A CONTAGION THEORY OF URBAN DEVELOPMENT: AN EMPIRICAL TEST OF THE TUCSON METROPOLITAN AREA (1967-1976) (ARIZONA)

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THE UNIVERSITY OF ARIZONA M.S. 1982

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A CONTAGION THEORY OF URBAN DEVELOPMENT: AN EMPIRICAL TEST OF THE TUCSON METROPOLITAN AREA (1967-1976)

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL ECONOMICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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STATEMENT BY AUTHOR

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APPROVAL BY THESIS DIRECTOR

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Nov. 29, 1986
Date

To my parents, Malcolm and Bessie Willis, in appreciation of their love and support.

ACKNOWLEDGMENTS

The author wishes to express her sincere thanks and appreciation to Dr. Dennis C. Cory for his guidance and patience throughout the preparation of this thesis. I also wish to thank my committee members, Dr. David C. Barkley and Dr. Robert C. Angus for their constructive comments.

Appreciation is extended to Katrina Richter of the City of Tucson Planning Department for providing land-use maps for this thesis and Than Van Cao, Research Associate, The University of Arizona, for his assistance in compiling statistical data.

The author is also grateful to Dr. Ron Oaxaca, Department of Economics, The University of Arizona, for his instruction in the interpretation of statistical models used in this thesis.

This work was funded through Regional Project 125, Department of Agricultural Economics, The University of Arizona.

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ABSTRACT

Present decisions concerning the development of high-intensity land uses dictate to a great extent the living environment of present and future generations. This is due in part to the irreversibility associated with most urban expansion. Long-range planning goals are needed to assure a safe and healthy environment for society well into the future. To successfully achieve long-range planning goals, it is helpful to understand forces that affect urban growth. Analysis of conversion data for the Tucson Metropolitan Area in the 1967-1976 period indicates that one factor influencing growth rates is the density of existing high-intensity land use. Development of high-intensity land uses increases the likelihood of further development until the availability of vacant land becomes a limiting factor. Awareness of the contagious nature of urban growth can affect public programs designed to guide urban growth, such as zoning, transferable development rights, use-value taxation, and development taxes.

CHAPTER 1

INTRODUCTION

Urban growth results in an ever-present need for the expansion of accommodations designed to support an increasing population in a manner reflecting individual income and/or personal taste. These accommodations include, among others, employment opportunities, housing, public goods and services, recreational activities, and the associated infrastructure. Land suitable and available for such development is a limiting factor in urban expansion, resulting in competition among various land uses for the development of a given land tract.

Left solely to market forces, the right to develop any given land tract would be awarded to the highest bidder. This allocation may result in short-run economic efficiency, but will not necessarily produce a land-use mix that, in the long-run, will be either efficient or equitable. In fact, it is possible that such a mix would actually prevent an optimal land-use pattern in the future. This is due to the irreversible nature of most types of development. Permanent structures such as homes, offices, commercial outlets, and industrial complexes are characteristic of much of the development that occurs in an expanding urban area. These structures are designed to remain functional for an indefinite period, rendering the land upon which they are built unsuitable for other uses. Thus, present decisions concerning land-use conversion dictate to a great extent the environment in which future generations will live.

Because of the irreversibility associated with urban expansion, most city, state, and county governments are concerned with long-range land-use planning to provide a safe and healthy environment for the present as well as future generations. To successfully achieve these long-range goals, it is necessary to understand those factors that affect urban growth. Foresight into the affects of local socioeconomic conditions and public policies on the rate and direction of growth can be a very useful tool in the successful achievement of these goals.

In this thesis, the effects of the density of existing high-intensity land uses on the rate at which further development occurs is examined. Historical conversion data for the Tucson Metropolitan Area are documented, and then analyzed to determine the extent to which existing development exerts an influence on future growth.

Conversion from low- to high-intensity land uses is likely to occur slowly in sparsely developed areas. Lack of a sophisticated infrastructure of roads and utilities, and less accessibility to facilities such as schools, shopping centers, and places of employment tends to lower aggregate net benefits associated with developing those areas. The contagious affects of growth become more apparent as more land area is intensely developed. The liklihood of rapid conversion is greatest in those areas that have developed a sound infrastructure, yet retain substantial amounts of vacant land suitable for development. This contagious effect diminishes after development has occurred to the extent that land availability becomes a limiting factor in urban expansion.

Public awareness of the contagious nature of urban growth can enable individuals to make predictions concerning future activity in any given area. This, in turn, can have an affect on public reaction to policies designed to guide development in a manner deemed desirable. Several tools commonly used to guide urban growth may become less effective as the public becomes more aware of the contagious nature of that growth. These tools include use-value taxation, transferable development rights, development taxes, and zoning. Knowledge of the possible pitfalls in these programs resulting from awareness of contagious growth is needed to maximize their effectiveness.

CHAPTER 2

THEORY OF LAND-USE ALLOCATION

Land can be viewed as a commodity with fixed physical supply. Land area cannot be augmented by human efforts, thus the existing supply must be allocated between competing uses. The relative desirability of any one land use over another at any given time is largely a function of location. Because land is fixed in space, a large part of its value is derived from the manner in which surrounding land is utilized. Thus, spatial setting is a determinant of when and what manner land resources are to be utilized.

This chapter deals with the intertemporal allocation of land resources to provide needed services to society, and is organized into four sections. First is an overview of the supply and demand for the real estate services which land can provide. Second is a discussion of the changes in the supply and demand of those services with respect to location, defined as distance from an urban center. Third, theory pertaining to the optimal intertemporal allocation of land resources is presented. Traditional theory is presented, followed by a modified theory that includes the effect of location on the present and future desirability of a land parcel. Fourth, implications of location as a factor affecting future net benefits of development are discussed.

Supply and Demand for Real-estate Services

Although the physical supply of land is fixed, the manner in which land is utilized is dependent upon the economic supply and demand of real-estate services. Real property is much more than a number of square feet of soil in a specific geographic location. Land ownership includes a bundle of services associated with that piece of property. For example, a parcel of land used for residential purposes can provide shelter and various levels of privacy amenities, accessibility to schools, shopping centers and places of employment, and a general environment determined in part by the way in which nearby acreage is utilized. The relative desirability of these and other services varies from one individual to the next and forms the basis for real estate transactions (Shafer, 1977, pp. 72-75).

Although some services are inherent in the acreage itself, others can be controlled through zoning ordinances. Some activities can result in external effects such as excessive noise, air and water pollution, and aesthetic disamenities. Zoning is one of the most widely used techniques to reduce or eliminate these effects by restricting the types of activities which may take place in a given area (Irwin, 1980, Chapter 5). Residential services provided in some areas preclude the provision of commercial services. Within the residential sector itself there may be constraints as to density, building specifications such as width and height, and the overall neighborhood character. All of these constraints affect the services available to the owners of a given land unit. Personal preference and the budget constraint of an individual determine the particular combination of available real estate services that he is willing to purchase.

As with most other commodities, aggregate demand for real estate acreage is a downward-sloping function of price. More land units are purchased as the price falls. Economic supply, on the other hand, increases as the price increases. Although the actual supply of land acreage remains constant, modification of the land by the construction industry to supply services is dependent upon the price it can receive. The intersection of supply and demand functions determines how much land is transformed to provide desired services.

Economic Impacts of Increasing Distance from Urban Centers

The dominant underlying price component is location. Since a given land unit is fixed in space, the services obtained through its use depend in part on its spatial setting. Land in remote regions has less access to highly developed urban areas and the services associated with urban environments. Likewise, some services associated with rural regions, such as privacy, scenic amenities, and absence of noise and pollution, are less prevalent in areas more densely developed. The location of any given land parcel, in terms of distance from an urban center, or Central Business District (CBD), is a major factor determining the services provided and subsequently the price that a consumer is willing to pay to take advantage of those services. Shafer (1980, pp. 91-92) discussed site advantages associated with location and the resulting effects on property values. Empirical evidence relating land values and distance from the CBD was reported by Diamond (1980) and Lee (1979).

As the availability of real estate services changes with the distance from the CBD, so do the marginal costs and benefits associated with those services. Assuming a competitive real-estate market, marginal benefits can be represented by the demand function, marginal costs by the supply function, and thus the change in supply and demand relative to a change in location can be determined.

Two sets of supply and demand functions were compared to illustrate the effect of location on the development of high-intensity land uses. In an initial supply-demand diagram, acreage is assumed to be located on the rural-urban fringe. There is often little potential for further development within a highly urbanized area because there is little vacant land on which further development can occur. The rural-urban fringe, however, affords proximity to previously developed areas and the infrastructure therein, yet vacant land for potential development is available. A second set of curves was generated under the assumption that acreage is found farther from the urban center in the rural area beyond the rural-urban fringe. The relative changes in supply and demand were found by determining the changes in marginal costs and benefits of real estate services as one moves away from urbanization.

Change in Marginal Benefits

As population moves outward from the rural-urban fringe, some marginal benefits decline and others rise. The most significant loss in benefits results from increasing transportation costs. Rural areas generally afford less assessibility to facilities such as schools, shopping centers, entertainment, and places of employment. Utilization of urban-based services requires greater expenditures on fuel and car maintenance and more driving time. As a result, there is downward pressure on the demand for land located farther from the urban center.

There are, however, some benefits that increase in rural environments. Driving costs due to traffic congestion, pollution and noise tend to be less, whereas values derived from privacy and scenic amenities may rise.

These positive aspects may outweigh the negative effects of assessibility, resulting in an upward shift in some individual demand curves (Richardson, 1977).

An individual considers his personal preferences in terms of trade-offs between costs and benefits in relation to budget constraints when deciding where to reside. It is well documented in urban-economic theory that population density decreases with distance from the CBD (Figure 1). The rate of decline, however, may vary in response to efficiency of transportation networks and average income, among other factors. Segal (1977, pp. 344-351) presented population density gradients of some U.S. cities and the changes in those gradients as modes of transportation improved. This trend supports the view that in the aggregate net marginal benefits decline with distance from an urban center.

Change in Marginal Costs

Whereas the demand curve represents marginal benefits accrued to consumers, the supply function represents marginal costs of producing those services as viewed by the construction industry. As distance from the CBD changes, so do construction costs, resulting in a shift of the supply curve. Although land costs are generally lower in more rural areas, increasing construction, marketing, and overhead costs tend to raise net marginal costs of development (Ricks, 1970).

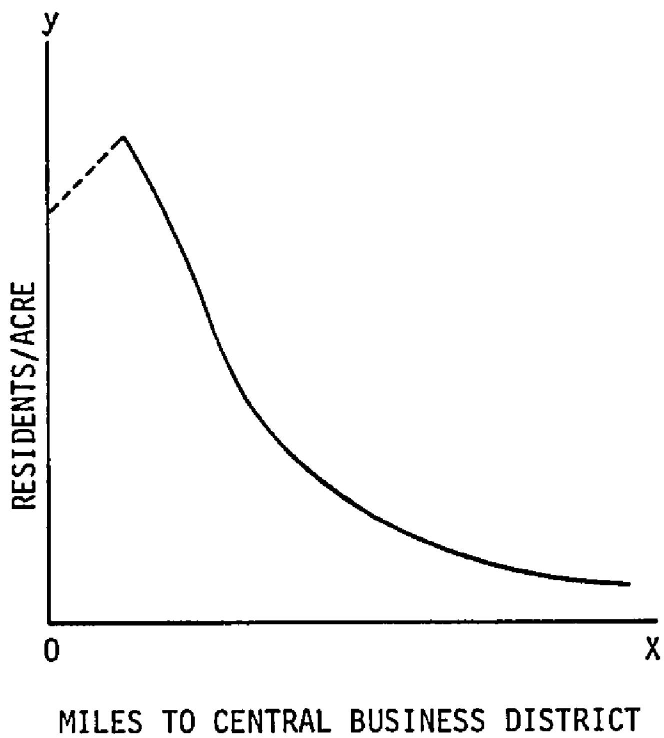
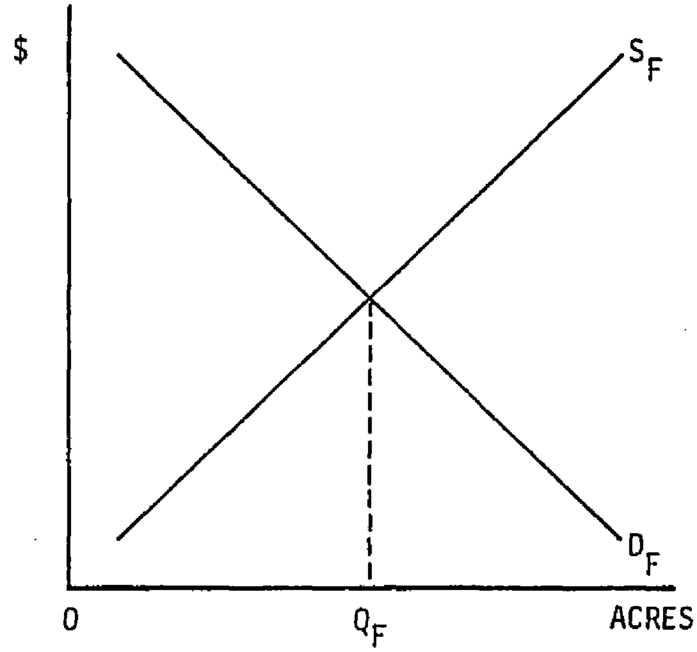


Figure 1. Population density as a function of distance from the central business district. -- Residential density may be measured at some distance outside the actual central business district because this area may be composed primarily of commercial establishments.

Construction costs constitute the most significant cost increase. Transportation costs required to bring materials and workers to the site are higher for more removed areas. It may also be necessary to build access roads or install pipes or cables to provide public utilities. To acquire the right to build in some areas, developers must agree to donate land for schools or other public facilities and may be required to construct some of those facilities. In addition to these costs, interest rates may be higher due to the more speculative nature of such developments. Thus, marginal costs of developing rural areas are greater than those in the rural-urban fringe.

Net Effects of Transition

Figure 2 represents initial supply-demand conditions assuming that acreage is located in the rural-urban fringe. Q_F is the equilibrium level of development in the fringe area. In response to the above changes in marginal costs and benefits, supply and demand functions, as well as the equilibrium level of development, change when distance from the CBD increases. The supply curve shifts upward as marginal costs increase, and the demand curve shifts downward as the marginal benefits fall. This is illustrated in Figure 3a. Q_R, the equilibrium level of development in the rural area, is less than the equilibrium



S_F = The economic supply of land in the rural-urban fringe

D_F = The demand for land in the rural-urban fringe

Q_F = The optimal high-intensity acreage in the rural-urban fringe

Figure 2. Supply and demand for land (or land services) in the rural-urban fringe

Figure 3. Comparison of supply, demand, and net marginal benefits in fringe and rural areas

S_R = the economic supply of land in the rural area

S_F = the economic supply of land in the rural-urban fringe

D_R = the demand for land in the rural area

D_F = the demand for land in the rural-urban fringe

MC_R = the marginal cost of developing acreage in the rural area

MC_F = the marginal cost of developing acreage in the rural-urban fringe

MB_R = the marginal benefits of developing acreage in the rural area

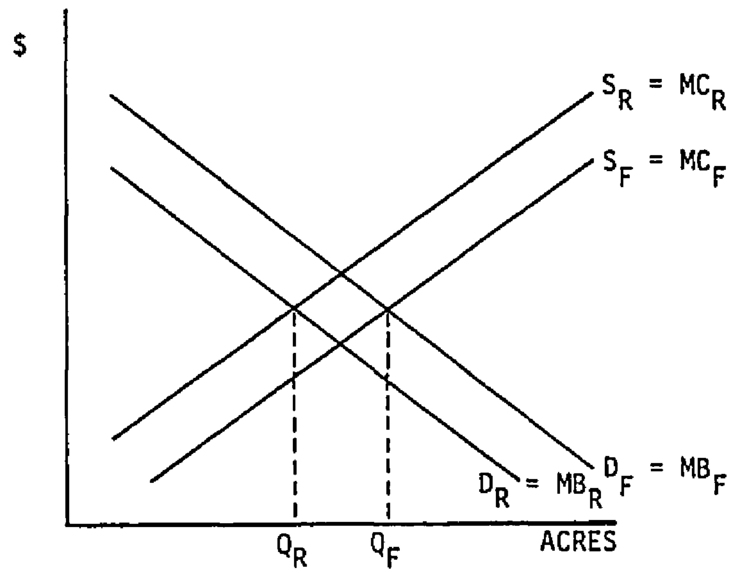
MB_F = the net marginal benefits of developing acreage in the rural-urban fringe

NMB_R = the net marginal benefits of developing acreage in the rural area

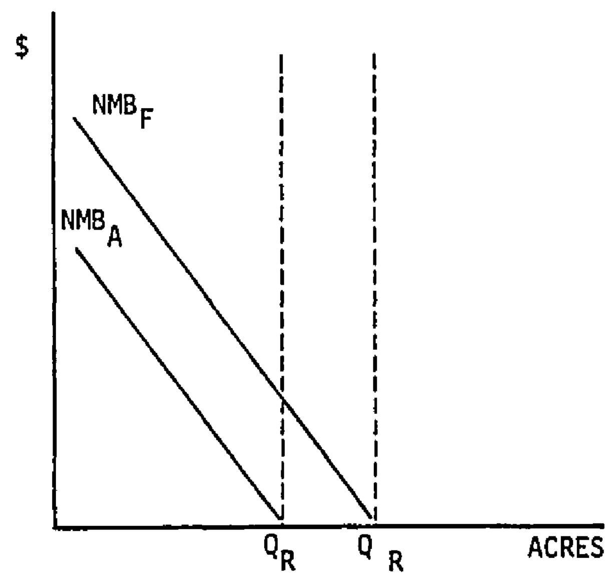
NMB_F = the net marginal benefits of developing acreage in the rural-urban fringe

Q_R = the optimal high-intensity acreage in the rural area

Q_F = the optimal high-intensity acreage in the rural-urban fringe



a.



b.

Figure 3. Comparison of supply, demand, and net marginal benefits in fringe and rural areas

level of development in the rural-urban fringe. Net benefits, represented by the area between marginal cost and marginal benefit curves associated with each location, are greater in the fringe area.

A net marginal benefit curve can be derived by subtracting marginal costs from the marginal benefits associated with each location. It can be seen in Figure 3b that net marginal benefits of development increase with proximity to an urbanized area.

Net benefits derived from residential and other high-intensity uses dictate the rate at which conversion of land to those uses will occur. Increasing benefits as a result of urban encroachment raise the likelihood that surrounding acreage will also be intensely developed. This concept of contagious growth is one factor to be considered when determining how land resources should be managed over time.

Intertemporal Allocation of Land Resources

Irreversibility of Resource Use

Natural resources such as land are unique in that their existence precedes any economic activity. The supply of natural resources is neither generated nor controlled by man, but exists as a fixed stock or is replenished at natural rates. Natural Resource Economics has been defined as "the study of society's choices in the intertemporal allocation of resources (or resource services) derived from stocks which are either fixed, or are changing at 'natural' rates" (McInerney, 1976, p. 32), addressing the problem of how much of a resource should be consumed now and how much should remain for future consumption. This definition includes three key ideas distinguishing this branch of economics from others. First, emphasis is placed on societal rather than individual preference. Second, the time element is crucial, resulting in a dynamic rather than static model. Third, supply constraints are beyond man's control.

Land differs from other resources in that its utilization results in alteration of the service flows it can provide, rather than actual physical depletion. The ability of land to provide services is a constant feature. Land can be used for residential, industrial, and agricultural purposes or a variety of other purposes. This flow of services, as well as the physical stock of land, remains fixed. Forsaken current consumption is lost forever, and any service utilized or consumed will be replaced by an equivalent service flow in the next time period. This is analogous to a characteristic of inexhaustible resources such as solar energy and scenic amenities. The "supply" of these resources is continually replinished to remain fixed, regardless of how it is utilized. Similarly, land indefinitely retains the ability to provide some service, whether that be through the construction of facilities such as residential or commercial units or retention as a vacant tract to be developed in the future.

In the case of inexhaustible resources, current consumption has no effect on future flows. Consumption in any period can continue until the current cost of obtaining a service is equal to current benefits or the available service is consumed. There is no need for a forward-looking conservation policy because no user cost is incurred. This is not the case, however, when considering service flows derived from a land stock. Although it is true that the flow of services remains constant, the particular types of available services are subject to change. Some land uses are mutually exclusive, such that the existence of one results in permanent elimination of the other. For example, it is unlikely that land used for residential purposes will be suitable for agriculture in the future.

In summary, conversion of land to urban or high-intensity uses affects subsequent service flows as follows:

1. The flow of "space" services remains constant.
2. The flow of low-intensity services such as agricultural production and amenity benefits derived from unaltered land is reduced to zero and cannot be regenerated by any economically feasible means.

3. Lost low-intensity service flows are replaced by equivalent high-intensity service flows.

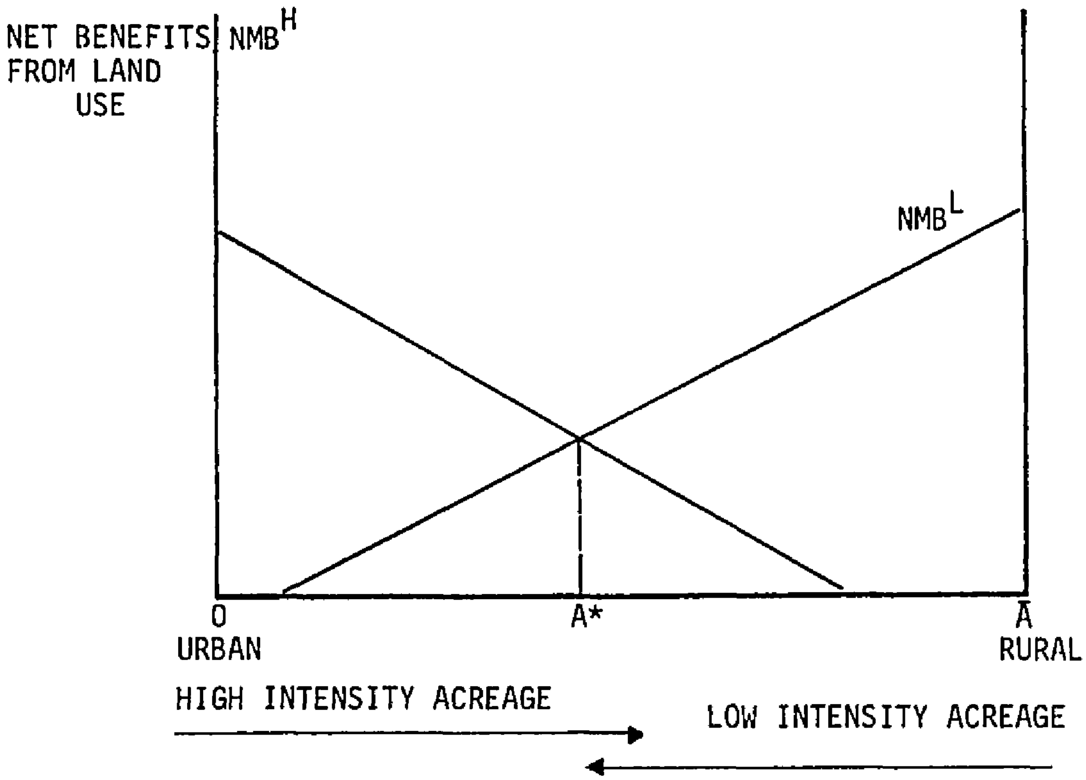
Thus, service flows are not lost or reduced but are irreversibly transformed.

Traditional Resource Allocation Theory

The irreversible effects of high-intensity land-use development on service flows makes it necessary to view land resource allocation in terms of a multi-period planning horizon in which benefits are maximized over time, rather than strictly within any given period. The following discussion presents the traditional theory through which an optimal intertemporal land-use mix can be determined (McInerney, 1976).

An optimal mix of high- and low-intensity land uses in any one time period is found by equating the net marginal benefits of developing an additional acre and the net marginal benefits of keeping that acre in a low-intensity use. This is illustrated in Figure 4, which assumes the following:

1. A fixed land area of $\overline{0A}$ acres is available for use.
2. As acreage moves from 0 to $\bar{A}$, it is located farther from the urbanized area, reflecting the assumption that more acreage is available for development.
3. Land can be used for one of two purposes--high-intensity uses such as residential, commercial and



NMB^H = the net marginal benefits of high-intensity land use

NMB^L = the net marginal benefits of low-intensity land use

A^* = the optimal acreage in high-intensity use

$\bar{A}$ = the total acreage

Figure 4. Optimal land-use allocation

industrial or low-intensity uses such as grazing and outdoor recreation.

4. Acreage allocated to high-intensity uses cannot revert to any low-intensity use in a future period.

The optimal balance between land-use types occurs at A*, where the net marginal benefits of an additional acre in high-intensity use (NMB^H) are equal to net marginal benefits of that acre in low-intensity use (NMB^L). The number of acres represented by A* are intensely developed, and $\bar{A}$ minus A* acres remain unaltered.

However, the service flows derived from those A* acres are irreversibly transformed. If, in the future, marginal benefits derived from high-intensity service flows on that acreage change such that the optimal level of development lies to the left of A*, continued optimality will be impossible to achieve. Net benefits which could have been obtained from low-intensity service flows are no longer available. Thus arises the need for an optimal intertemporal allocation of resources that maximizes the sum of present and future benefits. This can be represented mathematically over a two-period planning horizon in which net benefits of either land use are a function of acreage devoted to that use.

$$\text{Max } NB = NB_0^H(A_0^H) + NB_0^L(\bar{A}-A_0^H) + NB_1^H(A_1^H) + NB_1^H(\bar{A}-A_1^H) \quad (1)$$

where

$$A_0^H,\ A_0^L,\ A_1^H,\ A_1^L \geqslant 0$$

To maximize net benefits, the first derivatives of (1) with respect to A_i^H are set equal to zero

$$\frac{\partial NB}{\partial A_0^H} = NMB_0^H - NMB_0^L = 0 \qquad (2)$$

$$\frac{\partial NB}{\partial A_1^H} = NMB_1^H - NMB_1^L = 0 \qquad (3)$$

or

$$(NMB_0^H - NMB_0^L) + (NMB_1^H - NMB_1^L) = 0 \qquad (4)$$

or

$$NMB_0^H - NMB_0^L = NMB_1^L - NMB_1^H \qquad (5)$$

Equation 5 can be interpreted as a decision rule from which can be determined the current level of development that will result in an optimal intertemporal allocation of low- and high-intensity land uses. The increase in benefits of current development of an additional acre is equal to benefits foregone in the next time period.

This mathematical derivation can be illustrated by a 2-period model (Figure 5); A_0* is the optimal land-use mix in period t_0. However, in t_1, benefits from

Figure 5. Optimal intertemporal land-use allocation (traditional analysis)

t_0 = current time period

t_1 = future time period

$NMB_0{}^H$ = net margin benefits of high-intensity land use in t_0

$NMB_0{}^L$ = net marginal benefits of low-intensity land use in t_0

$NMB_1{}^H$ = net marginal benefits of high-intensity land use in t_1

$NMB_1{}^L$ = net marginal benefits of low-intensity land use in t_1

A_0^* = optimal high-intensity acreage in t_0

A_1^* = optimal high-intensity acreage in t_1

A^* = optimal intertemporal high-intensity acreage

$\bar{A}$ = total acreage

k = loss in benefits of low-intensity land use in t_1 if A_0^* acres are developed in t_0

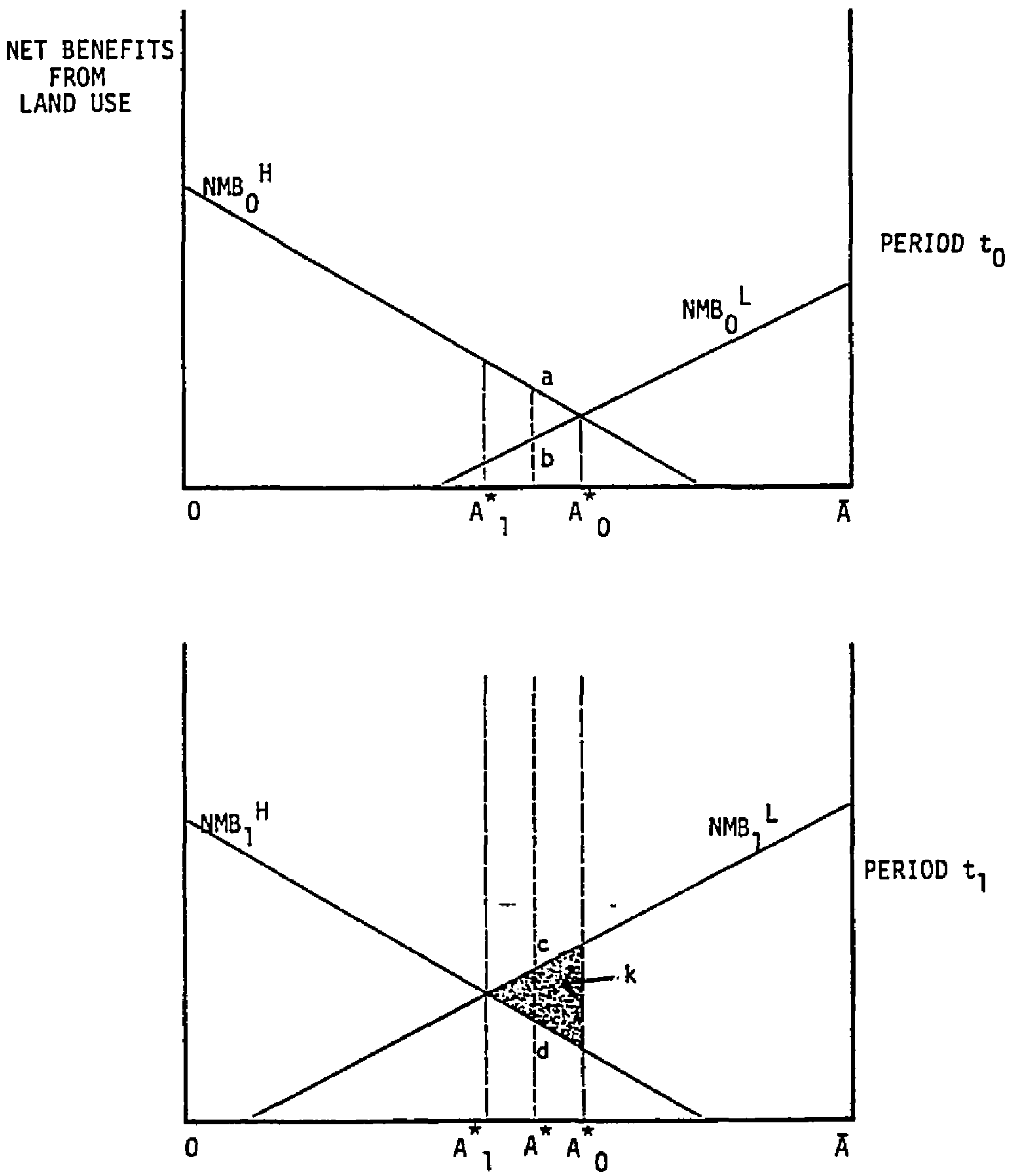


Figure 5. Optimal intertemporal land-use allocation (traditional analysis)

low-intensity use increase and the optimum mix in that period is A_1^*. A total loss of k benefits would be incurred in period t_1 if development were allowed to continue to the t_0 optimum.

To provide an optimal two-period allocation of land resources, the sum of net benefits derived from each land use during each period should be maximized. Current development can continue to A* acres without reducing future net benefits. After A_1^* acres have been converted, however, a user cost is incurred for each additional acre developed. As developed acreage increases from A_1^* to A_0^*, benefits in period t_0 increase, but potential future benefits are lost. Current development should continue only as long as the marginal gain in current benefits exceeds the marginal loss of future benefits. This is illustrated in Figure 5, in which A* represents an optimal intertemporal land-use mix. Benefits from the last acre committed to high-intensity use are offset by an equivalent loss of benefits in period t_1 (ab = cd).

Inclusion of Location in Traditional Analysis

The traditional theory presented above can be modified to include location as a determinant of future benefits. As was discussed earlier in this chapter, the net marginal benefits of converting acreage to high-intensity uses are higher if that acreage is located closer to an urbanized area. Also, as more acreage is developed, it is assumed that that acreage is located farther away from the central-city region, where there is more available land. This pushes the rural-urban fringe outward, and areas that had been more rural are, in effect, now located closer to the urbanized region. As a result, the net marginal benefits of developing a rural area are greater as that area approaches or becomes part of the rural-urban fringe. The incorporation of this concept into traditional resource-allocation theory results in a modified optimal intertemporal land-use mix.

As A_0 approaches $\bar{A}$, (Figure 6) acreage is located farther from the urban region. Net marginal benefits of outlying areas are therefore greater in period t_1 than they would have been had no development occurred in period t_0. Net marginal benefits of high-intensity development in period t_1 are thus a function of A_1, the acreage developed in period t_1, as well as A_0, the acreage developed in period t_0. Maximizing net benefits as before, the following equation is obtained:

$$\text{Max } NB = NB_0^H(A_0^H) + NB_0^L(\bar{A}-A_0^H) + NB_1^H(A_1^H, A_0^H) + NB_1^L(\bar{A}-A_1^H) \quad (6)$$

The first derivatives are set equal to zero.

$$\frac{\partial NB}{\partial A_0^H} = NMB_0^H - NMB_0^L + \frac{\partial \Sigma NB_1^H}{\partial A_0^H} \quad (7)$$

Figure 6. Traditional and modified optimal land-use allocation

t_0 = current time period

t_1 = future time period

NMB_0^H = net marginal benefits of high-intensity use in t_0

NMB_0^L = net marginal benefits of low-intensity use in t_0

NMB_1^H = net marginal benefits of high-intensity use in t_1

NMB_1^L = net marginal benefits of low-intensity use in t_0

$\frac{\partial NMB_1^H}{\partial A_0^H}$ = change in benefits of high-intensity land use in t_1 associated with development in t_0

A_0^* = optimal high-intensity acreage in t_0

A_1^* = optimal high-intensity acreage in t_1

A_T^* = traditional optimal intertemporal land-use mix

A_M^* = modified optimal intertemporal land-use mix

$\bar{A}$ = total acreage

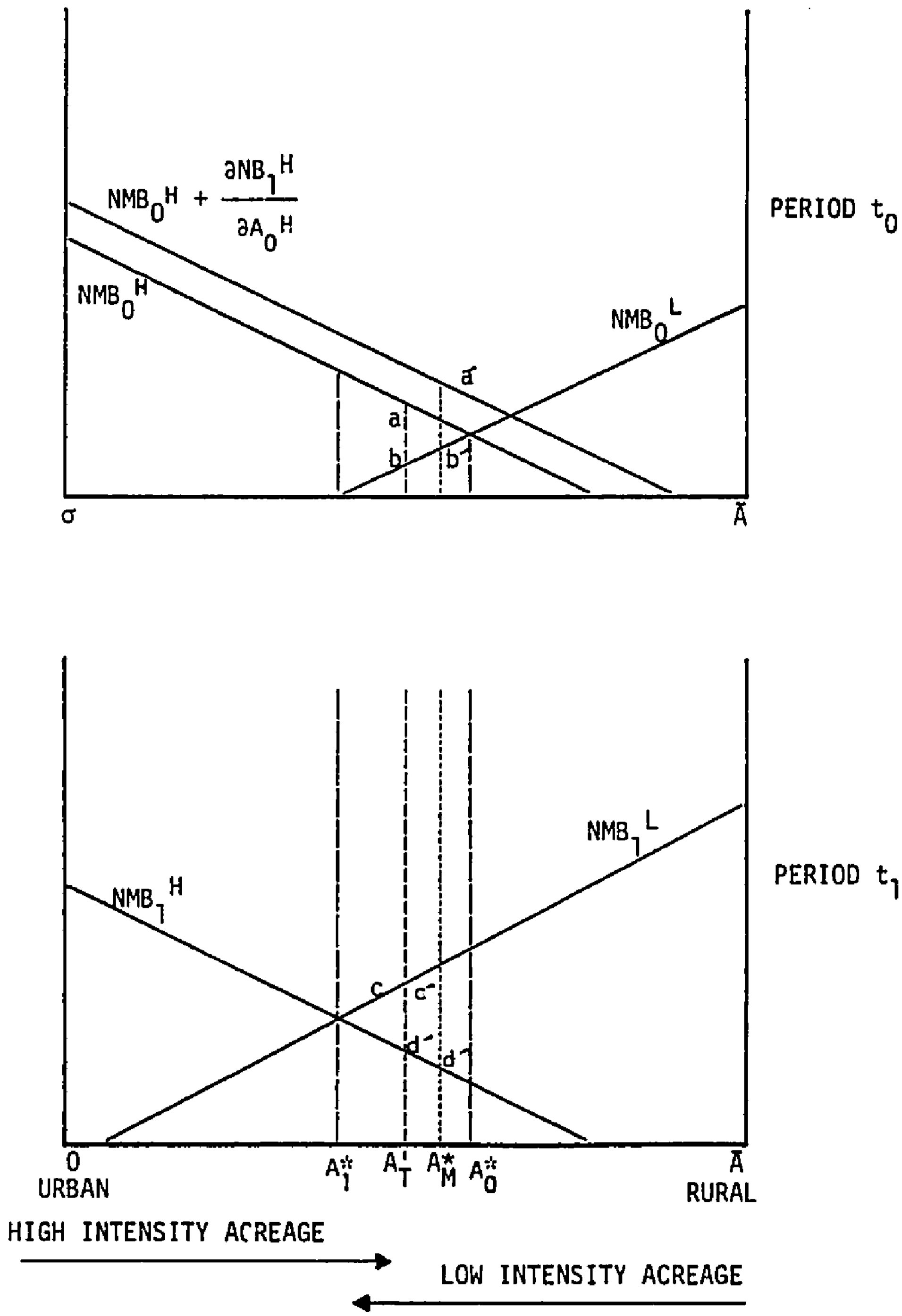


Figure 6. Traditional and modified optimal land-use allocation

$$\frac{\partial NB}{\partial A_1^H} = NMB_1^H - NMB_1^L = 0 \qquad (8)$$

Equating 7 and 8 results in a modified decision rule.

$$NMB_0^H - NMB_0^L + \frac{\partial \Sigma NMB_1^H}{\partial A_0^H} = NMB_1^L - NMB_1^H \qquad (9)$$

Implications

In formulating long-range planning goals, it is necessary to estimate the present and future net benefits associated with different types of land uses. Once some knowledge of these benefits has been gained, an optimal intertemporal allocation of land resources can be determined. Current development can then occur in such a manner as to maximize present and future net benefits.

The projected benefits of some land uses and the irreversibility associated with them interact in the determination of an intertemporal optimum. Traditional theory assumes that future benefits are independent of current activity. Net benefits are a function of location as measured by distance from an urbanized area. Urban expansion through current development of high-intensity land uses results in a relative change in location as the urban region extends closer to a given area. Future benefits of high-intensity land uses thus increase to the extent that current activity extends urban boundaries.

Inclusion of this factor in traditional allocation theory results in a change in the optimal level of current development.

In the absence of any forward-looking allocation policy, current development would occur on A_0 acres (Figure 6). Traditional allocation theory indicates that by restricting current conversion to A_T^* acres, net benefits derived from high-intensity land uses over current and future periods would be maximized. However, if the effect of current development on future benefits is included in the formulation of an intertemporal optimum, it is found that total net benefits can be increased by allowing for the additional development of A_M^* minus A_T^* acres. Thus, exclusion of this factor in long-range planning decisions could result in some needless restriction of current development and a resulting loss in some potential present and future benefits.

CHAPTER 3

DOCUMENTATION OF CONVERSION TRENDS IN THE TUCSON METROPOLITAN AREA--1967-1976

In determining an optimal intertemporal allocation of land resources, present as well as future needs must be considered. Whereas current needs are apparent, future needs must be predicted. Although future development trends reflecting those needs cannot be predicted with complete accuracy, some foresight can be gained by understanding the process of urban growth through analysis of past conversion activity. In this chapter, recent development trends in the Tucson Metropolitan Area (TMA) are determined by documenting the distribution of land-use changes in the TMA during the period of 1967 to 1976. The analysis of these trends in Chapter 4 can lend some insight into possible development trends in the future, and the effect of current development on future growth.

The chapter is divided into four sections. First, the study area for which data were collected is identified. Second, data collection sources and methodologies are discussed, followed by an evaluation of the overall reliability of the generated data base. Third, estimates of changes in high- and low-intensity land uses which occurred in the TMA during the period from 1967 to 1976 are presented as well as the relationship between those changes and population growth. Fourth, the TMA is divided into ten regions, and the growth of each region is examined separately.

Study Area

The study area is the Tucson Metropolitan Area (TMA) as defined by the City of Tucson Planning Department. This area is illustrated in Figure 7. The TMA boundaries extended northwestward to the vicinity of Oro Valley and southward to the vicinity of the Tucson International Airport. East and west boundaries include the Saguaro National Monument and Tucson Mountain Park, respectively. The Coronado National Forest in the Catalina Mountains forms the northeast boundary. This TMA definition was chosen on the basis of the rapid expansion the area has experienced during the last 20 years (Valley National Bank, 1980 and 1973), and availability of data through land-use maps covering most of the area.

Methods of Area Measurement and Data Collection

Technique of Area Measurement

One of the simplest techniques of area measurement employs a transparent grid overlay consisting of lines forming squares (or cells) of a known area. The grid is

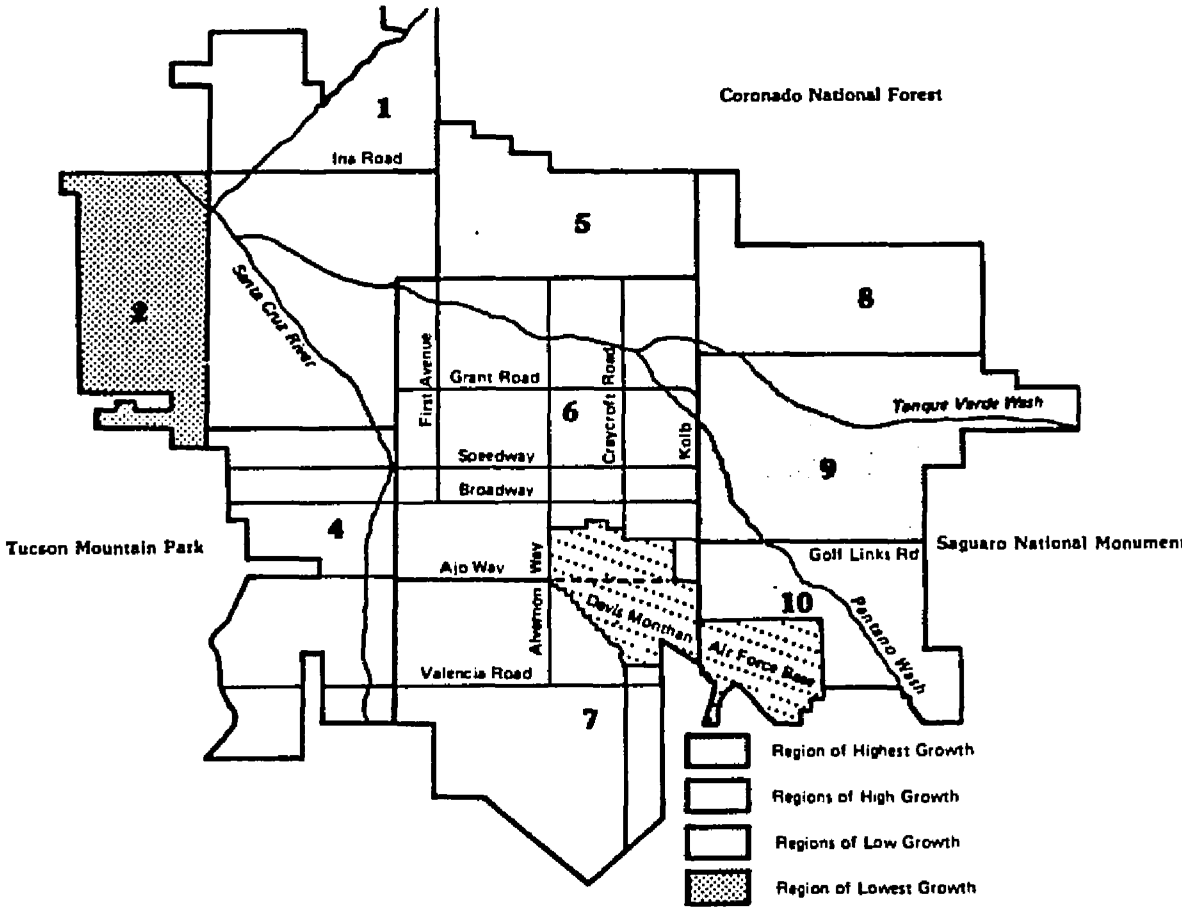


Figure 7. Defined regions of the Tucson metropolitan area

placed over the land-use map, and the area of a ground unit is estimated by counting grid units that fall within the unit to be measured. The most widely used grid overlay is a dot grid. This grid, composed of uniformly spaced dots, is superimposed over the land-use map, and the dots falling within the unit to be measured are counted. From knowledge of the dot density of the grid, the map area of the unit can be computed. The map area is then converted to a ground area.

Procedure for Measuring Land Changes

In this study, the measurement of land-use change was performed by using a dot grid technique (Foster and Gibson, 1973). The procedures of identifying changes in land use for each study period involved two steps:

1. A land-use map generated from air photographs was selected, showing the TMA as it was during the first year of a study period.
2. A second land-use map was selected, showing the TMA as it was during the final year of the study period. By the dot-grid technique described above, land-use changes in that period were recorded.

Comparisons were made for 373 approximately 1-square-mile cells making up the TMA. The subperiods used were 1967 to 1971, 1971 to 1973, and 1973 to 1976.

The development of each cell was carefully traced through each study year. The number of dots in each land-use category was counted at least three times, then averaged. The adjusted dot total was used to convert each land-use category from map area to ground area. Land-use changes in each cell were also visually compared from one year to the next to assure that figures accurately reflected conversion activity. Dots were recounted in those cells showing a discrepancy between visual and numeric interpretations. The changes which occurred in each cell, in terms of gain or loss of acreage in each land-use category, were traced from 1967 to 1976. Disaggregated in this fashion, groups of cells can be combined to trace the development of the TMA as a whole, or as a combination of smaller regions.

Classification of Land Uses

The land-use classification scheme employed places any given land area in one of nine categories. Each category is in turn classified as either a low- or high-intensity use, depending on the permanence of land alteration associated with that use. Conversion from low to high intensity implies some irreversible change of the land. For example, a land parcel on which high-rise apartments have been built is no longer suitable for low-intensity uses such as grazing or farming. The options for future conversion are considerably reduced. However, that same parcel held in a low-intensity use could be converted within a wider range of alternatives. The broad generalization is made that the conversion of land from low-intensity to high-intensity use is irreversible, although there are exceptions. The choice of land-use classification scheme for any given project depends on the detail of information needed. The Standard Land Use Coding Manual (U.S. Department of Transportation, 1977) provides a very detailed, multi-level code of land uses describing specific activities. Another classification scheme is presented in the 1976 U.S. Geological Survey Professional Paper 964, "A Land Use Land Cover Classification System for Use with Remote Sensor Data," in which categories are much more generalized. The classification of land uses in this report is a modification of the latter, chosen to best illustrate land-use changes without unnecessary detail. These uses are listed below.

Low-intensity Uses:

1. Vacant--land currently in its natural state, unaltered by man.
2. Agricultural--farm and grazing lands; also includes feedlots, corrals, and pens.
3. Natural Areas--parks, cemetaries, preserves.

4. Extractive--areas from which gravel and sand are extracted.

High-intensity Uses:

1. Residential--includes ranch houses and estates, single and multiple family dwellings, and mobile homes.
2. Commercial--business providing goods and/or services.
3. Industrial--private industry, as well as enterprises providing communication, transportation and utility services.
4. Institutional--government-owned structures, schools, and other miscellaneous public institutions.
5. Military--primarily the Davis Monthan Air Force Base.

Data Reliability

The method of data collection was chosen so that any particular land area down to 1-square mile (640 acres) could be isolated over the given study period. However, there are several shortcomings to this method. First, the information is, at best, only as accurate as the available maps. Any human error in map construction is automatically incorporated into data figures. Second, the maps are of small scale, so that miscalculation in map area could result in errors in acreage figures. Finally, in addition to these opportunities for human error, there is some loss of accuracy in the assumption of square-mile cells. Streets approximately 1 mile apart were chosen as guidelines for dividing the TMA into these cells in order to facilitate comparisons between successive land-use maps. Actual acreage of some cells may vary slightly above or below the 640-acre figure assumed.

Care was taken in the measurement of area in order to minimize the effects of these problems. The quantitative distribution of land-use types within each cell was estimated at least three times, and the average figures used in calculations. Although some cells may not contain exactly 640 acres, the data will still illustrate the proportional mix of land-use types and the change of that mix over time. It is this relative change in land-use proportions from which conclusions are drawn.

Changes in Low-intensity Land Use in the Tucson Metropolitan Area Over Time

This section presents a generalized overview of expansion within the TMA from 1967 to 1976, focusing on the quantitative distribution of land in the various land-use categories and annual rates of development occurring in each of the three periods. General conversion from low- to high-intensity uses are documented, followed by a discussion of the conversion trends of each land use type. These trends are then compared with changes in population.

Total Change in Low-intensity Land Uses

The TMA, as defined for this study, comprises 220,300 acres, or 344.2 square miles. Table 1 shows the percentages of this area occupied by low- and high-intensity uses in each year for which information was available, and the rates of conversion during the periods from 1967 to 1971, 1971 to 1973, and 1973 to 1976.

The percentage of the area in low-intensity use is substantially higher than that in high-intensity use. The

Table 1. Percentage of TMA in high- and low-intensity uses and changes since the preceding study year

			Change in High-intensity Use Since Preceding Study Year	
Year	High Intensity (%)	Low Intensity (%)	Region Converted (%)	Average Annual Conversion (acres)
1967	27.1	72.9	---	---
1971	31.0	69.0	3.9	2,177
1973	33.8	66.2	2.8	3,084
1976	39.6	60.4	5.8	4,259

TMA extends well beyond the Tucson city limits, and it is in this fringe area that most of the low-intensity land is located. However, even in the most densely developed areas of Tucson, there are very few cells that have been completely converted to high-intensity uses.

Annual figures are used to facilitate comparisons between successive periods of unequal length. Annual conversion figures show that growth did not occur at a constant rate from 1967 to 1976, but rather the growth rate increased steadily during those years. During the years from 1967 to 1971, 2,147 acres were developed annually, roughly 3.4 square miles of land area. This value increased to 3,084 acres or 4.8 square miles of converted land between 1971 and 1973. After 1973, the conversion rate continued to climb, averaging 4,259 acres, or 6.7 square miles, per year until 1976. Thus by 1976, conversion of land to high-intensity use was occurring at an annual rate nearly twice that of 1967 to 1971 average.

Conversion Trends by Land-use Type

Figures in Table 2 represent the breakdown of high- and low-intensity land-use categories into their specific land-use types and the net change of the area held in those uses during each period. Vacant land is by far the most extensive of all uses in 1967, and despite rapid

Table 2. Percentage of TMA in each land-use category and its net change between successive study years

		Low-intensity Uses				High-intensity Uses				
Year	Net Change Period	Vacant %	Agricultural %	Natural %	Extractive %	Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		67.9	3.3	1.4	0.3	16.6	2.2	1.9	1.3	5.1
1971		63.8	3.1	1.8	0.3	20.0	2.3	2.2	1.4	5.1
	1967-1971	-4.1	-0.2	0.4	0	3.4	0.1	0.3	0.1	0
1973		61.6	2.4	2.0	0.2	22.2	2.5	2.4	1.7	5.0
	1971-1973	-2.2	-0.7	0.2	-0.1	2.2	0.2	0.2	0.3	-0.1
1976		54.9	2.2	3.0	0.3	27.4	2.7	2.5	1.9	5.1
	1973-1976	-6.7	-0.2	1.0	0.1	5.2	0.2	0.1	0.2	0.1
	1967-1976	-13.0	-1.1	1.6	0	10.8	0.5	0.6	0.6	0

conversion rates, remains so throughout the entire study period. Of the high-intensity uses, residential acreage is the most extensive.

Between 1967 and 1976, 14.1 percent of the TMA was converted from vacant agricultural land to other uses. Because these two sectors alone decreased in acreage, it can be assumed that the development of the remaining categories occurred essentially on those acres removed from vacant or agricultural uses. Of this 14.1 percent, only 1.6 percent remained as a low-intensity area, transferred to the establishment of parks, public natural areas, or cemeteries. The remainder was converted by high-intensity development, mainly in the residential sector. Commercial, industrial, and institutional growth accounts for the conversion of only 1.7 percent of the TMA. Extractive industries and military installations show no net change from 1967 to 1976, although there was slight fluctuation within that period.

Commercial, industrial, and institutional growth occurred continually throughout the 9-year period, increasing most rapidly from 1971 to 1973. These years also experienced the greatest decline in agricultural acreage. However, land-use maps indicate that most of the land released from agriculture reverted, at least initially, to a vacant state, little of it being intensely developed. Thus, the decline of agricultural acreage does not appear to be a direct result of expansion of high-intensity facilities into those areas.

Conversion of Low-intensity Land Uses and Population Growth

As documented in Tables 1 and 2, expansion within the TMA did not occur at a constant rate during the study period, but rather grew more and more rapidly as the period progressed. This trend is not unexpected because develop- is influenced by a number of external factors that can either encourage or discourage buying, selling, and alteration of property. One of these influences is population density and growth (Clark, 1977). An influx of people into an area increases the demand for land allocated to residential, commercial, industrial, and institutional uses (Darin-Drabkin, 1977).

Table 3 compares average annual population growth with the average number of acres converted annually during each of the three periods. From 1967 to 1971, population increased by an average of nearly 8,000 residents per year. During the 1973 to 1976 period, annual migration into the area was more than double this level. The greatest influx, however, occurred between 1971 and 1973, when population grew by an average of 21,000 residents annually.

Development of high-intensity land uses can be expected to reflect changes in population size. As population increases, conversion is also expected to increase,

Table 3. Comparison of low-intensity land-use conversion with population growth

Period	Annual Conversion (acres)	Expected Annual Conversion Assuming Constant Growth (acres)	Average Population Growth[a]	Average Annual Population Growth (lagged)[b]
1967-1971	2,147	3,059	7,828	6,510
1971-1973	3,084	3,059	21,266	15,297
1973-1976	4,259	3,059	16,165	17,889

a. Computed from information in the Arizona Statistical Review published by Valley National Bank of Arizona (1978, p. 10).

b. Lagged values were determined by averaging population growth from 1966 to 1969, 1969 to 1972, and 1972 to 1975, respectively.

as demand for housing, goods, and services increases. However, acreage converted annually to high-intensity land-uses increased steadily from one period to the next, showing no exceptional jump corresponding to the 1971-to-1973 population growth. It has been previously noted that commercial, industrial, and institutional development did exhibit their highest growth rates during this period. These particular uses, though quite intensive in nature, do not make up a large percentage in the TMA area. Residential use is by far more extensive in terms of acreage requirements, thus the figures of combined high-intensity uses are essentially a reflection of changes in the residential sector. The effect of an influx of new residents on the housing market could be delayed, as some newcomers live temporarily in existing structures until increased demand is felt in the housing industry and new homes become more available.

Figures in the last column of Table 3 represent lagged average annual population growth. These figures were determined by averaging the annual population increases from one to two years preceding the study period to approximately the midpoint of the period, rather than within the three periods that have been discussed. Thus, there is roughly a half-period lag between population and conversion figures. Using lagged population figures, population and conversion rates show a better correlation. Development activity thus appears to respond to population growth, although the full effects of an increasing population in terms of induced development may not be felt for several years.

Regional Breakdown of Conversion Trends

The discussion of conversion trends thus far has focused on the TMA as a whole, including rates of conversion, types of land uses converted, and comparisons with population increases. To provide a more detailed description of development, the following tables and discussion center on specific regions within the TMA, each exhibiting a unique rate and pattern of growth. The TMA is subdivided into 10 regions chosen to best illustrate the nature and direction of TMA expansion as it occurred from year to year (Table 4). Regional boundaries were chosen primarily on the basis of familiarity acquired through the development of the data base.

Table 4 summarizes the changes in high- and low-intensity and uses that occurred within each of the defined regions of the TMA between 1967 and 1976. The location of these regions is shown in Figure 7. For purposes of discussion, each region will be placed in one of four categories according to its overall rate of development relative to the other regions. These categories are highest, high, low, and least growth.

Region with Highest Conversion Rate

The area showing the highest percentage of total converted land during the entire study period was Region 9 (Table 5), located in the east-central portion of the TMA. It can be seen in Table 4 that 22.4 percent of this region was converted from low- to high-intensity uses, a proportion well above that of the 12.5 percent average for the TMA as a whole. The area makes up roughly 10.8 percent of the TMA, yet 19.0 percent of total conversion occurred there.

Table 4. Percentage of each region in high- and low-intensity land uses and changes in low-intensity land uses during each period

				Conversion of Low-intensity Land Uses	
Year	Region	High Intensity %	Low Intensity %	Region Converted %	Average Annual Conversion (acres)
1967	1	15.9	84.1	---	---
	2	2.6	97.4	---	---
	3	22.8	77.2	---	---
	4	15.9	84.1	---	---
	5	15.4	84.6	---	---
	6	64.7	35.3	---	---
	7	30.6	69.4	---	---
	8	5.2	94.8	---	---
	9	16.6	83.4	---	---
	10	28.6	71.4	---	---
				1967-1971	
1971	1	15.9	84.1	0	0
	2	3.4	96.6	0.8	32
	3	28.1	71.9	5.3	322
	4	19.4	30.6	3.5	208
	5	19.8	80.2	4.4	167
	6	68.8	31.2	4.1	420
	7	33.5	66.5	2.9	214
	8	6.5	93.5	1.3	51
	9	24.6	75.4	8.0	470
	10	35.4	64.6	6.8	298
				1971-1973	
1973	1	18.1	81.9	2.2	154
	2	5.6	94.4	2.2	166
	3	33.5	66.5	5.4	657
	4	22.1	77.9	2.7	322

Table 4. Continued

Year	Region	High Intensity %	Low Intensity %	Conversion of Low-intensity Land Uses: Region Converted %	Conversion of Low-intensity Land Uses: Average Annual Conversion (acres)
	5	24.7	75.3	4.9	372
	6	70.3	29.7	1.5	307
	7	35.3	64.7	1.8	251
	8	9.9	90.1	3.4	265
	9	28.3	71.7	3.7	435
	10	36.7	63.3	1.3	123
				1973-1976	
1976	1	30.8	69.2	12.7	594
	2	7.7	92.3	2.1	116
	3	38.3	61.7	4.8	389
	4	27.8	72.2	5.7	452
	5	30.0	70.0	5.3	268
	6	73.6	26.4	3.3	451
	7	38.8	61.2	3.5	345
	8	18.7	81.3	8.8	457
	9	39.0	61.0	10.7	838
	10	42.7	57.3	6.0	351
				1967-1976	
	1			14.9	232
	2			5.1	90
	3			15.5	419
	4			11.9	315
	5			14.6	246
	6			8.9	405
	7			8.2	269
	8			13.5	234
	9			22.4	585
	10			14.1	275

Table 5. Percentage of Region 9 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses: Vacant %	Agricultural %	Natural %	Extractive %	High-intensity Uses: Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		79.4	2.5	1.2	0.3	13.6	1.3	0.5	1.2	0
1971		70.9	2.5	1.4	0.6	21.2	1.7	0.3	1.4	0
	1967-1971	-8.5	0	0.2	0.3	7.6	0.4	-0.2	0.2	0
1973		68.0	1.6	1.4	0.7	24.4	1.9	0.4	1.6	0
	1971-1973	-2.9	-0.9	0	0.1	3.2	0.2	0.1	0.2	0
1976		57.1	2.3	1.4	0.2	34.4	2.1	0.2	2.3	0
	1973-1976	-10.9	0.7	0	-0.5	10.0	0.2	-0.2	0.7	0
	1967-1976	-22.3	-0.2	0.2	-0.1	20.8	0.8	-0.3	1.1	0

The most active period was 1973 to 1976, during which time 10.7 percent of the region was intensely developed. Roughly half of the conversion in this region between 1967 and 1976 occurred during these 3 years. Most of the total change was toward expansion of the residential sector. Access by major streets such as Speedway and Broadway Boulevards and the proximity of a major shopping center contribute to the desirability of residential development in this area. Also, because Region 9 is located at the most eastern reach of the city rather than toward the center where development is more concentrated, there is acreage suitable for a wide variety of housing needs, from multi-family complexes to single-family units on sizable lots.

Acreage allocated to industrial use declined in this region by almost half by 1976, while commercial and industrial development increased at a rate slightly greater than that for the TMA as a whole. Annual increases in commercial establishments remained constant from 1967 to 1973, dropping slightly after 1973. Collectively, however, these changes were small in absolute terms, as less than one percent of acreage converted here between 1967 and 1976 was toward the development of high-intensity uses other than residential.

Regions with High Conversion Rates

Several regions exhibited relatively rapid development during the years observed. These areas, Regions 1, 3, 5, 8, and 10 were located roughly on the northern and eastern perimeters of the TMA, as shown in Figure 7. Conversion, as a percent of each region, was significantly less than the high rate of change in Region 9. Yet overall conversion, ranging from 13.5 to 15.5 percent, is above the 12.5 percent average conversion figure for the total TMA, indicating that these, along with Region 9, were the most preferred areas for development during the 9-year period studied.

Region 10 (Table 6), located in the southeast corner of the TMA, was minimally developed in 1967. The Davis Monthan Air Force Base occupied 27.2 percent of the area, 2.9 percent was used for resource extraction, 1.3 percent for agriculture, and most of the remainder was vacant. There were no institutional, commercial, or public recreation facilities in the area. A small amount of the area, 0.2 percent, was used for industrial purposes.

By 1976, this land-use mix had undergone a significant change. The most dramatic change occurred in the residential sector, which occupied 12.4 percent of the area in 1976 as opposed to 1.2 percent in 1967. This increase in residential acreage was accompanied by the addition of

Table 6. Percentage of Region 10 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses				High-intensity Uses				
		Vacant %	Agricultural %	Natural %	Extractive %	Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		67.2	1.3	0	2.9	1.2	0	0.2	0	27.2
1971		61.8	0.5	0	2.3	7.3	0.1	0.4	0.4	27.2
	1967-1971	-5.4	-0.8	0	-0.6	6.1	0.1	0.2	0.4	0
1973		62.4	0.4	0.1	0.4	8.6	0.1	0.4	0.4	27.2
	1971-1973	0.6	-0.1	0.1	-1.9	1.3	0	0	0	0
1976		55.1	0.9	0.5	0.8	13.6	0.2	0.4	1.1	27.4
	1973-1976	-7.3	0.5	0.4	0.4	5.0	0.1	0	0.7	0.2
	1967-1976	-12.1	-0.4	0.5	-2.1	12.4	0.2	0.2	1.1	0.2

commercial outlets and significant institutional development, as well as an increase in public natural areas. Acreage allocated to agriculture and extractive industries experienced a decline. Most development occurred in the northern half of the region, resulting in a continued potential for much more development in the area.

Region 8 (Table 7), located in the northeast corner of the TMA, developed in a manner similar to that of Region 10. The small amount of high-intensity development which had occurred by 1967 was confined to the residential sector. Low-intensity uses at that time occupied nearly 95 percent of the area. Most of that area was held vacant, although there was some acreage in agriculture, and a small amount was held as public natural areas. By 1976, an additional 11.9 percent of the region was being used for housing. Only a small portion of this increase occurred prior to 1971, after which residential development began expanding more rapidly, the greatest growth occurring after 1973. Commercial and institutional facilities were added to the land-use mix after 1971, coinciding with increased residential activity. Industry was not introduced to the area. Table 7 shows a decline of slightly more than 50 percent in acreage previously devoted to agriculture and public land. In 1976, more than 80 percent of the area remained vacant. Although growth did occur rapidly, especially in 1973-1976 period, development

Table 7. Percentage of Region 8 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses				High-intensity Uses				
		Vacant %	Agricultural %	Natural %	Extractive %	Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		92.8	1.2	0.8	0	5.2	0	0	0	0
1971		91.8	0.7	1.0	0	6.5	0	0	0	0
	1967-1971	-1.0	-0.5	0.2	0	1.3	0	0	0	0
1973		88.2	0.9	1.0	0	9.2	0.5	0	0.2	0
	1971-1973	-3.6	0.2	0	0	2.7	0.5	0	0.2	0
1976		80.4	0.5	0.4	0	17.1	1.3	0	0.3	0
	1973-1976	-7.8	0.4	-0.6	0	7.9	0.8	0	0.1	0
	1967-1976	-12.4	-0.7	-0.4	0	11.9	1.3	0	0.3	0

of the region remained relatively sparse owing to the vast amount of vacant land found there in 1967.

Region 5 (Table 8) corresponds roughly to the foothills area of the Catalina Mountains. The development that occurred there was almost exclusively residential, with minor increases in the public sectors, both institutional and natural. It is interesting to note that while residential acreage doubled, most commercial acreage was found in a large guest ranch. The region as a whole is noted for its natural desert environment and scenic views. Exclusive neighborhoods and large homes on sizable lots are characteristic of the area. These qualities make the region less desirable for the development of high-intensity land-use types other than residential.

Of all the regions that experienced moderately high growth since 1967, Region 3 (Table 9) seems to be the most diversified, developing a land-use mix in which paractically all of the various land uses coexist in a proportion roughly similar to that of the TMA as a whole. Agricultural acreage was the predominant exception, being somewhat more concentrated in this region. During 1967, commercial, industrial, and institutional facilities, as well as natural public areas were present in proportions slightly greater than that expected under the assumption of even distribution within the TMA, whereas residential development was slightly less by proportion. By 1976,

Table 8. Percentage of Region 5 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses				High-intensity Uses				
		Vacant %	Agricultural %	Natural %	Extractive %	Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		83.5	0	1.1	0	14.3	1.1	0	0	0
1971		79.1	0	1.1	0	18.5	1.1	0	0.1	0
	1967-1971	-4.4	0	0	0	4.2	0	0	0.1	0
1973		17.0	0	1.3	0	23.6	1.1	0	0.1	0
	1971-1973	-5.1	0	0.2	0	5.1	0	0	0	0
1976		68.8	0	1.2	0	28.8	1.1	0	0.1	0
	1973-1976	-5.2	0	-0.1	0	5.2	0	0	0	0
	1967-1976	-14.7	0	0.1	0	14.5	0	0	0.1	0

Table 9. Percentage of Region 3 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses: Vacant %	Agricultural %	Natural %	Extractive %	High-intensity Uses: Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		65.0	10.1	2.0	0.1	16.1	3.0	2.3	1.4	0
1971		59.7	10.0	2.1	0.1	21.6	2.5	2.6	1.4	0
	1967-1971	-5.3	-0.1	0.1	0	5.5	-0.5	0.3	0	0
1973		56.4	7.2	2.9	0	26.1	2.9	3.0	1.5	0
	1971-1973	-3.3	-2.8	0.8	-0.1	4.5	0.4	0.4	0.1	0
1976		51.6	5.9	4.2	0	30.4	2.9	3.7	1.3	0
	1973-1976	-4.8	-1.3	1.3	0	4.3	0	0.7	-0.2	0
	1967-1976	-13.4	-4.2	2.2	-0.1	14.3	-0.1	1.4	-0.1	0

this mix was somewhat altered. The most substantial changes were in agriculture, which was reduced by about 40 percent, and residential acreage, which nearly doubled. Surprisingly, commercial use declined by about 17 percent between 1967 and 1971, whereas industrial use doubled over the entire period. Rates of conversion for most high-intensity uses, namely residential, commercial, and institutional were greatest during the 1973 to 1976 period. During those same years, two-thirds of the decline in agricultural acreage occurred. In summary, this region exhibits a wide variety of low- and high-intensity land uses, with no particular use being predominately favored. The most active years of development were 1971, 1972, and 1973.

Region 1 (Table 10) is an irregularly-shaped area in the upper northwest portion of the TMA. Data from 1971 were unavailable for most of this region, and 1967 figures were substituted. There appears to have been little actual conversion between 1967 and 1971, however, because 1973 figures show that only 1.1 percent of the area which had been vacant in 1967 was developed by 1973. Residential development occurred very slowly before 1973, after which it increased extremely rapidly. Almost all of the 14.3 percent of Region 1 that was converted to residential use between 1967 and 1976 did so after 1973. Park land increased significantly during this same period,

Table 10. Percentage of Region 1 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses: Vacant %	Agricultural %	Natural %	Extractive %	High-intensity Uses: Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		77.2	3.7	3.1	0	14.0	1.5	0	0.5	0
1971		77.2	3.7	3.1	0	14.0	1.5	0	0.5	0
	1967-1971	0	0	0	0	0	0	0	0	0
1973		76.1	2.6	3.2	0	15.2	1.6	0	1.3	0
	1971-1973	-1.1	-1.1	0.1	0	1.2	0.1	0	0.8	0
1976		62.6	0.3	6.3	0	28.3	0.8	0	1.7	0
	1973-1976	-13.5	-2.3	3.1	0	13.1	-0.8	0	0.4	0
	1967-1976	-14.6	-3.4	3.2	0	14.3	-0.7	0	1.2	0

whereas agricultural acreage experienced its greatest decline. However, commercial development decreased by 50 percent rather than increasing as expected in the wake of such rapid residential expansion. This commercial loss is unusual compared to other regions in the TMA where a decline of commercial acreage did not occur in the face of rapid residential growth. It is possible, however, that acres removed from commercial use were not located near the areas where residential development occurred.

Regions with Low Conversion Rates

Minor conversion, ranging from 8.1 to 11.9 percent, occurred in Regions 6, 7, and 4. These regions make up the central, south-central, and south-western portions of the TMA, respectively.

Region 6 (Table 11) occupies a larger portion of the TMA than does any other of the defined regions, containing the older, more densely populated area within the Tucson city limits. Because of extensive and intensive development prior to 1967, the rate of conversion within the region was relatively low, the general land-use pattern having already been established. Vacant land is not found in abundance, as in most other regions, limiting land availability for further development. Most of the remaining vacant tracts are small in size and scattered throughout the region. Residential development within the TMA is

Table 11. Percentage of Region 6 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses: Vacant %	Agricultural %	Natural %	Extractive %	High-intensity Uses: Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		30.0	2.0	3.3	0	45.8	6.8	2.3	4.0	5.8
1971		25.3	1.8	4.1	0	40.8	7.3	1.6	4.3	5.8
	1967-1971	-4.7	-0.2	0.8	0	3.0	0.5	0.3	0.3	0
1973		24.1	1.6	4.0	0	49.8	7.5	2.8	4.7	5.5
	1971-1973	-1.2	-0.2	-0.1	0	1.0	0.2	0.2	0.4	-0.3
1976		20.5	2.0	3.8	0	52.5	8.1	2.6	4.6	5.8
	1973-1976	-3.6	0.4	-0.2	0	2.7	0.6	-0.2	-0.1	0.3
	1967-1976	-9.5	0	0.5	0	6.7	1.3	0.3	0.6	0

concentrated here, with more than 50 percent of the region used for high- and medium-density housing by 1976. Commercial and institutional development is also found in exceptionally high proportions, indicating that economic and social activities are concentrated in this area. City parks and recreational facilities are also prevalent, scattered in small areas throughout the region.

The overall rate of conversion was low, although some further development of most land-use types did occur. This trend, coupled with the existing density of development, suggests that this region is approaching its limit of capability for expansion.

Region 4 (Table 12) is located in the southwest corner of the TMA. Its development is similar to that in Region 3 in that there is a wide variety of activity, although overall development in the area is less. The residential sector grew to include 11.3 percent more of the region, with the greatest growth occurring after 1973, during which time commercial activity showed its only increase. Institutional facilities expanded, while industrial land use declined by more than half. Agricultural acreage, found in several large farms, was exceptionally high, second only to Region 3. Although agricultural acreage declined during each of the three periods, by 1976 it still occupied a greater proportion of the region relative to the distribution in most other

Table 12. Percentage of Region 4 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses: Vacant %	Agricultural %	Natural %	Extractive %	High-intensity Uses: Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		73.8	8.7	1.3	0.3	12.8	1.1	1.2	0.8	0
1971		69.8	8.2	2.2	0.4	16.1	1.1	1.0	1.2	0
	1967-1971	-4.0	-0.5	0.9	0.1	3.3	0	-0.2	0.4	0
1973		68.7	6.5	2.2	0.5	18.5	1.1	1.0	1.5	0
	1971-1973	-1.1	-1.7	0	0.1	2.4	0	0	0.3	0
1976		58.2	5.8	7.6	0.6	24.1	1.3	0.5	1.9	0
	1973-1976	-10.5	-0.7	5.4	0.1	5.6	0.1	-0.5	0.4	0
	1967-1976	-15.6	-2.9	6.3	0.3	11.3	0.2	-0.7	1.1	0

regions. Almost 75 percent of the area was classified as low-intensity in 1976, and there appears to be no exceptional development of any particular land-use type up to that time.

Region 7 (Table 13), located in the south-central portion of the TMA, is best characterized by its concentration of industrial activity, including transportation and communication facilities. It is the only area in which a high-intensity land use other than residential accounts for the highest percent of developed acreage. Industrial growth increased steadily after 1967, and will probably continue to do so because there are large expanses of vacant land and easy access to air and rail transport facilities. There is also a low concentration of residential units in the area relative to most other regions, reducing the problems encountered with their coexistence with industrial units. Moderate amounts of commercial and institutional acreage were found in the area, each expanding after 1971. Residential development, though relatively small in area, increased progressively through the years studied, although growth itself was light.

Low-intensity uses also underwent some changes. After 1973, agricultural use in the region was eliminated. Park land increased notably after 1971. Resource extraction fluctuated from 0.0 to 0.8 percent of the region.

Table 13. Percentage of Region 7 in each land-use category and its net change between successive study years

		Low-intensity Uses				High-intensity Uses				
Year	Net Change Period	Vacant %	Agricultural %	Natural %	Extractive %	Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		68.8	0.4	0.1	0.1	6.6	1.5	7.7	1.1	13.7
1971		65.9	0.3	0.3	0	8.2	1.5	9.0	1.1	13.7
	1967-1971	-2.9	-0.1	0.2	-0.1	1.6	0	1.3	0	0
1973		63.0	0.3	1.4	0	8.9	1.5	9.9	1.2	13.7
	1971-1973	-2.9	0	1.1	0	0.7	0.1	0.9	0.1	0
1976		58.9	0	1.5	0.8	10.3	1.8	11.0	1.9	13.0
	1973-1976	-4.1	-0.3	0.1	0.8	1.4	0.2	1.1	0.7	0.1
	1967-1976	-9.0	-0.4	1.4	0.7	5.2	0.3	3.3	0.8	0

Region with Lowest
Conversion Rate

Region 2 (Table 14), located at the far northwestern edge of the TMA, was the least developed area of the TMA in 1967 and showed the slowest growth during the years studied. By 1976 only 7.1 percent was developed for residential use, a figure very low in comparison with the remainder of the TMA. Commercial establishments occupied a small portion of the area, expanding in acreage slightly between 1971 and 1973. There was some industrial expansion after 1973, yet the 1976 figure remains relatively small. Land that had been used for institutional purposes was converted to an alternate use after 1973, an exception to the generalization that land converted to a high-intensity use remains in that use indefinitely.

A fair proportion of total land-use change occurred in the low-intensity use categories. Agricultural acreage increased slightly, unlike the negative growth of that sector which occurred in most other areas. Public natural land increased from 0.1 to 1.7 percent, almost all of this change occurring after 1973.

The combined changes in high- and low-intensity uses, however, remained a small percentage of the region as of 1976, with nearly 89 percent of the region still vacant. The lack of rapid development in the area can be partially

Table 14. Percentage of Region 2 in each land-use category and its net change between successive study years

Year	Net Change Period	Low-intensity Uses: Vacant %	Agricultural %	Natural %	Extractive %	High-intensity Uses: Residential %	Commercial %	Industrial %	Institutional %	Military %
1967		95.6	1.7	0.1	0	2.0	0.1	0.2	0.3	0
1971		94.8	1.7	0.1	0	2.8	0.1	0.2	0.3	0
	1967-1971	-0.8	0	0	0	0.8	0	0	0	0
1973		92.5	1.7	0.2	0	4.9	0.2	0.2	0.3	0
	1971-1973	-2.3	0	0.1	0	2.1	0.1	0	0	0
1976		88.7	1.9	1.7	0	7.1	0.2	0.4	0	0
	1973-1976	-3.8	0.2	1.5	0	2.2	0	0.2	-0.3	0
	1967-1976	-69	0.2	1.6	0	5.1	0.1	0.2	-0.3	0

attributed to topography and distance from the more developed areas of the city. Rugged hills and a sparse transportation network contrast with the flat topography of most other regions of the TMA, which are more easily accessible.

Conclusion

The information contained in this chapter is a documentation of the land-use changes that occurred in the TMA between the years 1967 and 1976 in terms of urban expansion in the TMA as a whole and in a number of sub-regions. Historical conversion data such as this can be analyzed to determine those factors that encourage or discourage urban development, making one area more conducive to rapid growth than another. Understanding past activity can lend some foresight to developing and meeting long-range planning goals.

CHAPTER 4

THE CONTAGIOUS EFFECTS OF URBAN GROWTH IN THE TUCSON METROPOLITAN AREA

As low-intensity land uses are converted to high-intensity uses, the relative desirability of remaining undeveloped land is enhanced. That is, conversion of low-intensity uses encourages further conversion of remaining undeveloped acreage because the net benefits of development for this land tend to increase, as was discussed in Chapter 2. Closer proximity to employment and commercial activities, coupled with lower costs for construction and provision of public services, results in rising benefits and falling costs for developing land near previously developed areas. Thus, it is hypothesized that a relationship exists between the density of existing high-intensity land uses and the rate at which low-intensity land is developed.

This relationship is explored with regard to the TMA. The chapter is organized into three sections, First, a discussion is presented of statistical regression methods used in developing and interpreting this relationship. Second, statistical results are presented. Third, the policy implications of these findings are examined.

Statistical Method

Several decisions were made in choosing an appropriate statistical model. First was a choice between the use of a continuous or a categorical dependent variable. Regression results using a continuous dependent variable would have given an estimate of the actual number of acres developed in a given period, given the density of existing high-intensity land uses. Results using categorical data translate into the probability of an area falling into one category rather than another. Since results could hopefully be used as a tool for evaluating policy choices, it was believed that information regarding the likelihood of high growth rates in a given area would be of greater interest to decision-makers than would predictions concerning the actual number of acres to be developed. Probit (Heshner and Johnson, 1981) was chosen as an appropriate probability model. Another choice was made between binary and multivariate models. Although more than two categories could have been used in the analysis, a simple distinction between high- and low-growth rates was believed to be sufficient to develop a basic relationship between the existing land use patterns and growth rates. Thus, probit analysis was used to estimate the probability that a given area exhibits high growth rates given the value of one or more independent variables (Appendix A).

Each of the 373 cells described in Chapter 3 was classified as a high- or low-growth area during each of the three periods between 1967 and 1976. Conversion was assigned a value of zero in low-growth cells and a value of one in high-growth cells. These values were assigned according to the following guidelines:

1. Cells in vast areas showing little or no activity were automatically assigned a zero value.
2. Remaining cells were listed in order of magnitude of converted acreage. The value for conversion in the upper third of these cells was assigned a value of 1.
3. Conversion in all other cells was assigned a zero value.

Individual cells did not necessarily retain the same value through each of the three time periods. Regressions were also run in which only the upper 10 percent of active cells were defined as high-growth areas. Absolute probability figures derived from regression coefficients were lower when the 10 percent cut-off value was used, but the general trends which will be discussed later in this chapter were much the same.

In the 1967-1971 period, the division between high and low growth was found to be 67 acres. Conversion of less than 67 acres during that time is considered low growth. Conversion of 67 or more acres is considered high growth.

The cut-off value was found to be 46 acres during the period from 1971 to 1973, and 53 acres between 1973 and 1976. This translates in annual terms to 11.5, 12.5, and 17.6 acres, respectively, reflecting the increasingly rapid conversion rates found in the TMA, established in Chapter 3.

There are numerous factors influencing urban growth, including tax rates, interest rates, zoning ordinances, availability of public services and the efficiency of transportation networks, among others. Although these factors may have a significant effect on urban expansion, they are held as constants in this analysis.

Explanatory variables regressed against conversion are limited to those describing the existing land-use pattern in terms of the percentage of area in some particular land-use category in and around each individual cell during the first year of a period. Regression results were evaluated on the basis of Student's t statistics and the magnitude of the derived probabilities to determine the types of existing land uses that exert the greatest influence on future growth rates. Variables consistently giving the most significant results were found to be:

1. PCTHLyy--the percentage of a cell in high-intensity use (Residential + Commercial + Industrial + Institutional + Military).
2. PCTSURHlyy--the percentage of the surrounding area in high-intensity use. The surrounding area is

defined as the 8 cells encircling any given cell. Unenclosed cells located on the border of the TMA were not included. Acreage in high-intensity uses in each of the 8 cells was summed, then divided by total acreage to calculate percentages.

3. PCTRESyy--the percentage of a cell in residental use.

4. PCTSURRESyy--the percentage of the surrounding area in residential use.

Several other variables were regressed against conversion. These included land area in commercial, industrial, institutional, and vacant use. Student's t statistics, however, were not significant throughout all three time periods for any of these regressions.

A significant quadratic relationship was found to exist between the explanatory variables listed above and the probability that a cell exhibits high conversion rates (Table 15). Because residential acreage makes up most of the high-intensity acreage, the following analysis is limited to the effects of an increase in residential acreage on the probability of rapid growth in that area. Results of using PCTHIyy and PCTSURHIyy show the same trends as are discussed for PCTRESyy and PCTSURRESyy. The only noticeable difference is that absolute probabilities tend to be slightly higher when including all high-intensity uses.

Table 15. Regression equations used in calculating probabilities

$$C67\text{-}71^{a} = -1.420 + \underset{(5.31)^{*}}{6.250(PCTRES67)} - \underset{(-4.41)}{7.534(PCTRES67^2)}$$

$$C67\text{-}71 = \underset{(-10.02)}{-\ 1.545} + \underset{(4.82)}{6.566(PCTSURRES67)} - \underset{(-3.90)}{8.741(PCTSURRES67^2)}$$

$$C71\text{-}73^{b} = .914 + \underset{(4.15)}{5.318(PCTRES71)} - \underset{(-4.46)}{10.451(PCTRES71^2)}$$

$$C71\text{-}73 = \underset{(-7.02)}{-1.048} + \underset{(3.81)}{6.181(PCTSURRES71)} - \underset{(-4.09)}{13.905(PCTSURRES71^2)}$$

$$C73\text{-}76^{c} = -1.152 + \underset{(6.02)}{6.755(PCTRES73)} - \underset{(5.68)}{9.648(PCTRES73^2)}$$

$$C73\text{-}76 = \underset{(-7.77)}{-1.360} + \underset{(5.21)}{7.826(PCTSURRES73)} - \underset{(-4.85)}{12.738(PCTSURRES73^2)}$$

a. C67-71 represents conversion in the period from 1967 to 1971.

b. C71-73 represents conversion in the period from 1971 to 1973.

c. C73-76 represents conversion in the period from 1973 to 1976.

*Numbers in parentheses are student's <u>t</u>-statistics.

Regression Results

Figures 8 through 13 show the probability curves generated for each of the three periods using first PCTRESyy and then PCTSURRESyy as independent variables. Curves are analyzed in terms of absolute (Table 16) and marginal probabilities associated with changes in residential acreage. To simplify the discussion of regression results, the term "probability" will be used to indicate the probability that an area exhibiting a specified percent of land area in residential use is an area of rapid conversion. "Contribution to probability" will refer to the marginal change in that probability if an additional 1% of total area is developed for residential use. "Average contribution" refers to the average of marginal contributions within each of the growth stages to be discussed.

Pressure from Interior Development: PCTRESyy

Periods 1 and 3: 1967-1971, 1973-1976. Periods 1 and 3 exhibited similar trends and are discussed together. Figure 8 and 10 can be divided into five stages illustrating how probabilities of rapid growth changes as residential services are established.

1. Stage I: 0-5 Percent Residential Use. If little or no acreage is developed for residential use, the absolute probability that that area is

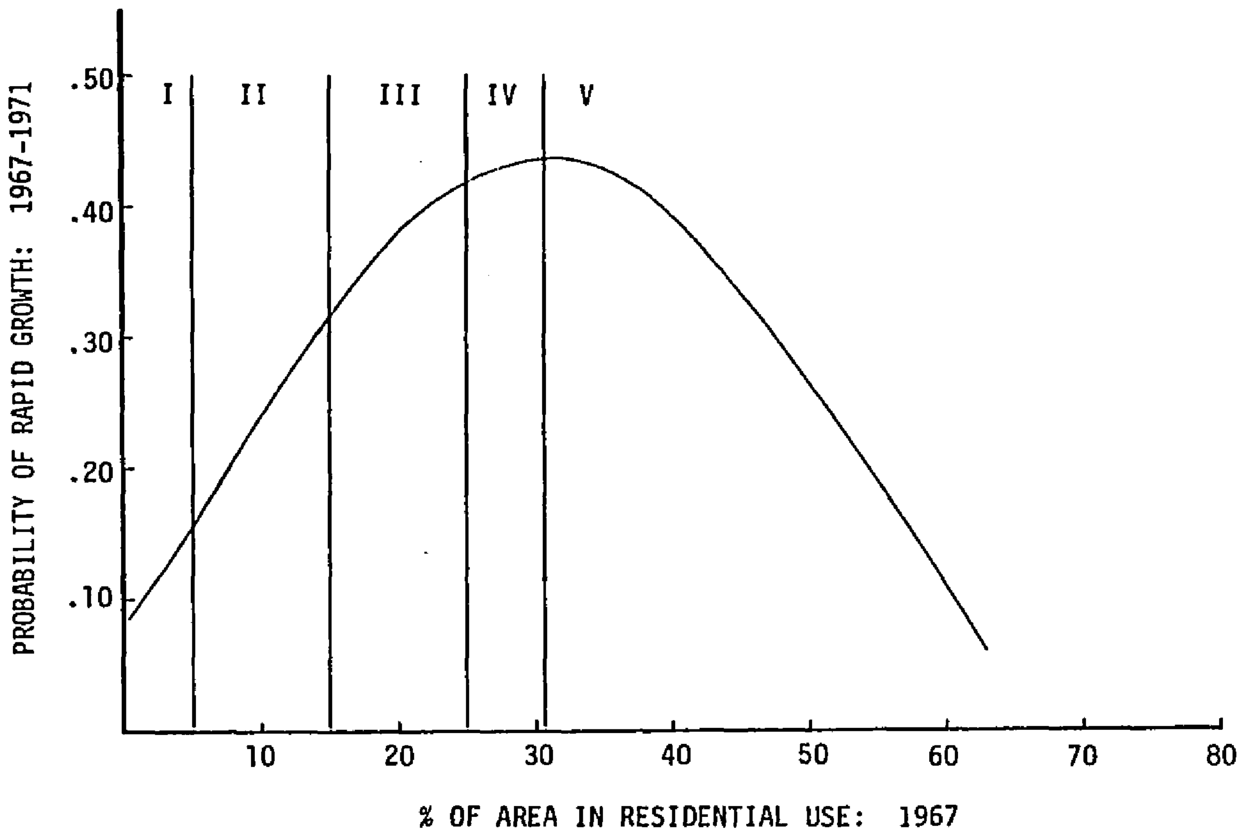


Figure 8. The probability of rapid growth given the percentage of an area in residential use, 1967-1971

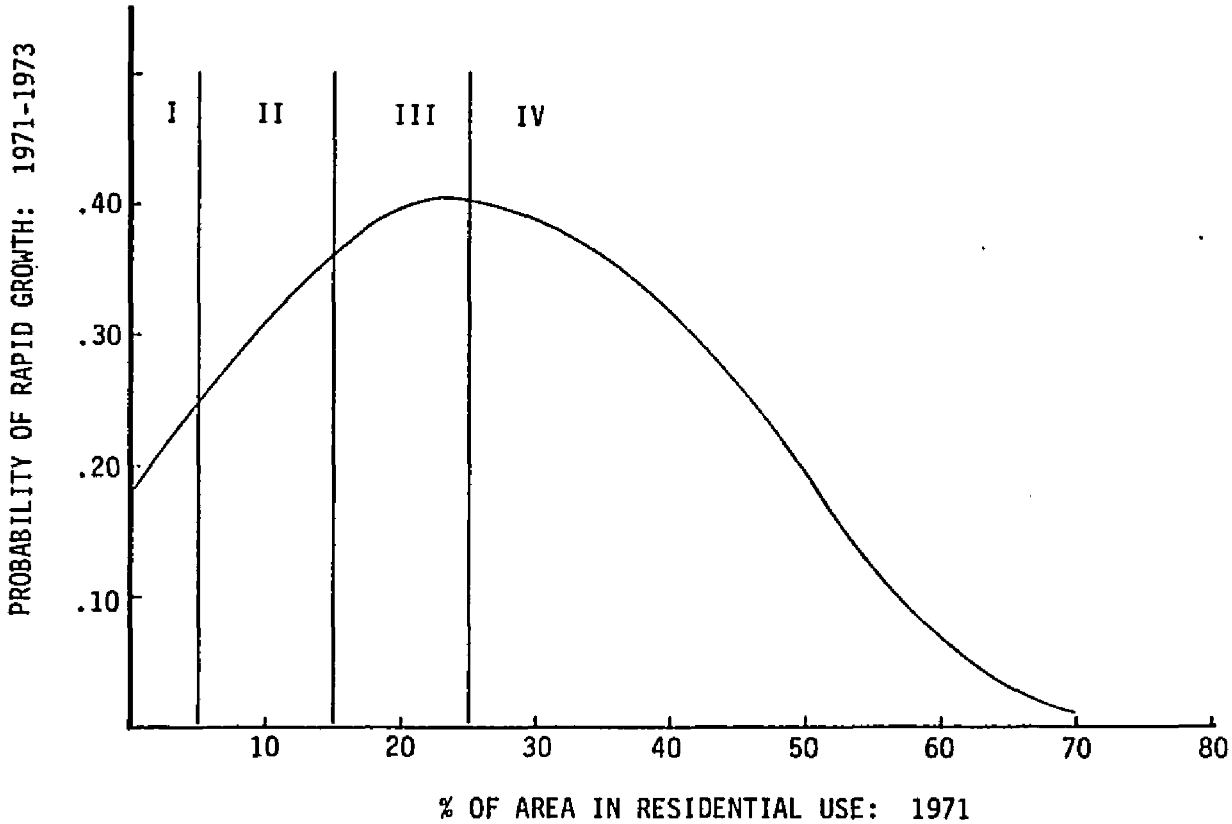


Figure 9. The probability of rapid growth given the percentage of an area in residential use, 1971-1973

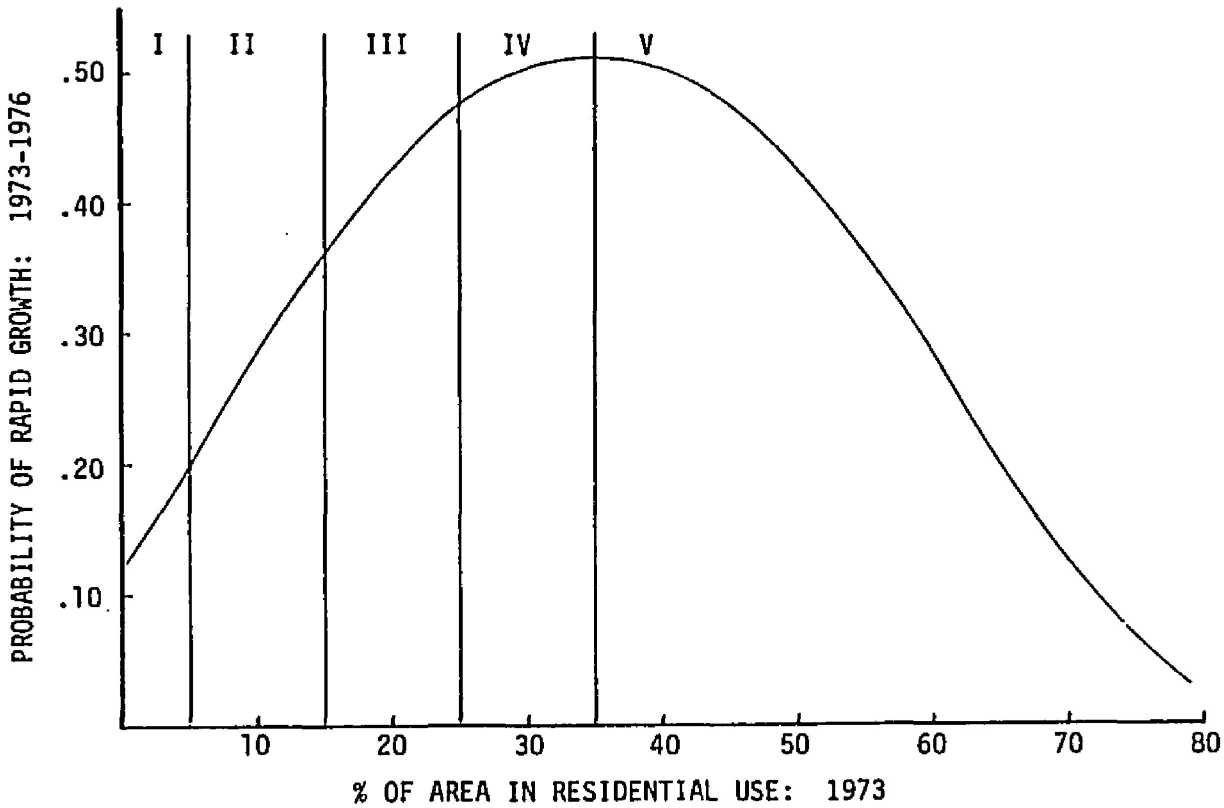


Figure 10. The probability of rapid growth given the percentage of an area in residential use, 1973-1976

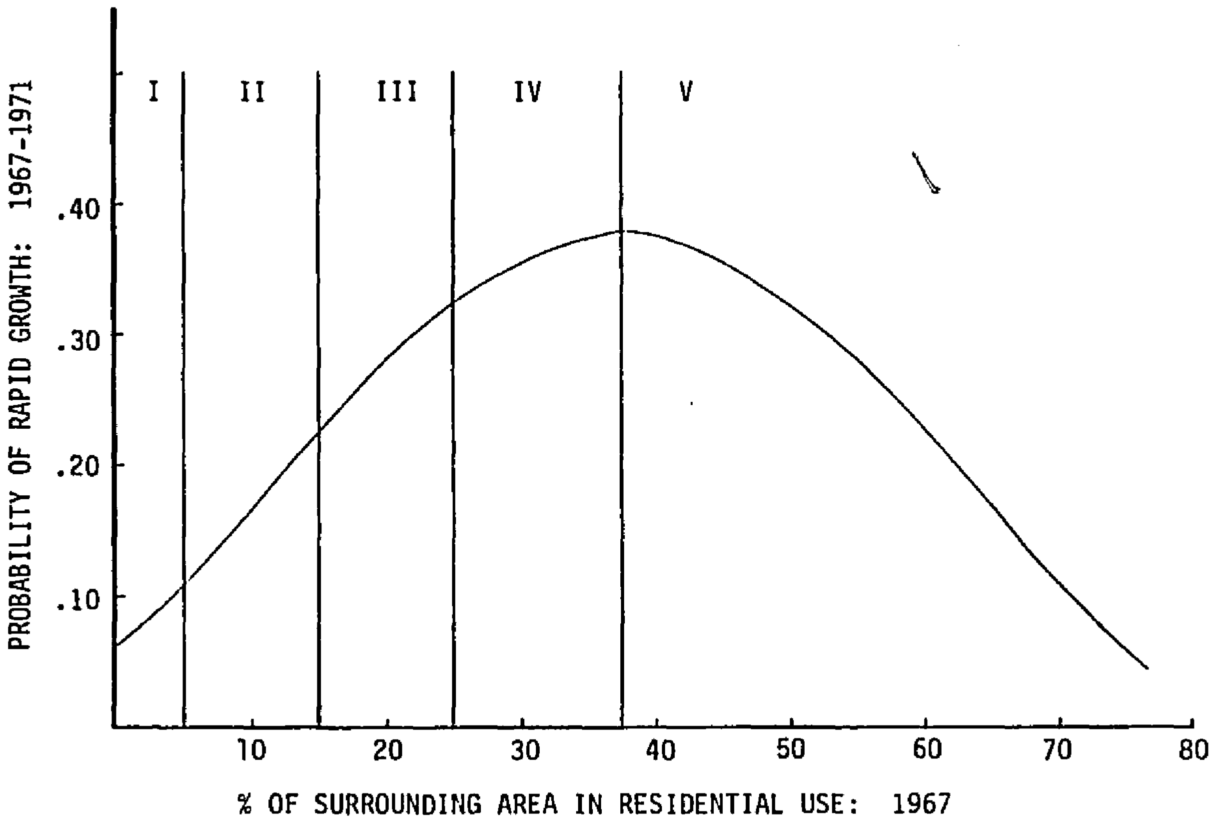


Figure 11. The probability of rapid growth given the percentage of surrounding area in residential use, 1967-1971

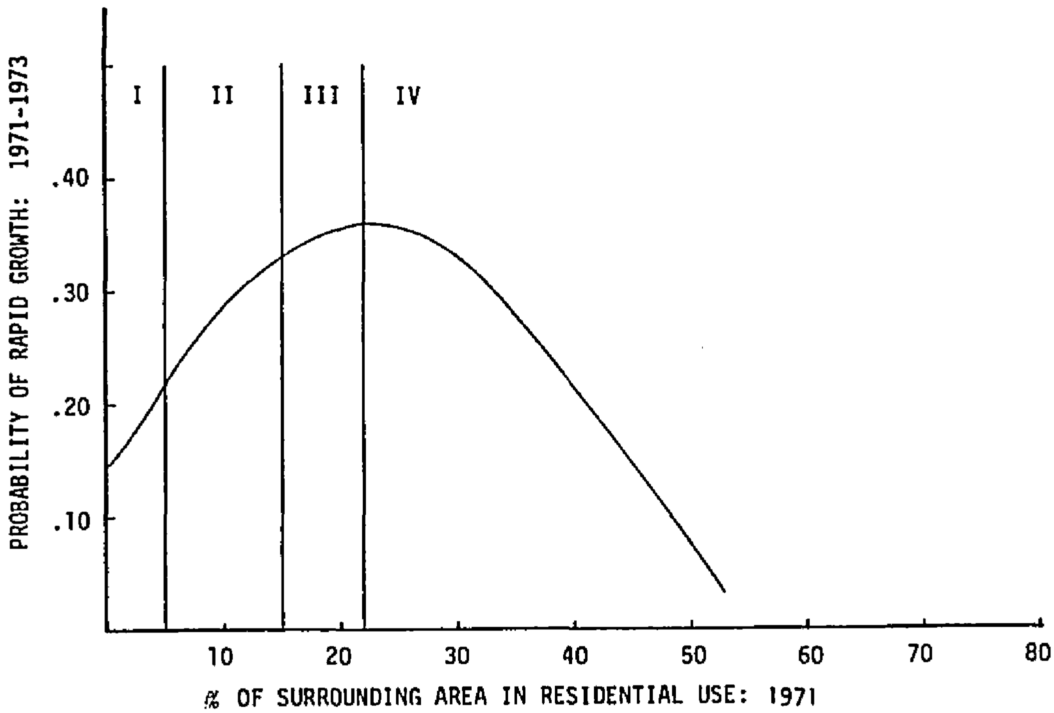


Figure 12. The probability of rapid growth given the percentage of surrounding area in residential use, 1971-1973

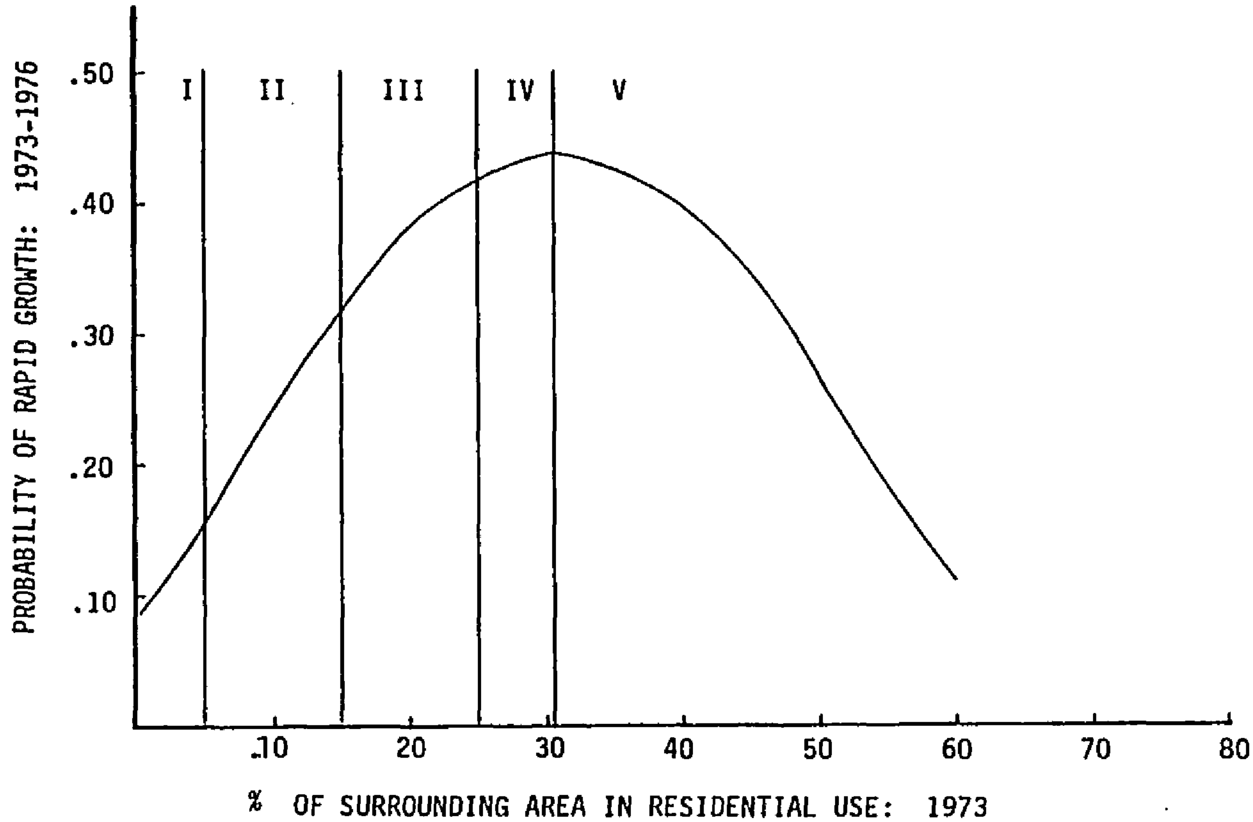


Figure 13. The probability of rapid growth given the percentage of surrounding area in residential use, 1973-1976

Table 16. Percentage of area in residential use and the probability of rapid conversion

Period	Area in Residential Use	Probability of Rapid Conversion
1967-1971	0	.078
	5.0	.129
	15.0	.256
	25.0	.370
	41.5	.451
1971-1973	0	.180
	5.0	.248
	15.0	.360
	25.0	.404
1973-1976	0	.124
	5.0	.199
	15.0	.359
	25.0	.472
	35.0	.510

entering a phase of rapid conversion is very low. Probabilities ranged from a minimum of 0.080 if there was no residential development to a maximum of 0.160 if 5 percent of the area provided residential services. Absolute probabilities indicate that an area very sparsely developed is not likely to be of great interest to developers and any development that does take place is likely to occur gradually. However, with each additional acre added to the residential sector, the marginal contribution to probability of that acre became increasingly larger. The average change in probability for each percentage of total area added to the residential sector was 0.010 between 1967 and 1971, and 0.015 between 1973 and 1976.

2. Stage II: 5-15 Percent Residential Use. The likelihood that an area will attract investment increases if some residential facilities have already been established. Stage II is defined as residential development of between 5 and 15 percent. The absolute probability of rapid conversion increased from a minimum of 0.129 if 5 percent was developed to a maximum of 0.359 if 15 percent was developed. This pressure for continued growth increased at an increasing rate throughout most of this range but then began to accelerate more slowly.

The average contribution of an additional percentage of total acreage in residential use in this range increased to 0.013 between 1967 and 1971 and 0.016 between 1973 and 1976.

3. Stage III: 15-25 Percent Residential Use. In Stage III, pressure for development continued to increase as the area became more extensively utilized to provide residential services. The infrastructure of roads and utilities associated with the existing land-use pattern makes an area more conducive to the development of additional facilities. However, the probability of continued rapid conversion increased at a decreasing rate as more land was shifted to residential use. Probabilities of rapid conversion ranged from 0.257 to 0.472 in this stage, with an average contribution to probability of 0.011 for each period.

4. Stage IV; 25-40 Percent Residential Use. The potential for further development was greatest if from approximately 25 percent to 40 percent of the area was developed for residential use. Absolute probabilities ranged from 0.370 to 0.510 in this stage. Regions falling into this category were the most likely to exhibit high conversion rates. Further development continued to increase the probability of rapid conversion, but those marginal

increases in pressure are progressively smaller. Marginal contributions to probability were only 0.005 and 0.004 for the two periods, respectively. Maximum probability in the period from 1967 to 1971 was found if 35 percent of cell area was in residential use. Between 1973 and 1976, maximum probability was associated with the development of 41.5 percent of the area.

5. Stage V: Continued Residential Development after Maximum Probability. After probability was maximized, further development no longer added to the likelihood that the area would experience a period of rapid conversion. Subsequent development of high-intensity land uses did necessarily cease, but the probability that the area was one of prime interest to developers began to diminish. Several factors may have influenced this decline. Availability of vacant land on which new structures may be built may exert a negative influence on the potential for further growth. Available land may be spatially dispersed throughout the area. Development of small tracts within the existing land-use pattern may result in conflicts arising from external effects imposed on some landowners by the intensive development on contiguous acreage. Thus, incremental development no longer has a positive

effect on the likelihood of rapid conversion. Probabilities found in Stage V were a result of past activity and further development did not exert added pressure on conversion rates. As such, changes in residential use cease to guide future development.

Period 2: 1971-1973. The probability curve found for the 1971-1973 period is seen in Figure 9. There are similarities as well as differences between probabilities associated with this period and the two periods discussed above. The general trends followed by absolute and marginal probabilities were much the same, but the value of those probabilities in relation to values of developed residential acreage are somewhat different.

Absolute probabilities in Stage I are noticeably higher than corresponding values in the other periods. The probability of rapid conversion is 0.180 if there is no residential use in the area, and increases to 0.248 with development of 5 percent of that acreage. Marginal contributions in this range also show a different trend. Whereas marginal contribution to probability was greatest in Stage III in Periods 1 and 3, it is maximized early in Stage I in Period 2. Thus, throughout Stages II and III, probabilities increase at a decreasing rather than increasing rate. Average marginal contribution is 0.014 in

Stage I, 0.011 in Stage II and 0.004 and Stage III. Maximum probability of 0.401 is reached with the development of 25.1 percent of area acreage. Both of these figures are lower than corresponding figures in the other two periods. After the development of 25.1 percent, probabilities decrease in the same manner as was described above.

Pressure from Exterior Development: PCTSURRESyy

Thus far, analysis has focused on development pressure on a given area stemming from existing development within its boundaries. The following discussion shifts this focus to pressure exerted on an area by development of surrounding land.

Regression results were similar in nature to those explained in the previous section. For each of the three periods, marginal contributions progress in the same manner and consequently are divided into the same stages as in the analysis of interior pressure. However, the probability curves associated with development in the surrounding areas show a downward shift when compared to curves associated with interior development. Thus, pressure exerted from surrounding areas or the growth potential of a given area follows the same trend, but is less strong than pressure exerted by development in the area itself.

Implication

These probability trends are indicative of the contagious nature of urban development in the TMA. Growth rates in areas which are either very sparsely or very densely developed do not appear to be directly influenced by the existing land-use pattern. Areas within the TMA which are most likely to expand rapidly are those which have substantial acreage providing residential services, as well as abundant vacant land which is suitable for development. Contagious growth exerts its greatest pressure when roughly 25 to 40 percent of land area is developed for residential use. Absolute probabilities of rapid growth are greatest within this general range, and increase as more acreage is added to the residential sector. Conversion in more extensively developed areas may still be influenced by existing residential acreage, but the pressure for rapid conversion diminishes as more acreage is developed.

This relationship between residential acreage and future growth rates can be a useful tool in evaluating land use alternatives. Areas of medium development are likely to exhibit the highest conversion rates in the TMA in any given period, and increases in residential acreage tend to increase that likelihood. It may be in some developing areas that public facilities such as sewers, roads, and schools, among others, are insufficient to provide services, given a period of rapid conversion. Awareness of the contagious effects of residential development, especially in the rezoning process, could lead to control of conversion rates in such a way as to prevent excessive increases in development pressure until such a time as that development is more desirable.

CHAPTER 5

SUMMARY AND IMPLICATIONS

In this thesis, land-use changes in the Tucson Metropolitan Area (TMA) were documented for the period between 1967 and 1976. Changes in four low-intensity land uses and five high-intensity uses were estimated for the TMA as a whole, and for 10 regions comprising the TMA.

Conversion to high-intensity, or urban land-uses in the TMA increased progressively during the years studied. Between 1967 and 1971, an average of 3.4-square miles of land area was developed annually. Between 1971 and 1973, annual conversion averaged about 4.8-square miles. This figure increased to 6.7-square miles in the years 1973 and 1976.

Residential use was by far more extensive than any other high-intensity land use. Average annual conversion to this use was progressively higher for each of the three periods observed. Collectively, the commercial, industrial, and institutional sectors experienced their highest growth between 1971 and 1973.

As expected, there is a positive relationship between rates of population growth in the TMA and land-use conversion rates. The average annual increase in TMA.

population was 6,510, 15,205, and 17,889 individuals for the periods from 1966-69, 1969-72, and 1972-75, respectively. This growth corresponds well with subsequent land-use conversion rates of 2,147, 3,084, and 4,259 acres annually for the periods from 1967-71, 1971-73, and 1973-76, respectively. Two points are illustrated by these figures:

1. the full effect in terms of induced development of an increase in population may not be felt for several years, and
2. the conversion of low-intensity land uses has responded more than proportionally to population increases in recent years.

The TMA was divided into 10 regions, each examined separately. Some regions showed more rapid development than others, with specific types of land uses developing in response to the particular characteristics of individual regions. The regions exhibiting the highest overall conversion rates during the entire study period were roughly located on the eastern and northern extremities of the TMA. Areas of less rapid overall conversion were roughly in the central, south-central and southwestern regions, whereas the far western area showed the least total conversion.

Conversion data were then used to determine what effect, if any, existing development in an area has on the likelihood of further expansion. Results indicate that as long as low-intensity land is available for development, the likelihood of rapid development increases with the overall density of existing development. This contagious nature of urban growth has thus been identified as one factor that affects the rate and direction of urban expansion. Public awareness of contagious growth can affect public response to programs designed to guide development to meet long-range planning goals. Some possible effects of this awareness on four such programs are discussed below.

Zoning

Zoning is the oldest and most popular land-use control. Zoning can be used to

1. regulate external effects by separating competing uses,
2. protect property values,
3. control population density, and
4. help control the cost of public services.

Land values generally increase with the density and intensity of permitted uses. Urban encroachment often results in increased pressure for upzoning to permit landowners or potential landowners to derive maximum profit from their property. Rezoning is usually costly, in terms of both time and money, because the various parties affected by the manner in which any particular land parcel is utilized represent a broad range of interests. Expectations of future increases in land values associated with contagious growth can intensify the struggle between those in favor of and those opposed to upzoning. Upzoning becomes a more likely occurrence if it is perceived that land values will continue to rise, and some landowners may wish to take advantage of the full value of their property by selling it at a high price to those who wish to develop it more intensely. As a result, rezoning conflicts could increase in number and intensity, making the four zoning goals listed above more difficult to achieve.

Use-value Tax

Use-value taxation is a voluntary program in which the owner of low-intensity acreage agrees to retain that land in its current use in exchange for a reduced tax rate. Such land is taxed according to the value of its current use rather than at the value of surrounding land, which may be used more intensely and may have a higher value. The lower tax rate lessens the incentive for owners to sell acreage to those who would pay a high purchase price in order to develop it. However, if the landowner chooses to sell his acreage, a portion of the tax discount must be repaid.

If a landowner is aware of the likelihood of urban encroachment and the resulting increase in property values of surrounding land, he may be less likely to enter into such an agreement. The longer that land is retained, the greater the tax payback should he decide to sell. Even if the program is implemented, landowners may terminate the program sooner than they would otherwise if they perceive that the tax payback will progressively increase with time. Thus, a program of use-value taxation could lose some effectiveness toward achieving goals of preservation of low-intensity acreage.

Development Tax

A development tax is an ad valorem tax on transactions that will result in the conversion of land to high-intensity uses. Different land parcels are taxed at different rates to control the timing and direction of development. If pressure for development increases, the tax must also increase in order for the program to be effective. If a potential buyer perceives that the land value and subsequently the development tax are likely to increase, he is likely to purchase and develop that area sooner than he would have otherwise. Thus, this program also could lose some effectiveness as a means of directing urban expansion.

Transferable Development Rights

Transferable development rights (TDR) can be used as a tool in the preservation of open spaces, and historical or architectural landmarks. In TDR programs, development rights are separated from property rights. Within each TDR district, TDRs are allocated at a given number of rights per acre. In acres to be preserved development is prohibited, yet landowners can sell their development rights to other landowners who are then allowed to develop their land but did not possess the required number of development rights to do so. In this way, owners of land that is more restricted in acceptable uses are compensated by those who are allowed to develop, thus reducing political pressure for rezoning and public expense of compensation. A market is established in which the timing of transactions is based on current and expected future values.

Sellers of TDRs may consider the contagious nature of growth in deciding when to sell their rights. If it is perceived that the likelihood of rapid conversion has yet to be maximized, sellers would be more likely to keep their rights until such a time that they believe profits would be maximized. In sparsely developed areas, there would be little incentive to sell, as the price of TDRs would be expected to rise. Potential buyers could be unable to purchase for a longer period enough rights to develop their property. This could result in slower growth in areas desirable for development until sellers perceive that contagious growth has reached its maximum effect.

Understanding the contagious aspects of urban growth can aid landowners in making rational decisions concerning the use of their property. Likewise policy-makers can gain more insight into possible development trends in the future and the effectiveness of programs designed to develop and maintain a healthful environment for present as well as future generations.

APPENDIX A

APPLICATION OF PROBIT ANALYSIS

Most regression models are associated with a continuous dependent variable and independent variables which may be continuous or dichotomous. Dichotomous, or dummy, explanatory variables may be assigned a value of zero or one to represent categorical data or information which is non-numerical. Models of qualitative choice make it possible to use such dummy values to represent the dependent variable as well. Such models are widely applicable in the field of economics, especially as an effective means of analyzing survey data. Many survey responses are qualitative in nature--one votes either yes or no in an election; one uses either the bus, subway, or automobile; one is either in or out of the labor force; etc. Analysis of data through a qualitative choice model can lead to the identification of external factors which may cause an individual to choose his particular option.

Probit is a model of qualitative choice in which the independent variable represents one of two alternatives. A simple example will be presented here to illustrate the functional relationships which can be estimated through Probit analysis.

Consider a bond issue in which one's voting choice is assumed to be a function of income. For each sample individual, two pieces of information are known--

1. his voting choice of yes or no, and
2. his personal income.

Voting choice is assigned a vlue of 0 for a "no" vote, and 1 for a "yes" vote, and represents the dependent variable Y for each observation. The independent variable Xi is a continuous variable representing that individual's income. The Probit model estimated parameters α and β such that $Zi = \alpha + \beta Xi$. Associated with each individual is a normally distributed random variable Z^* such that if

$$Y = 1,\ Zi \geq Z^*$$

and if

$$Y = 0,\ Zi < Z^*$$

Since limited information makes it impossible to predict the behavior of each individual on the basis of this information alone, it is more realistic to predict the probability that he will vote yes, given his particular income level. The probability that a yes vote is cast $(Y = 1)$, given a specified income level Yi, is equal to the probability that $Z^* \leq Zi$

$$Pr(Z^* \leqslant Zi) = Pr(Y = 1|Xi)$$

or

$$F(Zi) = Pr(Y = 1|Xi)$$

The probability that $Z^* \leqslant Zi$ can be found from the standard normal density function, and represents the probability that an individual with a specified income level will vote yes on a bond issue.

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