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Impacts of Land Managers' Decisions on Landuse Transition within Missisquoi Watershed Vermont: An Application of Agent-based Modeling System

Yushiou Tsai, Asim Zia, Christopher Koliba,

Justin Guilbert, Gabriela Bucini, Brian Beckage

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Yushiou Tsai, Asim Zia, Christopher Koliba, Justin Guilbert, Gabriela Bucini, Brian Beckage
Research on Adaptation to Climate Change
Vermont EPSCoR, University of Vermont
Burlington, Vermont, U.S.

Abstract— **The primary objective of this study is to identify macro emergent phenomena pertaining to landuse transitions within the Missisquoi Watershed, Vermont, by accounting for land managers' landuse decision making processes with respect to landscape characteristics, climate change scenarios and public policies. Due to the heterogeneity and the complexity of the interactions among human decision makers and potential trade-offs among natural and socio-economic losses and gains, a landuse transition agent-based model (LTABM) is developed to simulate landuse transitions with respect to several climate change scenarios and public policy interventions. It is expected that land managers' landuse decisions will be primarily dominated by profit maximizations, but also heavily driven by new technologies, risk perceptions and tax and subsidy policies. The results of this study will identify influential factors affecting landuse change, policy implementation hurdles, and alternate public policies leading to more sustainable landuse planning in the face of climate change.**

Keywords— *Landuse Transition; Agent-based Modeling; Coupled Natural-Human System; Climate Change*

I. INTRODUCTION

The Missisquoi Watershed, one of the tributary watersheds of Lake Champlain, is mainly located within the U.S. state of Vermont and stretched northward into the providence of Quebec, Canada. The Lake's Missisquoi Bay, located at the northeastern corner of the Lake and where runoffs from the Missisquoi Watershed drain, has recorded highest nutrient loads across the Lake. The exceedingly high nutrient loads, particularly the phosphorous (P) loads, which consistently surpass water quality standards, have been the primary driver of noxious algal blooms in summer (Smeltzer et al., 2012[1]; Levine et al. 2012[2]; Levine et al. 1997[3]). Studies indicate that agricultural activities leading to dissolved runoff, surface erosion, and farm discharge are the primary sources for increasing phosphorous influxes into the Missisquoi Bay (Ghebremichael et al., 2010[4]; Gaddis et al., 2010[5]; Medialie et al., 2012[6]; Michaud and Laverdiere, 2004[7]). Thus better landuse management is critical in mitigating erosion and non-point source agriculture runoffs which reduces the P loads entering the lake. Within a coupled natural-human system, like the Missisquoi Watershed, landuse decisions reflect trade-offs among household incomes, environmental quality, policy interventions, climate change, personal values and risk perceptions. The population of the landuse decision makers for the watershed consists of heterogeneous individuals with respect to income levels, property sizes, current landuse management, intrinsic landscape characteristics, perception of public policies, perception of environment degradation and perception of climate change. Due to the heterogeneity and the complexity of the interactions among decision makers and potential trade-offs among natural and socio-economic losses and gains, a bottom-up simulation approach such as agent-based modeling suits the need to identify emergent phenomena that are associated with positive and negative feedback (Miller and Page, 2007[8]; North and Macal, 2007[9]). This method also meets the need to identify the thresholds at which these factors lead toward or away from specific emergent events. Agent-Based modeling allows us to simulate the complex interactions among diverse landuse decision makers and the lands they manage to identify emergent macro phenomena and critical points of change.

II. LITERATURE

Several studies have attempted to incorporate agent-based modeling with other modeling approaches to examine issues concerning both landuse patterns and water quality. Bithell and Brasington (2009[10]) presented a prototype coupled modeling system to simulate land-use change by bringing together three simple process models: an agent-based model of subsistence farming, an individual-based model of forest dynamics, and a spatially explicit hydrological model which predicts distributed soil moisture and basin scale water fluxes. However, in this study by Bithell and Brasington (2009[10]), an agent does not communicate with other agents and past events do not impact an agent's current action. Evans and Kelley (2004[11]) explored a household's landuse decisions based on land available, labor allocated among farming, pasture/grazing and off-farm actives, and aesthetics associated with a forested landscape to maximize its utility. The weakness of their model is that it does not include stochastic components. Ng et al. (2011[12]) developed an agent-based model in combination with SWAT (Soil and Water Assessment Tool) to identify factors impacting farmers' decisions on adopting Best

Management Practices (BMPs) and corresponding nitrate load reductions. However, Ng et al. (2011[12]) did not collect empirical data on how farmers, individually or aggregated, make decisions on adopting BMPs. Instead, 50 semi-hypothetical farmers were used for modeling the farmers' decisions making. Le et al. (2008[13]; 2010[14]) also applied agent-based modeling to landuse transitions. While empirical data and stochastic processes have been used in these two studies, they still require extensions for improved insight. Le et al. (2008[13]; 2010[14]) developed an agent-based modeling system in which both farm households and land parcels are treated as agents that produce utility and bio-mass respectively. In these two studies, household behaviors are specified for each different livelihood group based on household data by using multivariate statistical analyses. In addition, stochastic components are integrated into determination of the initial households' population and locations, preference of landuse choice and other status variables. Our study aims at improved representation of the complex and heterogeneous dynamics among landuse, water quality and public policy under various climate change scenarios by including interactions among agents, by stochastically modeling human agents' decision making processes based on empirical data, and by incorporating discrete choice modeling and the theory of planned behavior (Fishbein and Ajzen, 2010[15]).

III. METHOD AND DATA

In our study, we evaluate landuse transitions resulting from interactions among the landuse decision making agents in response to different policy, environmental and climate scenarios. To achieve this, we develop a landuse transition agent-based model (LTABM) which simulates landuse change with respect to landuse decision making agents' annual decision making processes. The LTABM consists of seven procedures. Fig. 1 shows a flow chart illustrating the hierarchical structure of the LTABM with these seven procedures in details. First, the LTABM initializes agents and exogenous parameters. In the LTABM, agents are categorized into two major types: human agents, who make landuse decisions to maximize utility from the properties they manage, and land grid cell agents, which produce goods and services. Exogenous parameters include policy, social, and environmental conditions. As a baseline scenario simulation, current policy, social, and environmental conditions are used as inputs. Alternate public policies are determined by mediated modeling sessions in which focus groups and interviews are organized to solicit feasible policy interventions.

In the second procedure of the LTABM, decision making agents obtain information to update their expected utilities or social psychological functions. Within this phase of the LTABM, the human agents are subdivided into land owners who are considered as agriculture, forest, and urban entities. Human agents categorized as agriculture entities are further subdivided into land owners who manage crop, dairy, and crop-dairy combined farms. These subcategories within the forest entities are the land owners who manage private and public land-holdings. These subcategories within the urban entities are land owners who manage residences and businesses. In the third procedure of the LTABM, decision making agents maintain or change current landuse practices based on the results of procedure two. Different decision making processes are formulated differently for each of the land owner subcategories within the agriculture, forest and urban entities. The fourth procedure of the LTABM determines landuse transitions given the inputs from procedure three. The fifth procedure of the LTABM updates decision making agents' properties, re-categorizes agents, creates additional agents and deletes exiting agents. The sixth procesure of the LTABM updates landuse information and outputs simulated landuse patterns for the given year. The last procedure of the LTABM involves the model calibration. Long term landuse transition patterns under several scenarios, including baseline, varying policy interventions and varying climate change scenarios, are simulated using the calibrated LTABM to assess the relative impacts of these policies and climate change scenarios on landuse transitions. For consideration of alternate climate change scenarios, future climate conditions are projected based on global climate projections from World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset by using a two-step downscaling technique: bias-correction and spatial downscaling.

The LTABM can also be viewed as a system consisting of several main components, as shown in Fig. 2. Generally, at this stage of the model development, two types of transitions are simulated by the LTABM: landuse and land ownership patterns. The LTAMB simulates the landuse transitions as the consequences of the landuse decisions made by the land owners who also determine whether to sell and/or buy lands. The LTABM will rely on empirical data from a variety of sources, such as census, surveys, focus groups, the National Land Cover Database (NLCD) and other historical datasets. This study uses the eight-class classification NLCD for years 1992, 2001 and 2006 instead of the NLCD in their original and finer classifications. The eight-class NLCD 1992 has been retrofitted to allow direct comparisons among the NLCD 1992, 2001 and 2006. The modified NLCD 1992 is fed into the LTABM to initialize the simulation. Subsequently, the LTABM is calibrated against NLCD 2001 and NLCD 2006. TABLE I shows characteristics of the eight landuse classes and the associated color scheme used by the LTABM to represent these eight classes.

The records show that the perennial ice/snow class, which is designated by the value of eight, has never been observed in the Missisquoi Watershed. As stated in the previous paragraph,

TABLE I. Eight-class NLCD classification and LTABM color scheme.

Class Value	Class Description	LTABM Color Scheme
1	Open Water	Blue
2	Urban	Red
3	Barren	Gray
4	Forest	Lime
5	Grassland/Shrub	Rosy-brown
6	Agriculture	Yellow
7	Wetlands	Cyan
8	Perennial Ice/Snow	N/A
	No Data	Black

I. Initialization
  Initialize agents (decision making agents & land grid cell agents)
    (1) GIS data
    (2) Datasets of decision making agents
  Initialize exogenous parameters
    (1) Baseline scenario (policy, social, environmental conditions)
    (2) Alternative scenarios decided from mediated modeling
       sessions

Observed land use
NLCD 1992

Landuse Transition Agent-based Model

year + 1

II. Decision making agents obtain information, update their expected
utilities or social psychological functions

Agriculture entities
Farmers incoporate new and updated information pertaining to intrinsic properties of land holdings and farms

  (1) crop (corn or hay),
  (2) dairy (confined, pasture, or confined pasture),
  (3) crop & dairy

Forest entities
Decision making agents incoporate new and updated information

  (1) private
  (2) public (federal, state, town, or non-profit)

Urban entities
Use UrbanSim

  (1) residences
  (2) bussinesses

III. Decision making agents determine whether to maintain or change
the current land use practices

Agriculture entities
Farmers adopt BMP(s), determine crop types and/or change existing farming practices on land grid cell(s) based on properties of land holdings and farms (stochastic processes)

Forest entities
Decision making agents determine whether to convert forested land to agriculture or urban lands or stay as forested land (stochastic processes)

Urban entities
Cities grow in fractals

IV. Determine landuse transitions

V. (1) Update decision making agents' properties
    (2) Recategorize agents
    (3) Create new agents and delete exit agents

VI. (1) Update land use information
     (2) Output landuse patterns
       1993-2050

year = 2001 or 2006 NO
YES

VII. ABM is calibrated against observed landuse
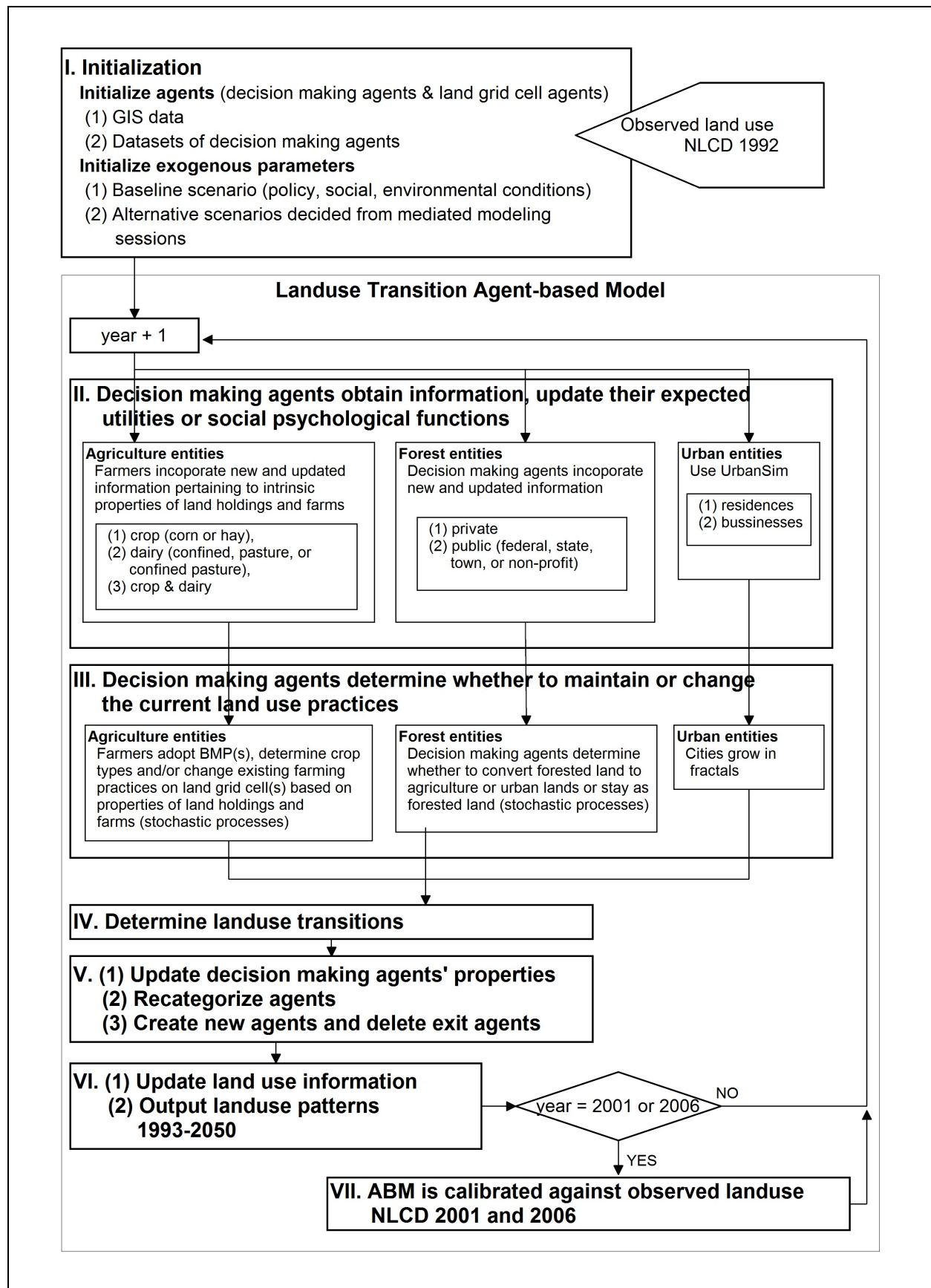**NLCD 2001 and 2006**

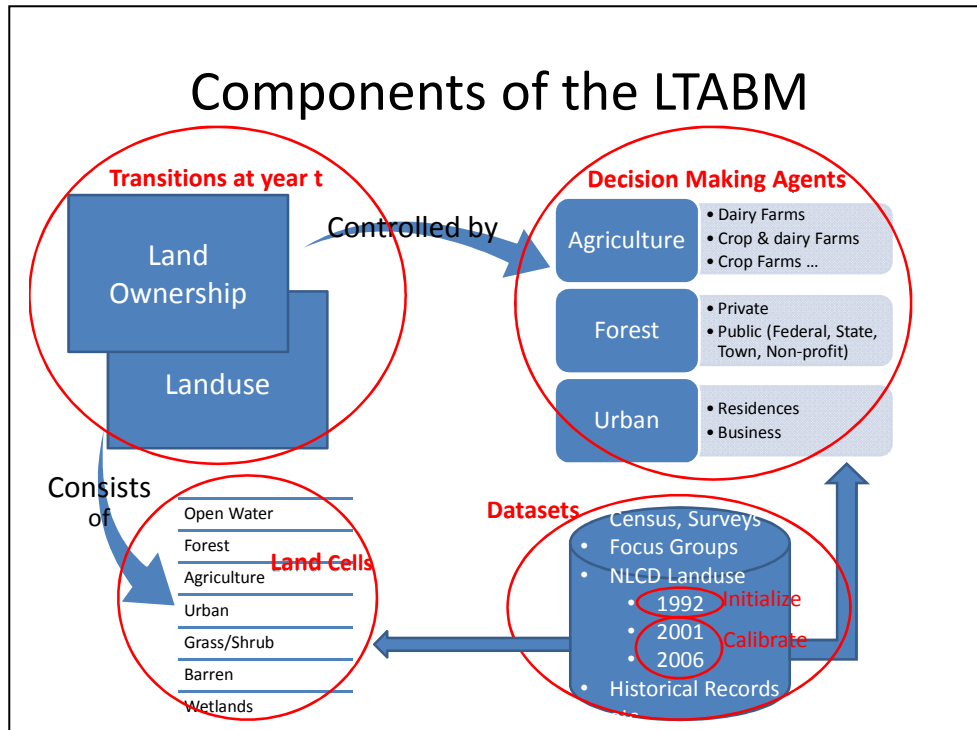Fig. 1. Flow chart of the landuse transition agent-based model for the Missisquoi Watershed.

Fig. 2. Main components of the landuse transition agent-based model (LTABM) for the Missisquoi Watershed.

the LTABM classifies the landuse decision making agents into three main categories: agriculture, forest and urban entities. For the agricultural and forest agents, their historical landuse decision rules are generalized from surveys and census conducted in the last decade by using discrete choice modeling and the theory of planned behavior. Additional farm surveys and focus group sessions will also be conducted to derive human agents' current landuse decision making rules. For the urban land owners, the LTABM simulates urban sprawl by incorporating UrbanSim components developed by Troy and Voigt (2009[16]).

IV. PRILIMINARY SIMULATION

The western Missisquoi watershed, as shown in Fig. 3, is chosen as the initial study area to develop and test the LTABM. This study area consists of land grid cells in a scale of 30 meter by 30 meter. The eight-class classification system is used to label the landuse of these land cells. A landuse class value, ranging from one to seven, is kept for each land cell. The LTABM treats each land cell as a single agent. The LTABM uses the color scheme shown in TABLE I to display the landuse patterns. The land cells outside of the study area or lacking landuse classification information are displayed in black in the LTABM.

For our preliminary simulation, two assumptions are made. First, we assume that the entire study area is managed by farmers only and these farmers' landuse decision processes are fairly homogeneous across the entire study area. Second, we assume that the financial conditions of the farms within the study area is the dominant factor affecting these farmers'

landuse decisions. With these two assumptions in mind, we derive an aggregate landuse decision rule based on the financial conditions provided by one of the farmers' surveys. TABLE II shows the relationship between rates of landuse transitions and the farmers' financial conditions, where, for each year, the probabilities that the farmers experience major stress, moderate stress and feel good financially are 33%, 43% and 24%. When facing major financial stress, the farmers are assumed to abandon 25%, 75% and 90% of the agriculture, barren and grass lands under their management, respectively.
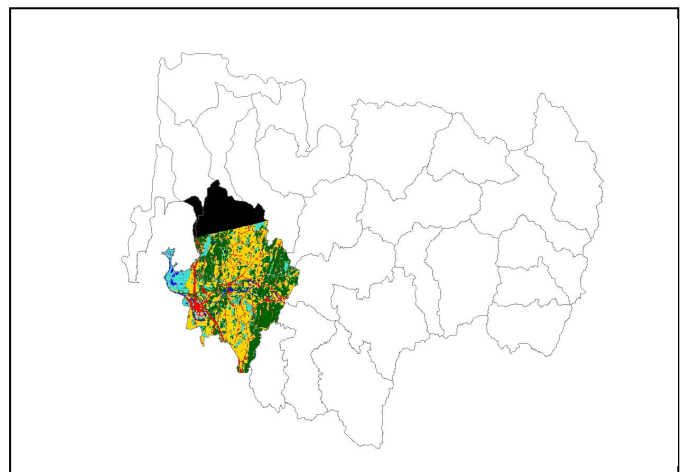

Fig. 3. The western Missisquoi Watershed (colored area) versus the entire Missisquoi Watershed. The colored area displays the observed landuse pattern from the NLCD 1992. The details of the color scheme is shown in TABLE I.

TABLE II. Rates of hypothetical landuse transitions with respect to the farmers' financial conditions.

Landuse transitions as percent of A land is turned into B land during one year time interval		Three possible financial conditions for the farmers during a year (Probability that the financial condition occurs)		
A	*B*	*Major Stress (33%)*	*Moderate Stress (43%)*	*Feel Good (24%)*
Agriculture	Barren	25%	0%	0%
Barren	Grass	75%	0%	0%
Grass	Forest	90%	0%	0%
Forest	Agriculture	0%	0%	25%
Barren	Agriculture	0%	0%	90%
Grass	Agriculture	0%	0%	90%

Consequently, the agriculture, barren and grass lands left abandoned will turn into barren, grass and forest lands within one year. When facing moderate financial stress during a specific year, the farmers are assumed to keep their current farming practices, hence, the landuse patterns will not change during that year. However if the farmers feel good financially during a specific year, we assume that they will cultivate 25%, 90% and 90% of the forest, barren and grass lands under their management, and then turn these lands into agriculture lands during that year. For each year, the financial conditions of the farmers are determined by the probability distribution shown in TABLE II. The land cells undergoing a landuse transition within a specific landuse class are randomly selected.

The results of this preliminary simulation are shown in Fig. 4, where the LTABM is initialized at year 1992, and then it simulates the landuse patterns for years 1993, 1997 and 2012. The results of this preliminary simulation show that, within the study area, lands transitioning into agriculture lands is a dominant trend.

V. Discussion

The results of the preliminary simulation exercise do not reflect the observed landuse transition patterns within the study area. We are aware that one or all of the two underlying assumptions for this preliminary simulation are not sound. It is unrealistic to assume that the entire study area is managed by farms only. The unrealistic landuse patterns produced from the preliminary simulation indicate that it is important to diversify landuse decision rules in the LTABM. Thus, the next steps for this ongoing study are (1) to determine relatively more realistic land ownership boundary maps for initializing the LTABM, (2) to derive landuse decision rules for different land owner categories, and (3) to incorporate the agricultural, forest and urban stormwater best management practices (BMPs) into the LTABM. It is expected that human agents' decisions would be heavily driven by profits, new technologies, tax and subsidy policies, and ease of following tax and subsidy applications. Taking BMPs into account would shed lights on how the phosphorous loads observed in the Missisquoi Bay are affected by landuse transitions and implementation of BMPs. Moreover, the future version of the LTABM will execute simulations with respect to several scenarios developing from focus group sessions. We endeavor to identify important factors and policy interventions that will lead the current landuse patterns toward a more sustainable and resilient one.

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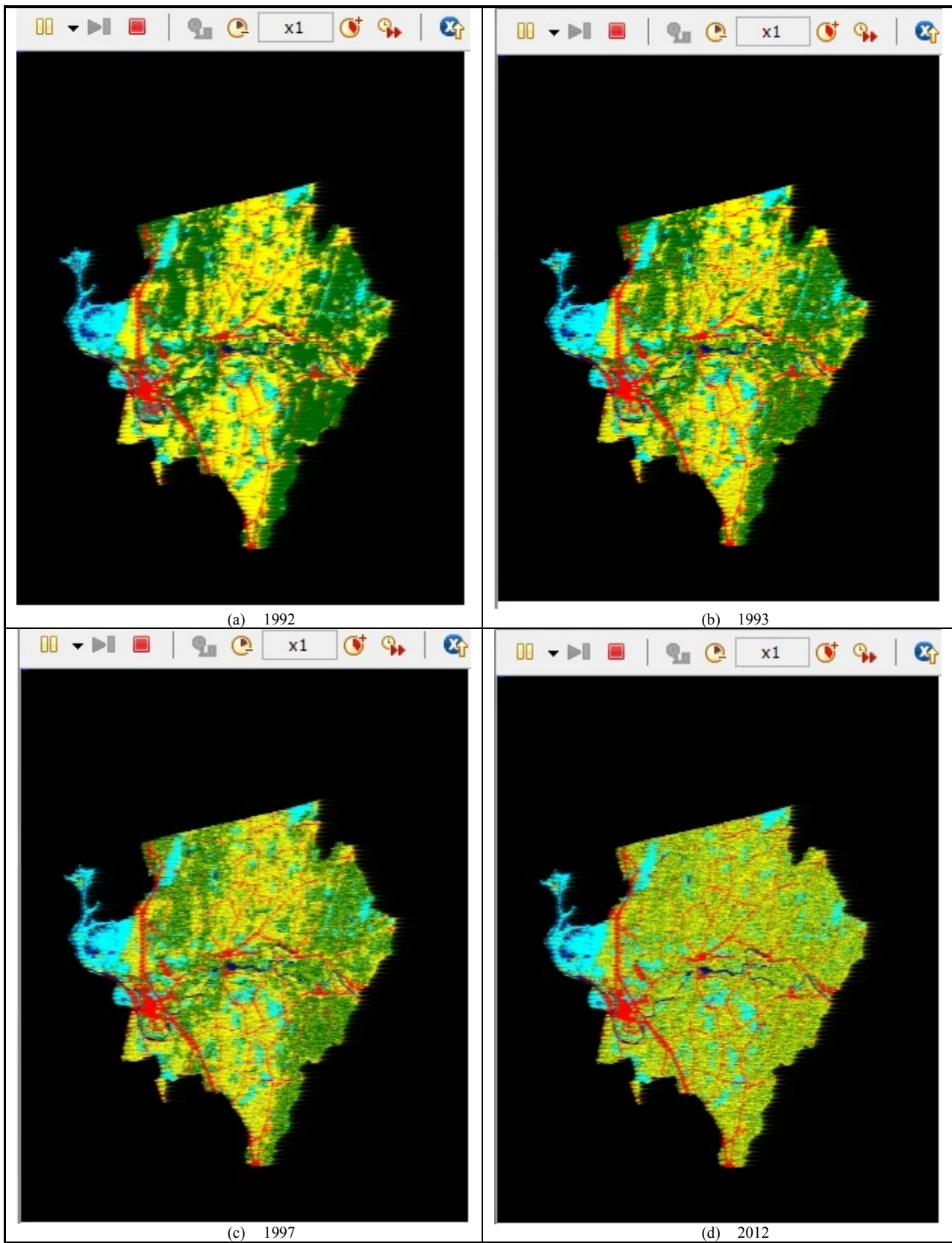
Fig. 4. Landuse Patterns simulated by the LTABM for years (b) 1993, (c) 1997 and (d) 2012. The landuse pattern for year (a) 1992 represents the observed landuse pattern from NLCD 1992.