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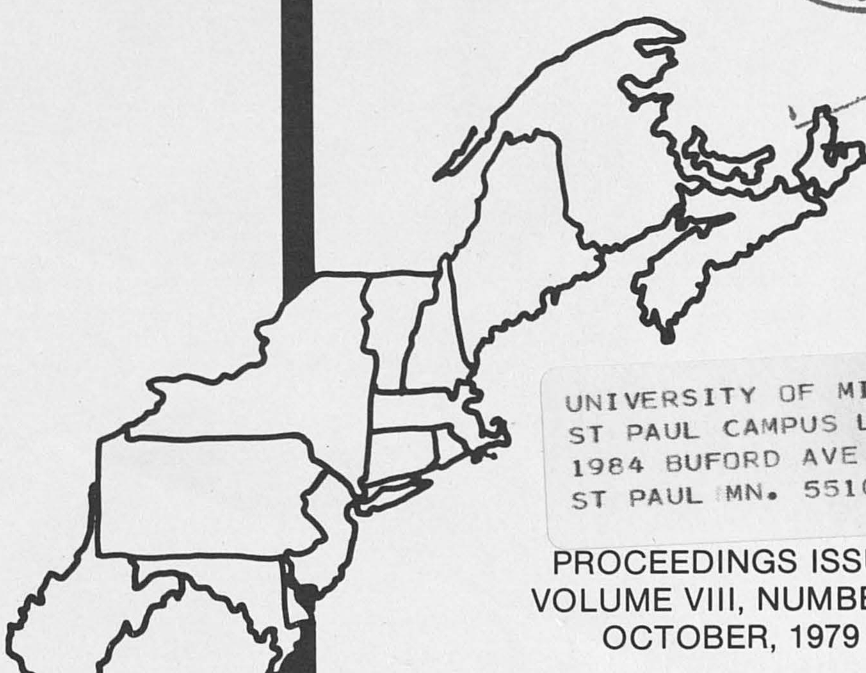

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LAND USE PROJECTIONS UNDER ALTERNATIVE POLICIES: A TRANSITION MATRIX APPROACH

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As a result of accelerated growth during the past decade, land use change over time and its accompanying problems represents a policy area germane to New Hampshire. Accurate projections of the future pattern of land use would be helpful to decision makers responsible for land use policy. Such projections could assist policy makers either directly in formulating land use plans or indirectly in justifying the need (or lack of need) for overt land use planning. Future projections, based upon various alternative land use policy scenarios, will increase the quantitative supply of information to decision makers in a two-fold manner. First, such estimates provide an insight into the current trend in land use mix and, secondly, give an overview of what impacts various policies directly have upon land use change.

Land use acreage data for New Hampshire are readily available from aerial photographs for the 1955 and 1970 years (Coppelman, Pilgrim, and Peschel, 1978). These data are classified into five categories: agriculture, forest, idle, developed and other.[1] On the basis of this information, it is the objective of this paper to apply a Markov chain process to project acreage for each of the five classes for designated future years, given assumptions specifically applicable to the New Hampshire situation. Three different policy scenarios will be implemented so that land use change comparisons over time can be made. The alternatives are the status quo (unregulated) trend without any policy implementation, incorporation of a current use assessment land control, and allowance for a ten percent growth rate in developmental acreage. It should be noted that this particular framework, with a high degree of flexibility allowed for assumptions, could easily be adopted for other regional application.

This paper will be organized as follows. The second section contains an explanation of the methodology employed. Empirical results for each scenario are discussed in the third section. The final section consists of some concluding comments.

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METHODOLOGY

The first order Markov chain process, often called a transition matrix approach, consists of two primary parts, the transition matrix and the transition probability matrix (Halberg, Burnham).

The transition matrix, T, is an (n x n) array of acreage values a_{ij}, which represent the intertemporal land use shifts between n land use categories over a measured period of time t, where $t = t_2 - t_1$ and $t_2 > t_1$. Thus, a_{ij}, the element in the i^{th} row and j^{th} column of T, represents the amount of land previously in land use category i at time t_1 which has transferred to land use category j by time t_2. For our purposes, total land acreage for New Hampshire is disaggregated into five use categories with the years 1955 and 1970 depicting our historically observed period of time, as stated previously. The observed T-matrix for these years is presented in Table 1.

Table 1

Transition Matrix (T) for New Hampshire Land Use, 1955 to 1970

Conversion from row i to column j	Agricultural	Idle	Forest	Developed	Other	1955 Total
			(Acres)			
Agriculture	447,899	75,357	6,345	35,839	953	566,393
Idle	1,522	26,724	56,267	4,608	217	89,338
Forest	2,371	47	4,676,801	58,719	7,690	4,745,628
Developed	8	23	46	102,753	17	102,847
Other	0	0	0	793	58,979	59,772
1970 Total	451,800	102,151	4,739,459	202,712	67,856	5,563,978

For instance, the element in Column 1 row 3, a_{31}, can be interpreted to mean the 2,371 acres of forest land were converted to agricultural land for the period between 1955 and 1970. The diagonal elements relate to the initial acreage in a particular land use category that remained in that class over the measured period of time. The elements, a_{ij}, of the T-matrix are read as use shifts from row i to column j with the row and column totals of the matrix in Table 1 representing the 1955 and 1970 land use mix for the state, respectively.

Once the specific movement between categories is established, we then calculate the probability for each land class of converting to each of the other land categories over the measured period of time t. These probabilities are arrayed in a transition probability matrix, P. The P-matrix is an (n x n) matrix consisting of probability values P_{ij}, which measure the probability of acreage in land use category i shifting to land use category j over a period of time t. The P_{ij}'s are calculated directly from the observed T-matrix, by taking the individual elements, a_{ij}'s, of the T-matrix, and dividing each by the amount of land classified under use category i at time t_1. The initial amount of land in use category i is found in the T-matrix as the sum of the elements of row i. The P-matrix for our data is shown in Table 2.

For example, the element in Column 2, row 1, p_{12}, of Table 2, suggests that 13.3 percent (75,357/566,393) of agricultural land in 1955 shifted to idle land by 1970. The calculated probability of one acre of agricultural land transferring to idle land over a period of sixteen years is 13.3 percent. The main diagonals are interpreted as the probability that a particular category will remain in the same use over the measured period of time.

Table 2

Transition Probability Matrix (P) for New Hampshire, 1955 to 1970

Conversion from row i to column j	Agriculture	Idle	Forest	Developed	Other
Agriculture	.7909	.1330	.0112	.0633	.0017
Idle	.0171	.2991	.6298	.0516	.0024
Forest	.0005	0	.9855	.0124	.0016
Developed	.0001	.0002	.0004	.9991	.0002
Other	0	0	0	.0133	.9867

To project the amount of acreage corresponding to each of the n land use categories at a future time t_3 ($t_3 = t_2 + t$), one simply takes the land use mix at time t_2, C_{t2} (found as the column totals of the observed T-matrix), and post-multiplies this by the original P-matrix, the result being a projected land use mix for time t_3, C_{t3}. More specifically, a ($1 \times n$) row vector (C_{t2}) is post-multiplied by an ($n \times n$) matrix (P), resulting in a ($1 \times n$) row vector (C_{t3}), depicting the projected acreage totals for the n separate land use categories at time t_3. Intuitively, by classifying C_{t_3} as the base period land use mix and further utilizing the original P-matrix, one may predict for intervals of time t, land use mix into the future. In addition, through interpolation, it is possible to project intermediary land use configurations for a point in time lying within the measured period of time t.

Since the observed time interval of our data was sixteen years, it was decided, for consistency sake, that projections into the future should also be kept to the same time duration. Therefore, land use estimates for the years 1985, 2000 and 2015 were calculated for all alternative land use policies.

Scenario 1: Status Quo

The first alternative to be examined is that of status quo. This alternative assumes a stationary P-matrix over time, alluding to an unregulated trend without any further institutional implementation. The processes of the past are assumed to continue into the future, justifying the use of a constant P-matrix in predicting future land use mix.

The T and P matrices for the period 1955-1970 have been previously referenced above. Again, we are assuming this P-matrix is stationary over time. To project the land use mix for the year 1985, C_{t85}, one needs only to apply the above methodology; that is, pre-multiply the P-matrix by the row vector depicting the 1970 land use mix, C_{t70}, yielding C_{t85}. To predict acreage for land classes for the year 2000, the above calculated 1985 row vector C_{t85}, is post-multiplied by the original P-matrix. This same procedure is repeated to estimate land use change for the year 2015.

Scenario 2: Current Use Assessment

A land use control policy presently being administered in the state of New Hampshire is that of current use property tax exemption.[2] In general, under this policy owners of acreage classified as agricultural, forest, idle or other land may register this acreage and receive a substantial reduction in property tax liability. Below we will examine the effects on future land use mix of current use exemption.

The implementation of a current use exemption would generally have the effect of decreasing the amount of land in nondevelopmental use categories being converted to developmental use. After consulting with the New Hampshire State Department of Revenue Administration, we calculated a percentage reduction in the probabilities of land shifting to the developmental land use category from agriculture, forest, idle and other to be thirty, twenty-five, twenty-five, and fifty-four percent, respectively.[3] Due to the nature of current use assessment, it is also assumed that land previously projected to shift to the developmental land use category in excess of the amount predicted under this particular program will remain in its own land use classification.

This reduction will be mirrored in a new hypothesized P-matrix. This hypothesized P-matrix will consist of the same probability entries (p_{ij}'s) as the original P-matrix, except for the eight entries affected by the calculated reduction. The probabilities (p_{ij}'s) of land in the agricultural, forest, idle and other land use classes shifting to developmental use have been decreased by the above stated percentages, with the amounts of reductions in probabilities (p_{ij}'s) being added to the appropriate probability values of land remaining in its own classification over the period of measurement. For example, the probability of land in agriculture being converted to development over the sixteen year period has beed decreased by .0190 which is computed by multiplying .0633 by .30 and the probability of land remaining in agriculture has been increased by an equal amount (.0190). A similar procedure was followed for the idle, forest and other land use categories, producing the new hypothesized P-matrix shown in Table 3.

Future land use mix for 1985, 2000, and 2015 may be projected using the procedure outlined above and substituting the new P-matrix for the original one.

Table 3

Revised P-Matrix Under a Current Use Assessment Scenario for New Hampshire

Conversion from row i to column j	Agriculture	Idle	Forest	Developed	Other
Agriculture	.8098	.1330	.0012	.0443	.0017
Idle	.0171	.3120	.6298	.0387	.0024
Forest	.0005	0	.9886	.0093	.0016
Developed	.0001	.0002	.0004	.9991	.0002
Other	0	0	0	.0061	.9939

Scenario 3: Ten Percent Developmental Growth Limitation

The final alternative to be examined will be that of imposing a limitation on the growth of land classified under the development use category. In New Hampshire developed land will be allowed to grow at a rate of ten percent over each sixteen year period of measurement. This assumption of growth allowance results from a proposed state legislative bill which was heavily debated in subcommittee.[4] Of course, for investigative purposes other percentage limitations could be incorporated into this framework. Examination of our projections under the status quo alternative shows developmental growth in excess of ten percent per period of measurement.

Again, as in the current use alternative, projecting the effects of a ten percent limitation on the growth of developed land will necessitate alteration of the original P-matrix. In addition, due to our requirement of a ten percent ceiling on each sixteen year period, separate P-matrices will be in order for each period of projection. We will use the projection of land use for 1985 under this policy alternative to illustrate the procedure employed.

In constructing the P-matrices for future projections under this alternative we make three assumptions. First, as similarly allowed in the construction of the hypothesized P-matrix for the current use alternative, we assume that land previously predicted to convert to developmental use in excess of the ten percent allowed increase will remain in its original land use category over the measured period. The rationale behind this is that targets for restraining growth focus upon conserving the quantities of acreage within any particular land use category. Secondly, it is assumed that the probabilities of land predicted to shift from development to the other four land use classes, as well as that probability of land remaining in development itself over the period, will remain constant. In other words, land conversion from development to non-development categories will occur at a constant rate. Lastly, the decrease in land transferring from the nondevelopment land categories to development over the sixteen year period will be proportional for each category; that is, these four probabilities (p_{ij}'s) will be decreased by an equal percentage. We are thus assuming the neutrality of the decision makers towards a particular land use category. One may of course make similar or differing assumptions, as well as change the ceiling rate itself, to fit any desired policy.

Looking at the relevant data, we are allowing developed land to increase to 222,983 acres by the year 1985, or 110 percent of the 1970 developed acreage figure of 202,712 acres. Developed land will increase by 20,271 acres over the period. Since the probability of land projected to remain in development over the period is assumed to remain constant (.9991), 202,530 acres (.9991 x 202,712) of developed land will be predicted to remain in development between the years 1970-1985. Also, a constraint upon the amount of land shifting to development from the other categories over the period is calculated to be 20,453 acres (222,983 - 202,530).

The predicted amount of land shifting to development under the status quo alternative for this period was 93,451 (296,071 - 202,530).[5] We must

Table 4

Revised P-Matrix Under a Ten Percent Developmental Growth Limitation for New Hampshire, 1970-1985

Conversion from row i to column j	Agriculture	Idle	Forest	Developed	Other
Agriculture	.8403	.1330	.0112	.0138	.0017
Idle	.0171	.3394	.6298	.0113	.0024
Forest	.0005	0	.9952	.0027	.0016
Developed	.0001	.0002	.0004	.9991	.0002
Other	0	0	0	.0029	.9971

therefore decrease each of the probability values (p_{ij}'s) in the original P-matrix corresponding to shifts from non-developed land to developed by 78.135 percent $(1 - \frac{20453}{93451})$. This decrease in probability vaues will, by our first assumption, be absorbed by the non-development land use class diagonal elements of the P-matrix; that is, there will be an increase in each of the probabilities of non-developed land remaining in its own land class over the sixteen year period, equal to the decrease in probability of land for that class shifting to development for the same period. For example, the probability of land transferring from agriculture to development has been decreased from .00633 to .0138 or a decrease of 78.135 percent (see Table 4). The probability of land remaining in agriculture over the same period was subsequently increased by .0495 (0.0633 - .0138). Also, note that, due to our second assumption, the probability values in row 4, the development category row, have remained constant.

Following this process for future time periods, by considering the previous period's P-matrix as the original one, and taking its projections for the desired period as the status quo results for that interval, it is possible to predict the effects of a ten percent ceiling on the rate of growth of developed land on future land use mix. The new P-matrices for the periods 1985-2000 and 2000-2015 are contained in the appendix for comparative purposes.

EMPIRICAL RESULTS

Table 5 illustrates the land use projections estimates attached to each of the three land use policy scenarios. More agricultural land is preserved under the ten percent development growth (C) control than either the status quo (A) or current use assessment (B) alternatives for each of the three projected years. Focusing upon the "status quo" scenario, if the current trends continue, by the year 2015 acreage in agricultural land would have decreased by approximately 59 percent from 1955 acreages. Developed land would have increased by 351 percent. Forest land would have declined by .65 percent and remained relatively stable which would be a "positive" for New Hampshire's heavily forest based economy. Again, with respect to the status quo alternative, decision makers may make hasty conclusions based upon historical data. For instance, from 1955 to 1970 idle acreage increased, but surprisingly for future time periods the amount of acreage for this particular category declined. This occurs as a result of the decrease in the amount of agricultural land being converted to idle because overall amounts of agircultural land continue to decrease. Policy land use groups which look at observed data and assume that this trend will continue into the future can be misled. Such an approach will generally result in wrong recommendations which can only lead in the long run to a suboptimal land mix.

Table 6 depicts the percentage change from the status quo alternative for each of the two other scenarios. Scenario C has a dominance over alternatives A and B with respect to keeping acreage in all categories except for developed land. This logically follows because a slowing up of the amount of land classified as developed would have to increase the acreage in other categories. Over time, the generated results imply that scenario C

Table 5

Land Use Projections for New Hampshire Under Alternative Scenarios

Year	Scenario	Agri-culture	Idle	Forest	Developed	Other	Total
		Land Use Categories					
				(acres)			
1955	A*	566,393	89,338	4,745,628	102,847	59,772	5,563,978
1970	A	451,800	102,151	4,739,459	202,712	67,856	5,563,978
1985	A	361,420	90,683	4,740,213	296,071	75,591	5,563,978
	B	370,004	92,001	4,754,905	270,989	76,079	5,563,978
	C	383,676	94,800	4,786,132	222,983	76,296	5,563,978
	A	289,761	75,251	4,732,759	383,146	83,061	5,563,978
	B	303,607	77,969	4,762,894	335,381	84,127	5,563,978
	C	325,704	83,098	4,825,771	245,281	84,624	5,563,978
	A	232,834	61,122	4,714,926	464,817	90,279	5,563,978
	B	249,609	64,773	4,761,236	396,335	92,005	5,563,978
	C	276,082	71,268	4,854,005	269,809	92,814	5,563,978

*A, B and C refer to the status quo, current use assessment and ten percent limitation of developmental growth scenarios, respectively.

Table 6

Percentage Change from Status Quo Scenario for Land Use Categories for Future Years

Year	Scenario	Agriculture	Idle	Forest	Developed	Other
1985	B	+ 2.38	+ 1.45	+ .31	- 8.47	+ .65
	C	+ 6.18	+ 4.54	+ .95	-24.69	+ .93
2000	B	+ 4.79	+ 3.61	+ .64	-12.47	+1.28
	C	+12.40	+10.43	+ 1.97	-35.98	+1.88
2015	B	+ 7.20	+ 5.97	+ .98	-14.73	+1.91
	C	+18.57	+16.60	+ 2.95	-41.95	+2.81

has a greater impact upon slowing development than alternative B for each future year. Additionally, over time more agricultural land is preserved from implementation of control C rather than B for each future year. It can be readily seen that the impact of scenario C becomes stronger as future years are looked at.

These results should be viewed within the confines of the assumptions of the presented framework. Obviously, a different set of assumptions have the potential to alter projections.

CONCLUSIONS

New Hampshire legislative growth committees are in the process of studying various land use policy recommendations with the general objective being to slow the rate of development. In general, the evaluative procedures utilized are based upon hypothesized land use impacts presented in qualitative formats void of any numerical basis. Incorporation of the generated results that accrue from the transition matrix approach presented in this paper can only help to strengthen the validity of any land use policy decision deemed acceptable. Under various specified assumptions made as realistic as possible given current data, such results should aid land use policy makers in better understanding in a normative sense what will happen to land acreages over time. An overview of this nature ought to help improve the informational and operational basis for determining what policies have socially desirable impacts for land use in the long run.

It should be noted that any particular land use policy could be formulated and adopted into the methodology presented. Future land results are highly sensitive to particular matrix elements incorporated into the required P-matrices. This was very evident in the presented results.

Future research could focus upon an enlargement of the set of land use policy scenarios under study. Also, in a state like New Hampshire, delineation of regional planning areas are made geographically by the State. From a more micro view, it might be fruitful to look at land use mix for such planning areas so as to provide a more concrete basis for use control policy evaluation at this level of disagreegation. Future work could focus upon improving P-matrix elements so that verified and realistic assumptions can be developed from land use data information that becomes available over time.

FOOTNOTES

[1]For our purposes, agricultural land is tilled cropland, pasture, hayland, and any open area being cultivated, hayed or mowed. Forest land is land supporting tree growth with a minimum of thirty percent crown closure. Land formerly in agriculture which is now abandoned with woody plant growth is considered idle. Developed land encompasses residential, commercial, and industrial usage. Wetlands excluding open water depicts the "other" category.

[2]For additional information pertaining to this exemption, see New Hampshire

Statute (1973).

[3]These percentages were calculated by dividing the total amount of land currently qualified under current use assessment for each category by the total acreage existing for that particular land class for the State.

[4]It is felt that a no growth restraint is an extreme position to incorporate into this framework. A compromise of a ten percent limitation seems more realistic given the legislative discussions which centered on this level of constraint.

[5]The value 296,071 is taken from the projection of the amount of land classified as developed for the year 1985.

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New Hampshire Statute, RSA 79-A:1 to 26, 1973 amended 1974.

Appendix

Table A.1

Revised P-Matrix Under a Ten Percent Developmental Growth Limitation for New Hampshire, 1985-2000

Conversion from row i to column j	Agriculture	Idle	Forest	Developed	Other
Agriculture	.8382	.1300	.0112	.0159	.0017
Idle	.0171	.3377	.6298	.0130	.0024
Forest	.0005	0	.9948	.0031	.0016
Developed	.0001	.0002	.0004	.9991	.0002
Other	0	0	0	.0034	.9966

Table A.2

Revised P-Matrix Under a Ten Percent Developmental Growth Limitation for New Hampshire, 2000-2015

Conversion from row i to column j	Agriculture	Idle	Forest	Developed	Other
Agriculture	.8358	.1330	.0112	.0183	.0017
Idle	.0171	.3357	.6298	.0150	.0024
Forest	.0005	0	.9943	.0036	.0016
Developed	.0001	.0002	.0004	.9991	.0002
Other	0	0	0	.0039	.9961