AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

PER. SHELF

JOURNAL OF THE

Northeastern Agricultural Economics Council

DEPARTMENT OF AGRICULTURE
LIBRARY

**VOLUME V, NUMBER 2
OCTOBER 1976**

A MODEL TO SELECT OPTIMAL LAND-USE MIXES
IN RURAL-URBAN FRINGE AREAS*

Robert E. Lee, II
Economic Research Analyst
Department of Conservation
Springfield, Illinois

Robert L. Christensen
Professor
Food and Resource Economics
University of Massachusetts

Introduction

Agricultural land in rural-urban fringe areas has received strong competition from expanding urban communities during recent years. Much of this urban growth has occurred haphazardly and has removed many acres of prime agricultural land from production as the private land market has failed to fully account for the social costs of land-use transitions. The impacts from these shifts in land use are felt by farmers, municipalities and the general public.

Generally, as towns expand, the cost of public services to the new residential units increases by an amount larger than the new tax revenues these units generate [see 1 and 2] and some of the amenities contributing to the quality of life in the town change, e.g., once-large tracts of farmland or other open space may become dotted with new homes. It is expected that the magnitude and perhaps even the direction of these changes will vary with different patterns of urban expansion, e.g., for a given increase in the population, the amount and location of acreage used for housing will vary depending on restrictions such as minimum lot size, zoning regulations, allowance or prohibition of apartments, etc. Restrictions and regulations like these have been used by local officials in attempts to minimize the social costs of land development, but these attempts have been relatively ineffective because the restrictions and regulations were imposed piecemeal and the officials had no way of tracing their effects through time. This situation is primarily the result of inadequate information about the social costs involved and a lack of analytical models to evaluate the complex land-use mixes in developing rural-urban fringe areas.

The purpose of this study was to develop a model to serve as a planning tool to forecast future impacts of alternative land development patterns on local government finances and quality of life and select optimal land-use mixes in rural-urban fringe areas.

---

*The research reported here was supported by the Massachusetts Agricultural Experiment Station-Hatch 325 and the ERS, USDA. This paper results from Robert E. Lee's unpublished Ph.D. dissertation titled "Economic Evaluation of Land-Use Alternatives on the Urban Fringe", University of Massachusetts, 1975. Massachusetts Experiment Station Paper 2076.

Procedure

General:

Given the purpose of this study, it was desired to study the financial (monetary) and quality-of-life (non-monetary) impacts on local communities of changes in land use from productive agricultural or other open space land use to residential use. Since the analytical model was to be a planning tool for controlling development on rural-urban fringe lands, no consideration was given to the existing mix of housing in the urban center. Rather, the study focused on alternative patterns of development on fringe land near the urban center.

A case-study township in Western Massachusetts which was experiencing a loss of agricultural land to urban expansion was selected as a data base for the model. The relevant zoning regulations, tax structure, public service cost structure and population forecasts from this township were used in developing constraints, costs and revenues in the study.

A forecasting horizon of twenty years was selected and divided into four periods of five years each. During each of these five-year periods the objective was to maximize the township's net revenue, i.e., township tax revenue minus township costs, received from various rural-urban land-use mixes capable of housing the township's increased population. Certain environmental quality, land availability, etc., constraints were placed on the maximization function to simulate actual, physical constraints and to control quality-of-life impacts. The objective function and these constraints are briefly described in the "Model Specification" section below.

A recursive type of linear programming model was used to solve for the optimal land-use mixes during the forecasting period. This model is similar to a standard linear programming model but it finds a series of sequential solutions, one for each of the successive time periods within the forecasting period, rather than finding only one solution for the end of the twenty-year period. Results from the solutions for one time period change the constraints placed on the objective functions in following time periods, just as, in the real world, land development through time alters the constraints with which officials must work.

Model Specification:

Objective function.—The objective functions to be maximized in the model were linear functions of alternative rural and urban land-use activities. Ninety-four land-use activities fitting into four categories—residential, publicly owned outdoor space, productive rural and "other" rural uses—were used in each time period. Additional land uses, such as commercial and industrial uses, were omitted from the model because they used little land in the case-study township and evidence suggests that this is also true in most rapidly growing urban communities.

The residential activities included a group of four, different-valued, single-family homes—\$15,000, \$22,500, \$30,000 and \$42,500. Apartments were represented by three building sizes typical of the case-study town—four-family, eight-family and sixteen-family buildings. Each of these multi-family buildings was categorized into three classes based on the value of individual dwelling units—units of \$8,000, \$11,500 and \$15,000 value.

Publicly owned outdoor space was categorized into two classes—playground areas and hiking and picnicking areas. Playground areas were defined as public land located in a residential area which contained a large open area on which outdoor recreation activities were allowed. Hiking and picnicking areas were defined as publicly owned areas meant for observing and being a part of natural surroundings, generally located in wooded and hilly areas or along the edge of streams and ponds in "conservation areas" purchased by the town.

The predominant productive rural uses in the township were dairy farms and apple orchards. Activities representing each of these land uses were included in the objective function. The "other rural uses" activities primarily represented abandoned fields in various stages of regrowth to forest.

All of this land was zoned for residential use by the township. For single-family homes two zones represented two different minimum lot sizes—30,000 square feet for the R-O zone and 20,000 square feet for the R-N zone. Apartment buildings were allowed to be constructed in only the R-N zone. For the purposes of this study, the land in each of these zones was coded by a 1, 2 or 3, written as R-O-1, R-O-2, R-N-3, etc. These additional codes classed the land by the public service facilities, specifically water and/or sewer mains, available to it at the beginning of the study period. Class 1 land (R-O-1 and R-N-1) already had sewer and water mains installed in the ground; class 2 land (R-O-2 and R-N-2) already had water mains installed in the ground, but not sewer mains; and class 3 land (R-O-3 and R-N-3) had neither water nor sewer mains installed in the ground at the beginning of the study period.

Associated with each activity in the objective function was a coefficient (C_j) of net revenue, in 1970 dollars, contributed to the township by an acre of land in the use represented by the activity. Net revenue was defined as the total tax revenue generated by an acre of land in its specified use minus the cost of municipal services for an acre of land in this use.

The total tax revenue associated with each land-use activity was calculated by multiplying the tax rate by the value of the real estate of an acre of land in each use. The share of costs of municipal services were estimated individually for each land-use activity. While this procedure did not accurately represent marginal costs, it did allocate costs closely to their actual incidence.

Constraints.—Five constraint categories were used in the model to place limits on maximization of the objective function.

Land constraints were used to limit the amount of land used in either the R-O zone or the R-N zone to the amount available for each time period.

Municipal service constraints limited additional use during each period to the excess capacity of public service facilities available at the beginning of the period. Included in this category were school, water and sewer services. If the available excess capacity was insufficient to service the households added during the time period, the model permitted purchase of additional capacity through investment, i.e., at additional cost.

A series of housing constraints was used to insure that a mix and the proper quantity of housing units were provided to house the population increase in each time period. These constraints could be altered at will by officials using the model to explore the impacts of different housing mixes in the township, whether this mix changed as a result of changes in housing demand or new regulations, e.g., the banning of apartments.

A pair of recreation land constraints insured that adequate playground space and hiking and picnicking space to prevent higher density use of existing areas were also provided.

Finally, a series of four environmental quality constraints were used to assess the relative environmental impacts of the various land uses and to prevent environmental degradation from proceeding beyond a certain point. These constraints were labeled density, openness, visual quality and closeness to nature. Density was a measure of the population density per acre of each of the land-use activities competing for fringe land. Openness was a measure of the proportion of land not under buildings for each of the land-use alternatives. Visual quality was a measure of the pleasantness of the visual experience afforded by each land-use alternative, where pleasantness was defined in terms of visual variety and order. Closeness to nature was a measure of the naturalness of each land-use activity, determined by the relative degree of closeness to the natural state and the availability of the land to the public. These environmental quality constraints do not account for all aspects of environmental quality but they were not intended to. The major concern here was for man's impacts on open space and the visual amenities which land could offer, depending on its use.

A portion of the matrix is presented in Table 1 to illustrate the model formulation. Ninety-eight activities (the 94 land-use activities mentioned above plus four supplementary municipal service activities) were contained within the model for each time period, which is too many to show in this paper. Only those activities dealing with single-family dwelling construction are shown here.

Table 1

Period 1—Partial Activity Matrix

Constraint Name	Unit	Level	C _i	Sign	R-0-1 Zone			
					Single-family Homes			
					\$15,000 \$/Acre	\$22,500 \$/Acre	\$30,000 \$/Acre	\$42,500 \$/Acre
					92.13	203.42	314.71	500.20
Land								
R-0-1 ^{a,b}	Acre	92	-5,000	=	1.000	1.000	1.000	1.000
R-0-2 ^c	Acre	741	-5,000	=				
R-0-3 ^d	Acre	3,795	-5,000	=				
R-N-1 ^{e,b}	Acre	1,019	-5,000	=				
R-N-2 ^c	Acre	68	-5,000	=				
R-N-3 ^d	Acre	1,483	-5,000	=				
Unbuildable Land	Acre	3,027	-5,000	=				
Municipal Services								
Sewer Capacity	D.U. ^f	870		≤	1.162	1.162	1.162	1.162
Water Capacity	D.U.	16,106		≤	1.162	1.162	1.162	1.162
Elementary Capacity	Pupil	765		≤	.435	.435	.435	.435
Jr.-Sr. High Capacity	Pupil	2,475		≤	.315	.315	.315	.315
Housing								
Minimum Housing	D.U.	-2,023		≥	-1.162	-1.162	-1.162	-1.162
Single-family Homes								
< \$20,000	D.U.	172		≤	1.162			
\$20,000-\$24,999	D.U.	149		≤		1.162		
\$25,000-\$34,999	D.U.	232		≤			1.162	
\$35,000-\$49,999	D.U.	149		≤				1.162
Apartments								
\$ 8,000	D.U.	726		≤				
\$11,500	D.U.	403		≤				
\$15,000	D.U.	192		≤				
Four-family	D.U.	325		≤				
Eight-family	D.U.	525		≤				
Sixteen-family	D.U.	525		≤				
Maximum Housing	D.U.	2,023		≤	1.162	1.162	1.162	1.162
Recreation Land								
Hiking & Picnicking	Acre	0		≥	.049	.049	.049	.049
Playground	Acre	0		≥	.024	.024	.024	.024
Environmental Quality								
Density	Units	28,792		≤	2.000	2.000	2.000	2.000
Openness	Units	28,792		≤	2.000	2.000	3.000	3.000
Visual Quality	Units	28,792		≤	4.000	2.000	1.000	
Closeness to Nature	Units	28,792		≤	4.000	4.000	3.000	3.000
Integer Transfer Rows								
Additional Sewage Capacity	D.U.	10,000		≤				
Additional Elementary Capacity	Pupil	400		≤				
Sewage Integer	Plant	1	-999,999	=				
Elementary Integer	Classroom	0		=				

Table 1 (continued)

Constraint Name	R-0-2 Zone				R-0-3 Zone			
	Single-family Homes				Single-family Homes			
	\$15,000 \$/Acre	\$22,500 \$/Acre	\$30,000 \$/Acre	\$42,500 \$/Acre	\$15,000 \$/Acre	\$22,500 \$/Acre	\$30,000 \$/Acre	\$42,500 \$/Acre
	-111.67	-0.38	110.91	296.40	-205.38	-94.09	17.20	202.69
Land								
R-0-1								
R-0-2	1.000	1.000	1.000	1.000				
R-0-3					1.000	1.000	1.000	1.000
R-N-1								
R-N-2								
R-N-3								
Unbuildable Land								
Municipal Services								
Sewer Capacity	1.162	1.162	1.162	1.162	1.162	1.162	1.162	1.162
Water Capacity	1.162	1.162	1.162	1.162	1.162	1.162	1.162	1.162
Elementary Capacity	.435	.435	.435	.435	.435	.435	.435	.435
Jr.-Sr. High Capacity	.315	.315	.315	.315	.315	.315	.315	.315
Housing								
Minimum Housing	-1.162	-1.162	-1.162	-1.162	-1.162	-1.162	-1.162	-1.162
Single-family Homes								
< \$20,000	1.162				1.162			
\$20,000-\$24,999		1.162				1.162		
\$25,000-\$34,999			1.162				1.162	
\$35,000-\$49,999				1.162				1.162
Apartments								
\$ 8,000								
\$11,500								
\$15,000								
Four-family								
Eight-family								
Sixteen-family								
Maximum Housing	1.162	1.162	1.162	1.162	1.162	1.162	1.162	1.162
Recreation Land								
Hiking & Picnicking	.049	.049	.049	.049	.049	.049	.049	.049
Playground	.024	.024	.024	.024	.024	.024	.024	.024
Environmental Quality								
Density	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Openness	2.000	2.000	3.000	3.000	2.000	2.000	3.000	3.000
Visual Quality	4.000	2.000	1.000		4.000	2.000	1.000	
Closeness to Nature	4.000	4.000	3.000	3.000	4.000	4.000	3.000	3.000
Integer Transfer Rows								
Additional Sewage								
Capacity								
Additional Elementary								
Capacity								
Sewage Integer								
Elementary Integer								

Table 1 (continued)

Constraint Name	R-N-1 Zone				R-N-2 Zone			
	Single-family Homes				Single-family Homes			
	\$15,000 \$/Acre	\$22,500 \$/Acre	\$30,000 \$/Acre	\$42,500 \$/Acre	\$15,000 \$/Acre	\$22,500 \$/Acre	\$30,000 \$/Acre	\$42,500 \$/Acre
	145.98	312.82	479.66	757.73	-57.82	109.02	275.86	553.93
Land								
R-0-1								
R-0-2								
R-0-3								
R-N-1	1.000	1.000	1.000	1.000				
R-N-2					1.000	1.000	1.000	1.000
R-N-3								
Unbuildable Land								
Municipal Services								
Sewer Capacity	1.742	1.742	1.742	1.742	1.742	1.742	1.742	1.742
Water Capacity	1.742	1.742	1.742	1.742	1.742	1.742	1.742	1.742
Elementary Capacity	.652	.652	.652	.652	.652	.652	.652	.652
Jr.-Sr. High Capacity	.472	.472	.472	.472	.472	.472	.472	.472
Housing								
Minimum Housing	-1.742	-1.742	-1.742	1.742	-1.742	-1.742	-1.742	-1.742
Single-family Homes								
< \$20,000	1.742				1.742			
\$20,000-\$24,999		1.742				1.742		
\$25,000-\$34,999			1.742				1.742	
\$35,000-\$49,999				1.742				1.742
Apartment								
\$ 8,000								
\$11,500								
\$15,000								
Four-family								
Eight-family								
Sixteen-family								
Maximum Housing	1.742	1.742	1.742	1.742	1.742	1.742	1.742	1.742
Recreation Land								
Hiking & Picnicking	.074	.074	.074	.074	.074	.074	.074	.074
Playground	.035	.035	.035	.035	.035	.035	.035	.035
Environmental Quality								
Density	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Openness	2.000	3.000	3.000	4.000	2.000	3.000	3.000	4.000
Visual Quality	4.000	2.000	1.000		4.000	2.000	1.000	
Closeness to Nature	4.000	4.000	3.000	3.000	4.000	4.000	3.000	3.000
Integer Transfer Rows								
Additional Sewage								
Capacity								
Additional Elementary								
Capacity								
Sewage Integer								
Elementary Integer								

Table 1 (continued)

Constraint Name	R-N-3 Zone				R-N-1 Zone		
	Single-family Homes				Four-family Apartments		
	\$15,000 \$/Acre	\$22,500 \$/Acre	\$30,000 \$/Acre	\$42,500 \$/Acre	\$8,000 \$/Acre	\$11,500 \$/Acre	\$15,000 \$/Acre
	-151.53	15.31	182.15	460.22	-0.70	193.99	388.68
Land							
R-0-1							
R-0-2							
R-0-3							
R-N-1					1.000	1.000	1.000
R-N-2							
R-N-3	1.000	1.000	1.000	1.000			
Unbuildable Land							
Municipal Services							
Sewer Capacity	1.742	1.742	1.742	1.742	4.356	4.356	4.356
Water Capacity	1.742	1.742	1.742	1.742	4.356	4.356	4.356
Elementary Capacity	.652	.652	.652	.652	1.629	1.629	1.629
Jr.-Sr. High Capacity	.472	.472	.472	.472	1.180	1.180	1.180
Housing							
Minimum Housing	-1.742	-1.742	-1.742	-1.742	-4.356	-4.356	-4.356
Single-family Homes							
< \$20,000	1.742						
\$20,000-\$24,999		1.742					
\$25,000-\$34,999			1.742				
\$35,000-\$49,999				1.742			
Apartments							
\$ 8,000					4.356		
\$11,500						4.356	
\$15,000							4.356
Four-family					4.356	4.356	4.356
Eight-family							
Sixteen-family							
Maximum Housing	1.742	1.742	1.742	1.742	4.356	4.356	4.356
Recreation Land							
Hiking & Picnicking	.074	.074	.074	.074	.185	.185	.185
Playground	.035	.035	.035	.035	.088	.088	.088
Environmental Quality							
Density	3.000	3.000	3.000	3.000	4.000	4.000	4.000
Openness	2.000	3.000	3.000	4.000	2.000	3.000	3.000
Visual Quality	4.000	2.000	1.000		3.000	2.000	1.000
Closeness to Nature	4.000	4.000	3.000	3.000	4.000	4.000	4.000
Integer Transfer Rows							
Additional Sewage							
Capacity							
Additional Elementary							
Capacity							
Sewage Integer							
Elementary Integer							

^a R-0 stands for R-0 zoned land, i.e., house lots of 30,000 acres minimum size.

^b The "1" in R-0-1 and R-N-1 indicates land where water and sewer mains are already installed in the ground.

^c The "2" in R-0-2 and R-N-2 indicates land where water mains are installed but sewer mains are not.

^d The "3" in R-0-3 and R-N-3 indicates land where neither water nor sewer mains have been installed.

^e R-N stands for R-N zoned land, i.e., house lots of 20,000 acres minimum size.

^f D.U. stands for dwelling unit.

Results

During the twenty-year forecasting period, most new single-family homes were located in the R-N zone (see Table 2). Only during the third time period, when all the R-N-1 zoned land had been used up, were any single-family homes located in the R-0 zone. Also during this period, a total of 885 acres of land was converted to single-family home use in the optimal solution. Two hundred fourteen of these acres were allocated for \$15,000 homes (369 dwelling units), 185 acres for \$22,500 homes (321 dwelling units), 285 acres for \$30,000 homes (498 dwelling units) and 201 acres for \$42,500 homes (321 dwelling units). For apartment buildings, 436 acres were allocated during the forecasting period—87 acres to four-family buildings, 191 acres to eight-family buildings and 158 acres to sixteen-family buildings. In addition to these residential uses, 84 acres were allocated to urban use as playgrounds and 174 acres were designated for hiking and picnicking. Summing these acreages yields a total urban land conversion of 1,405 acres. This left 5,795 acres in agricultural use, all of which was in dairy farms.

Monetary Impacts:

The monetary impacts in these solutions were positive in each time period and contributed net revenues of \$332,449 to the town treasury over the full twenty-year period.

Non-Monetary Impacts:

A total of 4,346 quality units were used by the urban sector in the solution. The openness index indicated that 4,092 units were used by the urban sector. (The total constraint was 28,792 quality units.) Some 2,682 of the 28,792 visual quality units were used while 5,126 "closeness to nature" units were used.

The agricultural sector also used up quality units in each of these categories, but use of a five-point ranking scale, as in this study, proved inadequate to accurately reflect the agricultural sector's impacts relative to the urban impacts.

Stability of the Activities:

From a planning standpoint it is useful to examine the sensitivity of the residential activities in the optimal solutions to changes in the net revenue (C_j) values in the objective function. An analysis of this type showed that single-family home activities in the solutions were stable in the upward direction, i.e., no activities would replace them in the solution regardless of how high their C_j values were set. However, in the downward direction, the single-family homes were sensitive, being

Table 2

Optimal Land-Use Pattern After 20 Years
Using the Planning Model

Land-Use Category	R-O Zone ^{a/} (acres)	R-N Zone ^{b/} (acres)
Single-Family Homes:		
\$15,000 Average Value	3	211
\$22,500 Average Value	Nil	185
\$30,000 Average Value	Nil	285
\$42,500 Average Value	49	152
Subtotal	52	833
Apartment Dwellings:		
4-Family	Nil	87
8-Family	Nil	191
16-Family	Nil	158
Subtotal	0	436
Total Land Developed	52	1,269
Public Uses:		
Playgrounds	84	
Hiking-Picnicking, etc.	174	
Agricultural Uses:		
Dairy	4,522	1,273
Orchards	Nil	Nil
Other	Nil	Nil

^{a/} R-O zoned land is residential with minimum lot size of 30,000 square feet.

^{b/} R-N zoned land is residential with minimum lot size of 20,000 square feet.

replaced in the optimal solution if their C_j value were reduced by a range of 1.4 percent, for \$42,500 homes, to 7.7 percent, for \$15,000 homes.

Apartment buildings were generally much more sensitive. For the most part, apartments were readily interchangeable with one another, both by building size (four-family, eight-family or sixteen-family) and by value class (\$8,000, \$11,500 or \$15,000 per dwelling unit). The primary exception to this statement was the upper bound on \$15,000 dwelling units. These activities would not be replaced in the solution if their C_j values were raised, although they were quite sensitive to reductions in C_j values.

Remarks

The objective in this study was to develop a quantitative tool which could forecast local impacts of alternative land development patterns and select optimal land-use mixes on the rural-urban fringe. This paper reports the results using existing case-study township regulations, playground-to-dwelling-unit ratios, etc. and one set of population forecasts, information which is useful for forecasting purposes.

However, this model can also be used to explore the effects of different land-use or environmental quality regulations, population growth rates or other exogenous factors. In this use the model serves the purpose of a planning tool which officials can use for trial runs of new regulations and different exogenous factors.

References

1. Allee, David J.; Charles I. Hunt; Mary A. Smith; Barry R. Lawson and R. C. Hinman, Toward the Year 1985: The Conversion of Land to Urban Use in New York State, Special Cornell Series No. 8, Ithaca, New York, 1970.
2. Little, Charles E., Challenge of the Land, New York: Open Space Action Institute, Inc., 1968.