 (Rev. 2/16/62).
2. Howlett, Bruce, "Land Use Handbook: A Guide to Undertaking Land Use Surveys." Northeastern Illinois Metropolitan Area Planning Commission, Chicago (1961).