LINKING LAND-COVER CHANGE TO LOCAL LAND-USE POLICY: A GIS-BASED ANALYSIS

by

Jason J. Taylor
(jayt@umich.edu)

School of Natural Resources and Environment
University of Michigan

Introduction

Landscapes composed of natural land covers provide a variety of ecosystem services. For example, forests provide carbon fixation, oxygen production, hydrological flow regulation, prevention of soil erosion, timber harvesting, and recreation (Guo et al. 2001). Wetlands provide carbon and nitrogen cycling, climate stabilization, habitat for a large majority of the species considered endangered or threatened, nutrient and toxic filtering while recharging aquifers, and flood mitigation (Mitsch and Gosselink 1993). Open fields or grasslands provide erosion control, waste treatment, pollination, and food production (Costanza et al. 1997). In urbanizing areas, these ecologically and socially important land covers are being fragmented and replaced by covers and uses associated with human habitation such as residential developments, commercial (e.g., shopping centers) and office facilities, and transportation and utility networks (i.e., infrastructure).

Attempts are being made to ameliorate the negative effects of the conversion of natural land covers to anthropogenic land covers. For example, the use of detention basins, porous pavement, and vegetation buffers. Nevertheless, the land-cover alterations have profound effects on the environment. These effects include the loss of native biodiversity, the introduction of exotic species, elevated soil erosion, and degraded water quality (Collinge 1996).

Globally, alterations to the composition and configuration of contemporary landscapes are principally human-induced (Turner et al. 2001). Human land-use practices are typically guided by cultural factors such as history, economics, aesthetic preferences, social conventions, and politics (Nassauer 1995, Brown et al. 2000). These factors play roles in the development of land-use policy, the goal of which is to systematically determine where various types of activities should occur in the landscape while optimizing the primary dimensions of land-use planning – ecological conservation and economic vitality (van Lier 1998).

Between 1982 and 1997, within the United States (U.S.) lands considered to be urban or built-up increased by 34% (United States Department of Agriculture et al. 1997, Alig et al. 2004). Between 1990 and 2000, the seven counties that comprise southeastern Michigan's SEMCOG (Southeastern Michigan Council of Governments) region experienced residential, commercial, and infrastructure land use increases of 20%, 14%, and 5% respectively. Additionally, lands considered to be under development (i.e., developing portions of platted parcels) increased by 84%. During the same decade, the categories of grasslands and shrub and woodlands and wetlands decreased by 8% and 3%, but the most significant decrease (14%) within the region was the loss of agricultural lands (Southeastern Michigan Council of Governments 2004).

In the U.S., very little land-use planning occurs at the Federal or State levels; most land-use policy and planning is controlled by local and regional authorities (Arendt 2004). Typical land-use regulations include traditional minimum lot size zoning with no density restrictions, and a number of conservation zoning techniques. These conservation zoning techniques include neutral density, enhanced density, estate lots, country properties, and village designs (Arendt and Natural Lands Trust 1997). Each development type differentially provides land conservation via density control, from large lots to cluster development zoning with defined open-spaces. Additional land conservation techniques include the use of conservation easements, and the purchasing or transferring of development rights (Michigan Townships Association 2001). Participation in these conservation options is voluntary for the land owner, and designated lands are protected from development in perpetuity. While little literature exists that empirically evaluates growth management policies within the U.S. (Bengston et al. 2004), many municipalities interested in managing development at the urban-rural fringe have adopted the philosophy of large lot and open-space land-use planning (Dwyer and Childs 2004). Open-space planning, of primary interest in this study, has specifically been established to achieve a number of human-perceived values related to land use; they include the maintenance of rural character and the preservation of natural features.

This research empirically evaluates the question, is an open-space policy, introduced into southeastern Michigan's Fenton Township, effective? Evaluating the open-space policy's effectiveness requires determining how the landscape composition and configuration have changed as a result of the introduced policy. Since the stated intent of the policy is to preserve natural features and rural character, I hypothesized that developments established after the policy was introduced would have a positive effect on forest and other natural land-cover classes as compared to developments established before the policy was introduced. Additionally, I hypothesized that the effect on wetlands would remain constant, primarily because they are federally protected and by Fenton Township definition are considered to be non-developable.

To test these hypotheses and measure the effects on subdivision-scale land covers, the field of landscape ecology offers useful theories and techniques. Landscape ecology draws on a variety of disciplines including geography, ecology, landscape architecture, land planning, and economics to explore the interactions between landscape spatial pattern and ecological processes (Turner et al. 2001). To quantify landscape composition and configuration, landscape ecologists typically employ spatial pattern metrics (McGarigal et al. 2002). Gustafson (1998) notes that many pattern indices are of little use by themselves. Their value is in comparing alternate landscape configurations of the same landscape at different time steps, under alternate development scenarios, or different landscapes produced using the same mapping process (Gustafson 1998).

Study Area

The Charter Township of Fenton in Genesee County, Michigan, U.S.A. (Figure 1) is located on the northwestern edge of most densely populated portion of the state (i.e., southeast Michigan).

According to the 2000 Census, 12,968 residents and 5,248 housing units were located within the 8,500 hectare (32.8 square miles) township. Between 1990 and 2000, the township grew by 1,556 new housing units, an increase of 148%, 46%, and 73% over the number of housing units added during the decades of 1980-90, 1970-80, and 1960-70 respectively. A review of historical aerial photography from 1941 to the present reveals the township's transition from agriculture with sparse tree cover to primarily residential with regenerating forests; isolated agricultural areas still remain throughout the township today. The Township consists of 16% surface water, with 17 'named' lakes and a significant number (385) of other wetlands and water bodies totaling 1,357 hectares (5.2 square miles). Until recently, the majority of the township's development had focused on the boundaries of these 17 primary lakes.

To support the community's growth rate and protect its many water bodies, the Township introduced sanitary sewers to the most heavily populated portion of the township in 1968 (personal communication, Township staff). By 2003, the township was serviced by more than 110 miles of public sewer lines.

In 1999 the Planning Department at Fenton Township established a 'sliding scale' open-space policy for all new developments within specified zoning classes. This amendment to the Fenton Township Zoning Ordinance moved the Township away from traditional single-family residential zoning in an attempt "to encourage the preservation of unique natural features and the township's rural character" (Fenton Township 1999, Article 3.i). The goal was to encourage developers to use an open-space preservation option in exchange for a density bonus. The open-space set-aside and density bonus work in tandem by increasing the density in some areas in exchange for the retention of undeveloped land. Calculations related to determining the amount of open-space provided consider 'protected' landscape features or bodies of water as separate entities; the ordinance states that "…only useable land shall be considered. Wetlands, floodplains, or submerged land such as a lake, pond or stream shall be excluded from the land area calculation" (Fenton Township 2000, Article 3.h). The two eligible zoning classes are medium-density single-family residential (R-3) and single-family residential (R-4). In areas designated as R-3, a density of 1.00 unit per acre is permitted in exchange for the preservation of 20% of the total land as open space. When 50% of the land is preserved as open space, densities increase to 1.50 units per acre. Similarly, in areas designated as R-4, a density of 1.25 units per acre is permitted in exchange for the preservation of 20% of the total land as open space. When 50% of the land is preserved as open space, densities increase to 1.88 units per acre.

Methods

Site Selection

With help from Township planning officials, twenty residential sites developed before and after the 1999 policy implementation were selected. Ten sites were selected as the *after-policy* group, including all developments approved between 1999 and 2003. Ten sites that were developed in the three years prior to the policy implementation (between 1996 and 1998) were selected as the *before-policy* group. The geographic extent of each of the sites was defined by the platted boundary of the development.

Since the composition of the local landscape may influence development decisions within the sites, the distribution of pre-development land-covers was summarized using the mean, standard deviation, and range of land-cover percentages. For each class, the before- and after-policy group mean values were compared using a two-tailed Student's t-test.

At a significance level of 0.05, this analysis confirmed that there was no significant difference in the land-cover compositions of the before- and after-policy groups (Table 1). Though not significantly different, it should be noted that the before-policy group had a disproportionate number of tracts consisting primarily of open fields while the after-policy group had a large number of parcels with a large percentage of agriculture.

1992 Land-cover

Pre-development land-cover for all study sites was mapped with 1992 color aerial photography acquired from Michigan State University. Each photo was roughly three meters in resolution and covered an extent of approximately 260 hectares (one square mile). A statistical coordinate transformation process was applied to the original photos to geographically rectify the photos to an existing Fenton Township road centerlines dataset. The centerlines were derived from ortho-photographs and had an accuracy of +/- one meter. The rectification process used a minimum of nine ground control points for each photo (Figure 2), a nearest neighbor re-sampling method, and, depending on which method 'fit' each photo the best, a second- or third-order polynomial transformation. The root mean squared error (RMSE) for the transformation process ranged from 0.018 meters (m) to 1.193 m with an average of 0.146 m.

Next, land-cover classes (Table 2), selected to represent the mix of local natural and anthropogenic landscape features, were screen digitized for each site from the 1992 rectified photos (Figure 3). To account for the possibility of edge effects in later analyses a buffer of 100 meters was appended to the platted boundary of each site; land cover was also interpreted within the buffer.

Predicting 2003 Land-cover

The best method for mapping the 2003 land-cover would have been to duplicate the land-cover interpretation process by simply digitizing the appropriate classes from 2003 photography. From 1999 to 2003, the ten new subdivisions slated for development were to be examined. However, the newest available photography was from 2001, and several of the subdivisions, even though formally platted, had not begun observable development by 2001. To resolve the gap in data availability, a method was derived to predict land-cover in the fully built subdivisions from the 1992 land-cover dataset.

The basis for the land-cover prediction method was a map of residential land-use representing built-out conditions. The first step in creating the predicted residential class was to identify all residential parcel portions that had Agriculture (Ag) or Open land-cover designations within the subdivisions (Figure 4b). To accomplish this, parcel boundaries (excluding right-of-ways) for all subdivisions were intersected with the 1992 land-cover Ag and Open classes (Figure 4c). This step assumed that all portions of the residential parcels that were previously Ag or Open would be fully developed as residentially maintained areas, which included lawns and gardens (Figure 4d). To account for the effects of housing structures adjacent to the forest and mixed classes, all areas from the road centerlines to the rear of the structures were enclosed in a polygon using 326 structures identified within the Township's GIS structures layer (Figure 4e). The observed mean depth of the structures from the road centerline was 37.9 meters, but to account for the likelihood of disturbance at the edge of the forest and mixed classes (i.e., removal of natural vegetation for structure and lawn establishment), an additional ten meter depth of impact was applied. As a result, a depth of 47.9 meters was used to create an area surrounding the development's road network that incorporated the potential placement and effects of any structures within or adjacent to the forest or mixed classes (Figure 4e). The final average effective extent of the residential class (AEERC), and therefore the predicted built-out residential class, was completed by combining the 47.9 meter buffer area and the Ag and Open parcel portions (Figure 4f).

The last step in predicting the built-out land-cover was to combine the AEERC with the 1992 land-cover classes. Prior to the integration step (Figure 4h), the components of the AEERC were re-classified to residential (Figure 4g). Additionally, because farming practices would most likely no longer occur within a residential development, and because any forest re-growth that may be expected will take time, any Ag classes falling outside of the residential parcels but within the development boundary (i.e., within an open space and not part of the AEERC) were re-classified as Open.

Evaluating the Predictive Method

The validity of using the prediction method to create the built-out land-cover was evaluated using the three subdivisions (McCully Lake Estates, Orchard View, and River Oaks Hollow) that were the most fully developed by the time of the 2001 photographs. For these developments, a 2001 'actual' land-cover dataset was interpreted from the photographs using the same procedures and classes used in the creation of the 1992 land-cover. The procedural difference was that the 2001 photographs were black and white, high resolution (0.15 meters), and ortho-graphically corrected.

The 'predicted' 2001 built-out land-cover (created using the prediction method detailed above) and the 'actual' 2001 land-cover (digitized from the 2001 photography) were converted to raster form for comparative analysis. To simplify the evaluation, each of the land-cover datasets was re-classified into two categories, residential development and non-residential development. The goal of the evaluation was to quantify the agreement between the 'predicted' residential development map and the 'actual' residential development map. The re-classified images were processed to calculate cross-tabulation results identifying all combinations of the categories represented in each landscape cell (Figure 5).

To analyze the agreement between the predicted and actual maps, determinations of the accuracy of predictions for the location as well as the abundance of the 'developed' cells were necessary. Pontius (2000) states that the use of statistics like the Kappa index of agreement to calculate the expected portion of correctly classified cells for a classification scheme specifying both location and quantity is typically not appropriate because it confounds quantification and location errors. As a result, he presented statistics that divided the Kappa measure into four components: Kstandard (equivalent to Kappa – the proportion assigned correctly versus the proportion correct due to chance), Kno (measure of the proportion correctly classified versus the expected proportion classified under an assumption of no knowledge of quantity or location), Klocation (measure of the accuracy due to correct assignment of values spatially), and Kquantity (measure of the accuracy due to the correct assignment of quantities for each class).

Using the combination of Kno, Klocation, and Kquantity for evaluation allows for a determination of an overall success rate (Kno) while providing an understanding of the factors (i.e., location and quantity) that contribute to the strength or weakness of the results. Additionally, the Kappa components fix the major problems with using standard Kappa, specifically, the failure to penalize for large quantification errors, reward for quantities specified correctly, and account for quantification and location errors (Pontius 2000).

Similar to standard Kappa, the Kappa components equal one for perfect agreement between simulation and reality, and zero when the simulation does no better representing reality than a guess with no knowledge of location and quantity. Consequently, the evaluations producing Kno values of 0.808, 0.830, and 0.893 (Table 3) suggest that the land-cover prediction method presented was reasonably accurate. By reviewing Klocation and Kquantity, the effectiveness of the prediction method is additionally supported with average values of 0.856 and 0.546 respectively. The comparably low Kquantity average can be explained by the Kquantity value for McCully lake estates (-0.295). In this case, the quantity of the residential development category was slightly over estimated (Figure 5c) as many of the residents in this development chose not to fully develop the Open areas at the rear of their properties. However, the general pattern and spatial extent of the developed area was appropriately reproduced (illustrated by the high Kno and Klocation values).

Overall, the method is effective for determining near-future subdivision-scale land-cover configurations in lieu of up-to-date aerial photography.

Upon confirmation of the prediction method, the final post-development (built-out) land-covers were created for all 20 study sites. The process was completed by using 2003 Fenton Township parcels and road centerlines, and by applying the prediction method presented above to the 1992 land-cover.

Landscape Metric Analysis

The land-cover maps formed two groups, before-policy and after-policy, each with two subsets. These subsets consisted of two stages, *pre-development* (1992 actual land-cover digitized from the 1992 photos) and *post-development* (land-cover from the prediction method). To prepare the data for analysis (i.e., calculation of the spatial pattern metrics), all 40 vector datasets were converted to raster format.

The challenge in using spatial pattern metrics is that the many varieties of metrics are at least partially redundant and tend to quantify similar aspects of landscape pattern (McGarigal et al. 2002). To determine the number of independent dimnesions that are actually measured by the variety of available landscape metrics, Riitters and colleagues reduced 55 examined landscape metrics to 5 unique factors. They concluded that, while the factor analysis was an effective method for identifying multiple univariate metrics, it did not assign relevance to any particular metric for any particular land-use analysis. Using the research of Riitters et al. (1995) and others, Leitao and Ahern (2002) proposed a core set of metrics to “address the principle needs of applied landscape planning by describing landscape structure and its key associated spatial processes.” Their objective was to provide a set of metrics related to several fundamental ecological processes to serve as a standard for the planning community. For this reason, their core set of metrics was employed in this study.

The class- and landscape-level metrics (Table 4) included: class area proportion (PLAND), number of patches (NP), patch density (PD), mean patch size (AREA_MN), mean shape index (SHAPE_MN), total edge contrast index (TECI), mean patch extent (GYRATE_MN), mean Euclidean nearest neighbor distance (ENN_MN), mean proximity index (PROX_MN), a measure of class aggregation or contagion (CONTAG), and patch richness (PR). The metrics PLAND, NP, PD, AREA_MN, GYRATE_MN, ENN_MN, CONTAG, and PR directly quantify the amount and geometric form of the land-cover patches. SHAPE_MN, TECI, and PROX_MN adjust the measures for the area of the patch, the relative contrast between patch edges, and the proximity of all patches with their center inside a specified search distance, respectively.

TECI and MPI each required setting parameter values. TECI required a contrast weight file, which describes the differences in the content of patch types (i.e., their contrast). McGarigal et al. (2002) posit that in lieu of a strong experimental basis for constructing a weighting scheme, a sound estimation is likely an improvement over assuming all edges are similar. The presented TECI contrast weights (Table 5) were composed by comparing the variability within the land-cover classes using the descriptive definitions for each class (Table 2). PROX_MN required a search radius from a focal patch to direct its calculations. Since no patches external to the landscape border could be considered, the longest diagonal distance (2000 meters) for the largest subdivision was used as the search radius. This value was additionally selected to ensure the inclusion of all possible patches for all landscapes.

The described metrics were calculated for each of the pre- and post-development land-cover classes. The metrics were summarized for mean, standard deviation, and range. Differences in the amounts of change in the mean values, between the before- and after-policy groups, were evaluated to test the null hypothesis that the means of the two groups were equivalent ($\mu 1=\mu 2$). The analysis provides a test of the effectiveness of the policy in altering, in a positive way, the land-cover of subdivision developments. The analysis was completed using a two-tailed Student's t-test at a significance level of 0.05.

Results

Pre-development composition for Site 1 included 15.55% Forest, 80.83% Mixed, 1.81% Open, and 1.81% Wetlands with no Residential, Roads, Ag, or Lake (Table 6). For the same site, post-development composition included 13.86% Forest, 25.46% Mixed, 1.81% Open, 1.81% Wetlands, 53.52% Residential, and 3.54% Roads with no Ag or Lake. In this case, classes registering a change from pre- to post-development stages were Forest (-1.69%), Mixed (-55.37%), Residential (53.51%), and Roads (3.54%). Investigating across all study sites, the changes in the percent of Forest within each site for the before- and after-policy groups (Table 7) resulted in mean changes of -16.29 and -9.89 respectively. A difference that shows a tendency, that is not statistically significant, for after-policy subdivisions to have resulted in less forest clearing than the before-policy subdivisions.

Overall, the shift in local land-use policy for Fenton Township produced only a small number of observable and significant class- and landscape-level differences in the mean changes between the before- and after-policy groups (Table 8). The difference between the changes can be positive, negative, or no difference. Positive numbers indicate that the after-policy group experienced a larger increase from pre- to post-development, a smaller decrease, or a change to increasing from decreasing values in relation to the before-policy group. For example, from pre- to post-development, the number of Forest patches in the after-policy group (+2.70) increased more as compared to the before-policy group (+2.40); the proportion of Forest in the after-policy group (-9.89) decreased less than the before-policy group (-16.29); and, the mean patch size of the Open patches in the after-policy group (+0.33) changed to increasing from decreasing values as compared to the before-policy group (-1.63). Negative numbers indicate that the after-policy group had a larger decrease, a smaller increase, or a change to decreasing from increasing values as compared with the before-policy group. For example, from pre- to post-development, the mean Euclidean nearest neighbor distance of the Residential patches in the after-policy group (-32.41) decreased more than that of the before-policy group (-19.98); the total edge contrast index of the Mixed patches in the after-policy group (+6.13) increased less than the before-policy group (+14.42); and, the mean shape index of the Mixed patches in the after-policy group (-0.05) changed to decreasing from increasing values as compared to the before-policy group (+0.52).

Four of eleven metrics (SHAPE_MN, ENN_MN, PROX_MN, and PR) exhibited no significant difference in pre- to post-development change between the before- and after-policy groups for any of the land-cover classes (Table 8). The Open class (composed of the non-residential portions of developments including open fields, areas of 0-20 percent tree cover, and recreation areas) demonstrated the most notable changes between group means. For this class, six of nine class-level metrics (PLAND, NP, PD, AREA_MN, TECI, and GYRATE_MN) exhibited significant differences. The associated Open-class differences between the before- and after-policy groups, in terms of changes from the pre- to post-development stages, included: PLAND (+33.03), NP (+4.80), PD (+29.74), AREA_MN (+1.96), TECI (+50.36), and GYRATE_MN (+40.23). The mean values of change for the after-policy group were increasing compared with decreasing values in the before-policy group for: the proportions of open land present within the landscape; the density of open patches; the mean area of open patches; the contrast of open patches with neighboring patches; and the mean patch extent. The number of open-land patches for the after-policy group experienced a greater increase from pre- to post-development as compared to the before-policy group. Class area proportion (PLAND) for the Residential land-cover class also experienced a significant difference (-16.57), demonstrating that the after-policy group exhibited a smaller increase in residential land area from pre- to post-development than the before-policy group.

One of two landscape-level metrics evaluated demonstrated a significant difference. The CONTAG metric exhibited a difference of -9.39 as a result of decreasing values in the after-policy group compared with increasing values for the before-policy group. This difference indicates that, on average, the after-policy landscapes became more disaggregated and interspersed from pre- to post-development (i.e., the land-cover classes have become more fragmented) as compared to the before-policy landscapes.

Discussion

The 1999 open-space policy was intended to preserve unique natural features and the township's rural character. Under the assumptions detailed below, successful fulfillment of the objectives was not achieved according to my analysis of the data.

In lieu of any formal definition provided by the Township, I defined natural features as forest, wetlands, and open fields and additionally assumed that these natural landscape features also define 'rural character.' 'Preservation' should, therefore, have resulted in new developments that provided an increase, or lessened the decrease, in the amounts of these land-covers that are indicative of rural character, as compared to developments established prior to the new policy. The results show that the shift in land-use policy produced only a small number of observable and significant changes in the land-cover effects of development. Those changes that were significant paralleled the only clearly defined function of the 1999 open-space policy – to increase open or non-developed land.

The policy achieved an increase in the average percentage of open-space compared to sites developed before the policy, in which open-space decreased. A consequent decrease in the amount of land converted to residential area followed the increase in open-space. The increased amount of open-space can be attributed to an increase in the number, density, and average size of the patches in the after-policy landscapes, compared to the before-policy landscapes. While these increases may seem unquestionably positive, they begin to paint a picture of a landscape becoming highly fragmented. This notion is further supported by an increase in the values of TECI and GYRATE_MN from the pre- to post-development stages in the after-policy group, as compared to decreases in the before-policy group. Whereas the latter, indicating an increase in the average occupied extent of the patches, could be argued to result from the increase in mean patch size, the former suggests that the contrast (i.e., difference) between the edges of Open areas with adjacent cover types increased in the after-policy group. Such contrast can increase the edge effects associated with fragmentation.

While the metrics confirmed that the policy resulted in landscape changes that increase open-space, the policy does not specify the types of land covers that should be preserved or created within those spaces. Collectively, the open-space areas generated by the policy consisted of Forest, Mixed, Wetlands, and Open patches. Of these classes, I hypothesized that the wetlands would remain constant as they are federally protected and by definition in the township policy were not considered as developable land. Additionally, I hypothesized that an increased percentage of Forest, Mixed, and Open areas would be generated by the policy. The data indicate that, while the after-policy developments resulted in increased Open areas, the decline of the Forest and Mixed classes that resulted from the after-policy developments was not significantly reduced compared to the before-policy developments.

In several instances, Forest patches were selected as part of the developed areas (i.e., not as a portion of the set-aside open-space) even if other, more easily developable, land covers (e.g. Ag) were available. Example developments include Stoneybrook and Mallards Landing. Stoneybrook, an 88 hectare site, was 93% Ag prior to development; a 2 hectare Forest patch located in the extreme southwest corner of the property had 13 residential lots platted within or directly adjacent to its boundary. Mallards Landing, a 30 hectare site, was over 60% Ag prior to development; an 11 hectare Forest patch located on the rear half of the property received 26 residential lots totaling 5 hectares. At the same time, seven patches totaling 9 hectares were designated as open-space and established within the Ag portions of the property. In both instances, large Ag areas were designated as open-spaces while development occurred within or adjacent to the natural areas the policy intended to preserve. Such examples illustrate that land-covers with high ecological value must be explicitly defined as non-developable in order to preserve them.

Even though the Open land-cover class was primarily composed of agricultural remnants that seemed to be arbitrarily designated, these open-spaces do provide a palette from which future beneficial land-covers could be introduced. Potential future land-covers could include prairies or open fields (which may undergo a process of secondary succession with no additional influence), re-planting of forests or other native vegetations, or natural recreation areas. Depending on the selected design decisions, the open spaces have the potential to re-introduce or increase the ecosystem values (Forman 1995, Nassauer 1997) provided by natural land covers.

To achieve the original objective of preserving natural features, a suggested policy direction for the Township includes the incorporation of a pro-active spatial planning method into their open-space policy. These types of methods have the potential to preserve not only open-space, but spaces within the landscape that have the highest ecological value. One such method is presented by Forman and Collinge (1997) where a spatial solution (i.e., a pattern of ecosystems or land uses) is used to conserve the majority of the most important attributes of biodiversity and natural processes within portions of or within whole landscapes in a region. By comparing modeled patterns of random land conversion versus conversion directed with a spatial solution, they demonstrated that a spatial planning process that identifies ‘first removals’ (i.e., society designated areas prime for development) and ‘last stands’ (i.e., the large and medium areas of most ecological importance to be protected) preserved five times more of the areas with high ecological value. Specifically, a spatial solution is highly effective for conserving ecologically important landscape features if the planning commences prior to the removal of the first 40% of the natural vegetation (Forman and Collinge 1997). From a design perspective, large areas of agriculture (i.e., first removals) are to be developed first, avoiding last stands (e.g., large to medium patches of natural cover and streams). In addition, major corridors between smaller patches and last stands are to be conserved. As vegetation removal continues to 50%, some medium-sized patches of the natural land-covers begin to be removed. At 75% of vegetation removal, medium size patches have been eliminated with the large patches next in line, and so on. The idea would be to integrate such a method into the Township’s current open-space policy. Based on Forman and Collinge’s scale, a development designating 40% open space would be required to preserve the majority of the areas of highest ecological value.

Incorporation of a spatial solution into Fenton Township’s open-space policy would additionally provide a simple and effective method for addressing the latter two, of the three, zoning ordinance conditions that Arendt (2004) state are necessary to help implement conservation planning policies. The three conditions of higher standards are related to the quantity, quality, and configuration of the open spaces that developers are allowed to create. The first condition was previously met with the Township’s established open-space policy. These conditions also alleviate the “hit-or-miss” conservation efforts practiced by most developers (Arendt 2004).

An additional method to preserve the open spaces with the highest ecological value is outlined as a four-step approach by Arendt (2004). These steps include: 1) the identification of primary (e.g., designated as ‘unbuildable’) and secondary (e.g., prime soils, woodlands, etc.) potential conservation lands; 2) the placing of house sites at a ‘respectful’ distance from the natural areas; 3) the placement of streets and trails; and, 4) the establishment of lot lines. An example application of such a method can be evaluated by looking at a municipality near Fenton Township, that is, Hamburg Township in Livingston County, Michigan. This method for conserving open-space contrasts that of Fenton Township, in that the Hamburg Township Zoning Ordinance provides a definition of the composition and configuration of allowable open-space. The open-space shall provide the benefits of: the preservation of significant natural assets (e.g., woodlands, individual trees over 12 inches in diameter, significant views, etc.); the creation of recreation facilities or parklands if the site lacks natural features; or, the establishment of natural features if the site lacks existing natural features (Hamburg Township 2000, Article 14.3). Furthermore, "the development(s) shall be designed to promote the preservation of natural features. If animal or plant habitats of significant value exist on the site, the Planning Commission…may require the open-space community plan preserve these areas in a natural state and adequately protect them…(Hamburg Township 2000, Article 14.4.15)." Using this clearer conservation subdivision definition, Hamburg Township has protected over 530 hectares (two square miles) of open-space since 1992.

Conclusions

Local-scale landscapes in Fenton Township, Michigan were analyzed to empirically evaluate the influences that one local land-use policy has had on land-cover change at this urban-rural fringe. An open-space policy was established to increase open space within the community in an effort to preserve natural landscape features and rural character. This policy's effectiveness was evaluated through the comparison of changes in class- and landscape-level spatial metrics from pre- to post-development stages for developments initiated both before and after the policy implementation. It was determined that the policy shift produced only a small number of observable and significant effects on after-policy land-cover changes as compared to before-policy developments. The majority of the changes revolve primarily around increasing, rather than decreasing, amounts of the Open land-cover class. According to this analysis, the policy's objectives of preserving natural features and rural character were not achieved. Following Arendt's (2004) definition of the conditions necessary for successful open-space zoning, failure may be explained by a lack in the policy of several key points: a definition of natural features; a requirement that they shall be preserved; and a spatial context for design decisions.

Further research, under multiple scenarios, at multiple scales is needed to test the hypothesis that land-cover changes are affected by detailed policy objectives. In the context of a sustainable society (ecologically, socially, and economically), empirical documentation and assessment of the 'real world' effects of established and proposed land-use policies is essential for success. This paper contributes to an under-developed body of literature in this arena.

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Table 1: Pre-development percent of landscape class (PLAND) including T-test results comparing the means of the before- and after-policy groups.

Class	Before Mean	Before S.D.	Before Range		After Mean	After S.D.	After Range		P-Value	μ1=μ2
			Min	Max			Min	Max	(two-tailed)	
Ag	**28.2855**	30.8239	0.0000	65.7703	**52.3502**	37.1706	0.0000	92.5497	0.1330	**yes**
Forest	**31.4433**	23.0084	0.6979	73.3330	**23.4033**	19.4610	3.6443	62.4139	0.4102	**yes**
Lake	**0.2766**	0.4977	0.0000	1.4441	**0.7083**	2.2380	0.0000	7.0777	0.5649	**yes**
Mix	**10.9608**	26.3624	0.0000	84.6737	**10.5354**	25.2093	0.0000	80.8281	0.9710	**yes**
Open	**22.6597**	31.2344	0.0003	87.8730	**5.0386**	12.6375	0.0007	40.8869	0.1244	**yes**
Res	**0.7726**	1.4930	0.0008	4.2805	**1.1461**	2.1053	0.0007	6.8223	0.6533	**yes**
Roads	**0.0888**	0.2806	0.0004	0.8883	**0.1570**	0.4470	0.0001	1.4230	0.6894	**yes**
Wet	**5.5126**	6.6977	0.0000	21.2947	**6.6610**	7.6511	0.0000	17.8583	0.7252	**yes**

Table 2: Land-cover class descriptions for categorical mapping.

GridCode	Label	LabelCode	Description
1	Agricultural	Ag	Active agricultural fields
2	Forest	Forest	Forest stands, 60-100% tree cover
3	Lake	Lake	Open water or ponds (excluding open water within wetlands)
4	Mixed	Mix	Mixture of forest and open field, 20-60% tree cover
5	Open	Open	Fields and other open areas, 0-20% tree cover
6	Residential	Res	Structures and adjacent maintained lawns
8	Roads	Roads	Primary traffic flow surfaces (excluding driveway and trails)
9	Wetlands	Wet	Observable wetland features

Table 3: Kappa component values comparing actual vs. predicted land covers for the sites used to evaluate the prediction method (Pontius 2000).

Study Site	**Kno**	**Klocation**	**Kquantity**
McCully Lake	0.808	0.983	-0.295
Orchard View	0.830	0.713	0.981
River Oaks	0.892	0.872	0.951

Table 4: Description and interpretation of landscape metrics used to describe subdivision land-cover patterns.

Metric	***Description**	***Value Interpretation**
class-level:		
PLAND	Percentage of Landscape: provides the proportional abundance of each land-cover class within a landscape.	PLAND = 0 when a land cover is absent and = 100 when a single land-cover class covers the entire landscape.
NP	Number of Patches: returns the number of patches for each class within the landscape.	Actual number of patches, NP = 1 when the landscape consists of a single patch (i.e., the entire landscape is homogenous).
PD	Patch Density: calculates the density of patches per land-cover class.	PD = number of patches per 100 hectares.
AREA_MN	Patch Area-Mean: quantifies the average size of all patches within each land-cover class.	AREA_MN = actual mean area in hectares.
SHAPE_MN	Shape Index-Mean: computes an area-adjusted measure (to a square) of the average shape complexity for each class.	SHAPE index value = 1 when a patch reaches its highest level of compaction - a square in this case. The value increases as the patch becomes more complex.
TECI	Total Edge Contrast Index: quantifies the total relative abundance of contrast present along the edges of a class.	TECI = 100 when all edges between the land-cover classes are of greatest contrast, and nears 0 as the contrast between classes lessens.
GYRATE_MN	Radius of Gyration-Mean: returns the average extent covered by the patches of a class. The extent is calculated using the mean distance from the patch centroid to each cell.	GYRATE = 0 if the patch is a single cell, it increases as a patch includes more of the landscape.
ENN_MN	Euclidean Nearest-Neighbor Distance-Mean: provides a class mean of the straight-line distance to a nearest like-class neighbor.	Actual straight-line distance (meters) to the nearest like-class neighbor, ENN approaches 0 as the distance to a like patch lessens.
PROX_MN	Proximity Index-Mean: calculates the class mean index value for the distance between a focal patch and all others within a specified search radius.	PROX = 0 if no other like-class patches are present within the search radius, the value increases as more patches are present.
landscape-level:		
CONTAG	Contagion Index: computes an index based on the aggregation and dispersion of all land-cover classes present.	CONTAG nears 0 with higher levels of disaggregation and interspersion, and = 100 with maximum aggregation - when the landscape is a single patch.
PR	Patch Richness: provides the number of patches, of any class, within the landscape.	PR = actual number of patches present.

*Paraphrased from McGarigal et al. (2002).

Table 5: Contrast weights used in the calculation of the total edge contrast index (TECI).

Class	AG	Forest	Lake	Mix	Open	Res	Roads	Wet
AG	**0**							
Forest	0.8	**0**						
Lake	1	1	**0**		(table is symmetrical)			
Mix	0.6	0.2	1	**0**				
Open	0.2	0.6	1	0.4	**0**			
Res	1	1	1	1	1	**0**		
Roads	1	1	1	1	1	0	**0**	
Wet	0.8	0.6	0.4	0.4	0.2	1	1	**0**

No contrast - 0
Nearly similar - 0.2
Closer to similar - 0.4
Closer to different - 0.6
Nearly different - 0.8
Total contrast - 1

Table 6: Pre- and post-development percentage of landscape (PLAND) for each study site indicated as before- (B) and after-policy (A) changes.

Site #	Policy	Pre-AG	Post-AG	Pre-Forest	Post-Forest	Pre-Lake	Post-Lake	Pre-Mix	Post-Mix
1	A	0.00	0.00	15.55	13.86	0.00	0.00	80.83	25.46
2	B	0.00	0.00	15.04	6.45	0.00	0.00	84.67	4.93
3	B	0.00	0.00	55.16	22.26	0.00	0.00	0.22	0.22
4	A	0.09	0.00	62.41	23.26	7.08	6.72	16.52	5.68
5	A	72.11	0.00	5.10	1.99	0.00	0.00	4.27	0.25
6	B	0.00	0.00	1.07	0.78	0.00	0.00	11.06	0.07
7	A	60.80	0.00	38.20	11.57	0.00	0.00	1.00	1.00
8	A	87.80	0.00	9.52	9.52	0.00	0.00	0.00	0.00
9	A	76.84	0.00	16.82	10.99	0.01	0.01	1.76	0.42
10	A	70.91	0.00	8.60	4.08	0.00	0.00	0.98	0.83
11	B	59.82	0.00	32.73	16.13	0.02	0.02	0.87	0.55
12	B	54.00	0.00	37.24	20.41	0.07	0.07	0.00	0.00
13	B	65.77	0.00	23.28	11.43	0.34	0.34	0.00	0.00
14	A	61.11	0.00	32.03	18.02	0.00	0.00	0.00	0.00
15	B	0.00	0.00	0.70	0.70	0.89	0.89	12.79	12.74
16	B	37.49	0.00	45.81	14.71	0.00	0.00	0.00	0.00
17	B	0.00	0.00	73.33	38.14	1.44	1.44	0.00	0.00
18	B	65.77	0.00	30.07	20.48	0.00	0.00	0.00	0.00
19	A	1.28	0.00	42.14	39.34	0.00	0.00	0.00	0.00
20	A	92.55	0.00	3.64	2.49	0.00	0.00	0.00	0.00

Site #	Policy	Pre-Open	Post-Open	Pre-Res	Post-Res	Pre-Roads	Post-Roads	Pre-Wet	Post-Wet
1	A	1.81	1.81	0.00	53.52	0.00	3.54	1.81	1.81
2	B	0.09	0.09	0.19	80.78	0.00	7.74	0.00	0.00
3	B	39.99	0.00	2.75	70.25	0.00	5.43	1.88	1.84
4	A	3.13	0.79	0.47	50.79	0.00	4.53	10.29	8.23
5	A	0.34	13.09	0.17	61.80	0.15	5.66	17.86	17.20
6	B	87.87	0.00	0.00	91.93	0.00	7.22	0.00	0.00
7	A	0.00	8.47	0.00	70.83	0.00	8.14	0.00	0.00
8	A	0.00	30.43	1.44	56.37	0.00	3.65	1.24	0.03
9	A	1.56	36.93	0.22	45.55	0.00	3.31	2.80	2.80
10	A	0.85	10.30	0.10	60.64	1.42	7.02	17.14	17.14
11	B	0.00	1.01	0.00	70.76	0.00	4.98	6.56	6.56
12	B	0.00	0.09	0.29	67.13	0.89	5.09	7.50	7.21
13	B	0.64	0.00	0.00	73.65	0.00	4.60	9.98	9.98
14	A	0.03	15.27	6.82	61.27	0.00	5.43	0.00	0.00
15	B	64.33	7.74	0.00	53.88	0.00	2.76	21.29	21.29
16	B	15.72	0.00	0.21	78.87	0.00	5.66	0.76	0.76
17	B	13.79	0.00	4.28	50.16	0.00	3.89	7.15	6.37
18	B	4.16	0.11	0.01	74.35	0.00	5.06	0.00	0.00
19	A	40.89	0.69	0.22	40.52	0.00	3.99	15.46	15.46
20	A	1.79	45.36	2.01	48.54	0.00	3.61	0.00	0.00

Table 7: Pre- to post-development changes in land-cover percentages (PLAND) for each study site indicated as before- (B) and after-policy (A) changes.

Site #	B/A Policy	AG-Change	For-Change	Lake-Change	Mix-Change	Open-Change	Res-Change	Road-Change	Wet-Change
1	A	0.00	-1.69	0.00	-55.37	0.00	53.51	3.54	0.00
2	B	0.00	-8.59	0.00	-79.74	0.00	80.59	7.74	0.00
3	B	0.00	-32.91	0.00	0.00	-39.99	67.50	5.43	-0.04
4	A	-0.09	-39.16	-0.36	-10.84	-2.34	50.32	4.53	-2.06
5	A	-72.11	-3.11	0.00	-4.02	12.75	61.63	5.51	-0.66
6	B	0.00	-0.29	0.00	-10.99	-87.87	91.93	7.22	0.00
7	A	-60.80	-26.64	0.00	0.00	8.47	70.83	8.14	0.00
8	A	-87.80	0.00	0.00	0.00	30.43	54.93	3.65	-1.21
9	A	-76.84	-5.83	0.00	-1.34	35.37	45.33	3.31	0.00
10	A	-70.91	-4.52	0.00	-0.15	9.45	60.54	5.59	0.00
11	B	-59.82	-16.60	0.00	-0.32	1.01	70.76	4.98	0.00
12	B	-54.00	-16.82	0.00	0.00	0.09	66.84	4.20	-0.30
13	B	-65.77	-11.85	0.00	0.00	-0.64	73.65	4.60	0.00
14	A	-61.11	-14.01	0.00	0.00	15.23	54.45	5.43	0.00
15	B	0.00	0.00	0.00	-0.04	-56.59	53.88	2.75	0.00
16	B	-37.49	-31.10	0.00	0.00	-15.72	78.66	5.66	0.00
17	B	0.00	-35.19	0.00	0.00	-13.79	45.88	3.89	-0.78
18	B	-65.77	-9.59	0.00	0.00	-4.05	74.35	5.06	0.00
19	A	-1.28	-2.80	0.00	0.00	-40.20	40.29	3.99	0.00
20	A	-92.55	-1.15	0.00	0.00	43.57	46.52	3.61	0.00
Before MEAN		**-28.29**	**-16.29**	**0.00**	**-9.11**	**-21.76**	**70.40**	**5.15**	**-0.11**
Before S.D.		30.82	12.90	0.00	25.05	30.27	13.15	1.49	0.25
Before MIN		-65.77	-35.19	0.00	-79.74	-87.87	45.88	2.75	-0.78
Before Max		0.00	0.00	0.00	0.00	1.01	91.93	7.74	0.00
After MEAN		**-52.35**	**-9.89**	**-0.04**	**-7.17**	**11.27**	**53.84**	**4.73**	**-0.39**
After S.D.		37.17	13.07	0.11	17.28	23.53	8.93	1.49	0.72
After MIN		-92.55	-39.16	-0.36	-55.37	-40.20	40.29	3.31	-2.06
After MAX		0.00	0.00	0.00	0.00	43.57	70.83	8.14	0.00
Difference of Means		**-24.06**	**6.40**	**-0.04**	**1.94**	**33.03**	**-16.57**	**-0.42**	**-0.28**
p-value		0.1330	0.2847	0.3434	0.8430	0.0144	0.0046	0.5328	0.2661
µ1=µ2		**yes**	**yes**	**yes**	**yes**	**no**	**no**	**yes**	**yes**

Table 8: Summary of comparisons between before- and after-policy groups. Mean group-changes are indicated as before- (B-) and after-policy (A-) changes. Direction of the differences for the means are indicated as (+) for a positive difference, (-) for a negative difference, (0) for no difference; $\mu 1=\mu 2$ is no for study sites with a significant difference (at 0.05) in the metric values.

Class-level Metrics:	**Ag**	**Forest**	**Lake**	**Mix**	**Open**	**Res**	**Roads**	**Wetlands**
PLAND: B-policy	-28.29	-16.29	0.00	-9.11	-21.76	70.40	5.15	-0.11
PLAND: A-policy	-52.35	-9.89	-0.04	-7.17	11.27	53.84	4.73	-0.39
PLAND: direction of diff.	(-)	(+)	(-)	(+)	(+)	(-)	(-)	(-)
PLAND: p-value	0.13	0.28	0.34	0.84	0.01	0.00	0.53	0.27
PLAND: $\mu 1=\mu 2$	yes	yes	yes	yes	**no**	**no**	yes	yes
NP: B-policy	-1.90	2.40	0.00	0.70	0.50	0.80	1.00	0.00
NP: A-policy	-2.20	2.70	0.00	1.00	5.30	1.80	0.90	0.20
NP: direction of diff.	(-)	(+)	(0)	(+)	(+)	(+)	(-)	(+)
NP: p-value	0.83	0.85	n/a	0.80	0.00	0.24	0.68	0.34
NP: $\mu 1=\mu 2$	yes	yes	yes	yes	**no**	yes	yes	yes
PD: B-policy	-8.76	15.04	0.00	11.92	-1.62	8.19	8.77	0.00
PD: A-policy	-9.72	10.12	0.00	4.43	28.11	7.40	7.47	0.27
PD: direction of diff.	(-)	(-)	(0)	(-)	(+)	(-)	(-)	(+)
PD: p-value	0.84	0.43	n/a	0.56	0.01	0.90	0.71	0.34
PD: $\mu 1=\mu 2$	yes	yes	yes	yes	**no**	yes	yes	yes
AREA_MN: B-policy	-2.46	-2.38	0.00	-0.60	-1.63	6.22	0.63	< -0.01
AREA_MN: A-policy	-13.80	-2.11	-0.03	-0.56	0.33	3.74	1.11	-0.11
AREA_MN: direction of diff.	(-)	(+)	(-)	(+)	(+)	(-)	(+)	(-)
AREA_MN: p-value	0.18	0.85	0.34	0.95	0.02	0.27	0.26	0.24
AREA_MN: $\mu 1=\mu 2$	yes	yes	yes	yes	**no**	yes	yes	yes
SHAPE_MN: B-policy	-0.95	-0.07	0.00	0.52	-0.42	1.53	5.98	-0.01
SHAPE_MN: A-policy	-1.50	-0.05	0.00	-0.05	0.43	0.97	7.07	-0.06
SHAPE_MN: direction of diff.	(-)	(+)	(0)	(-)	(+)	(-)	(+)	(-)
SHAPE_MN: p-value	0.18	0.94	0.34	0.12	0.06	0.31	0.54	0.33
SHAPE_MN: $\mu 1=\mu 2$	yes	yes	yes	yes	yes	yes	yes	yes
TECI: B-policy	-25.29	16.15	0.00	14.42	-9.21	12.30	-8.10	2.60
TECI: A-policy	-46.06	6.65	-0.02	6.13	41.15	-1.70	-7.57	-0.80
TECI: direction of diff.	(-)	(-)	(-)	(-)	(+)	(-)	(+)	(-)
TECI: p-value	0.07	0.08	0.34	0.33	0.02	0.37	0.96	0.27
TECI: $\mu 1=\mu 2$	yes	yes	yes	yes	**no**	yes	yes	yes
GYRATE_MN: B-policy	-40.76	-31.12	0.00	-14.29	-31.65	106.16	113.56	-0.38
GYRATE_MN: A-policy	-115.32	-32.34	-0.11	-12.81	8.58	84.95	153.56	-5.08
GYRATE_MN: direction of diff.	(-)	(-)	(-)	(+)	(+)	(-)	(+)	(-)
GYRATE_MN: p-value	0.10	0.94	0.34	0.89	0.03	0.34	0.35	0.21
GYRATE_MN: $\mu 1=\mu 2$	yes	yes	yes	yes	**no**	yes	yes	yes
ENN_MN: B-policy	-3.40	17.65	0.00	3.63	11.42	-19.98	5.61	1.13
ENN_MN: A-policy	-30.07	6.51	0.00	17.23	35.70	-32.41	3.31	-3.22
ENN_MN: direction of diff.	(-)	(-)	(0)	(+)	(+)	(-)	(-)	(-)
ENN_MN: p-value	0.08	0.48	n/a	0.29	0.48	0.68	0.71	0.23
ENN_MN: $\mu 1=\mu 2$	yes	yes	yes	yes	yes	yes	yes	yes
PROX_MN: B-policy	-94.49	-43.84	0.00	0.10	-7.79	662.81	0.29	-5.54
PROX_MN: A-policy	-44.26	-13.92	-0.36	-0.95	107.75	1167.64	-0.57	0.10
PROX_MN: direction of diff.	(+)	(+)	(-)	(-)	(+)	(+)	(-)	(+)
PROX_MN: p-value	0.43	0.71	0.30	0.37	0.12	0.35	0.16	0.34
PROX_MN: $\mu 1=\mu 2$	yes	yes	yes	yes	yes	yes	yes	yes

Landscape-level Metrics:

CONTAG: B-policy	1.48	PR: B-policy	0.50
CONTAG: A-policy	-7.91	PR: A-policy	0.30
CONTAG: direction of diff.	(-)	PR: direction of diff.	(-)
CONTAG: p-value	0.01	PR: p-value	0.67
CONTAG: $\mu 1=\mu 2$	**no**	PR: $\mu 1=\mu 2$	yes

Figures:

Figure 1: The Charter Township of Fenton, Genesee County, Michigan. U.S.A.

Figure 2: An example of the photo rectification process using one survey section. Illustrations include (a) an aerial photograph with ground control points indicated, (b) roads data used for rectification, and (c) the final rectified image.

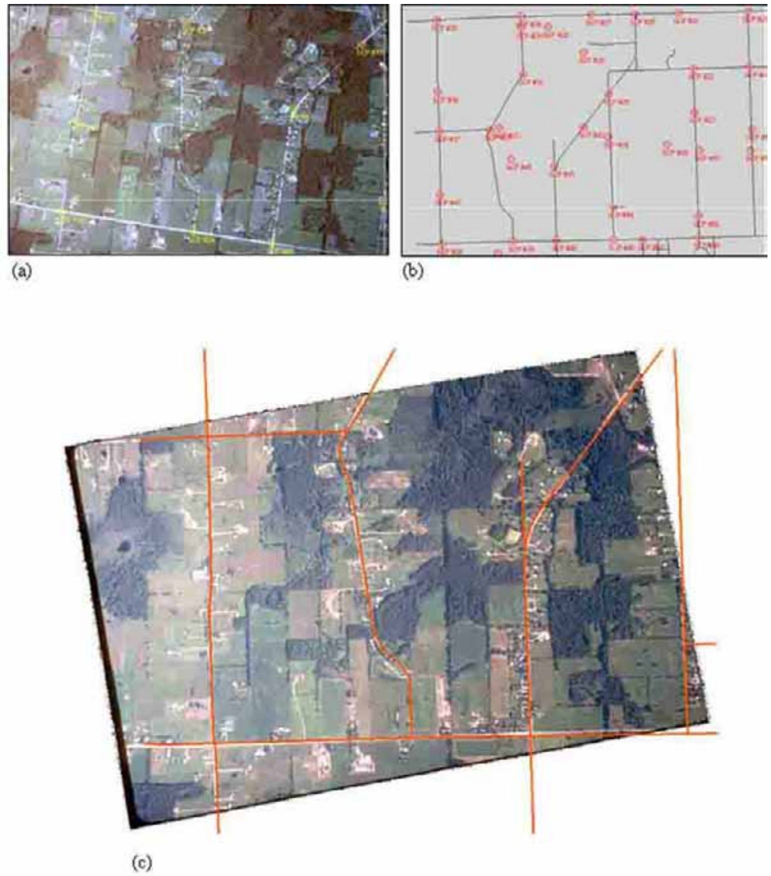

Figure 3: An example subdivision to illustrate land-cover interpretations. (a) 1992 color aerial photography and (b) the interpreted categorical land-covers (defined in table 2).

Figure 4: Diagram of the residential prediction method for River Oaks Hollow subdivision. The illustrations represent: (a) the photo interpreted land cover; (b) the Ag and Open isolated patches; (c) the parcel intersection with the Ag and Open classes; (d) the parcel portions that are co-incident with the Ag and Open classes; (e) the buffer of the average distance to the rear of all structures; (f) the union of the Ag and Open patches with the distance buffer; (g) the creation of the predicted residential developed extent; and, (h) the final predicted built-out land cover.

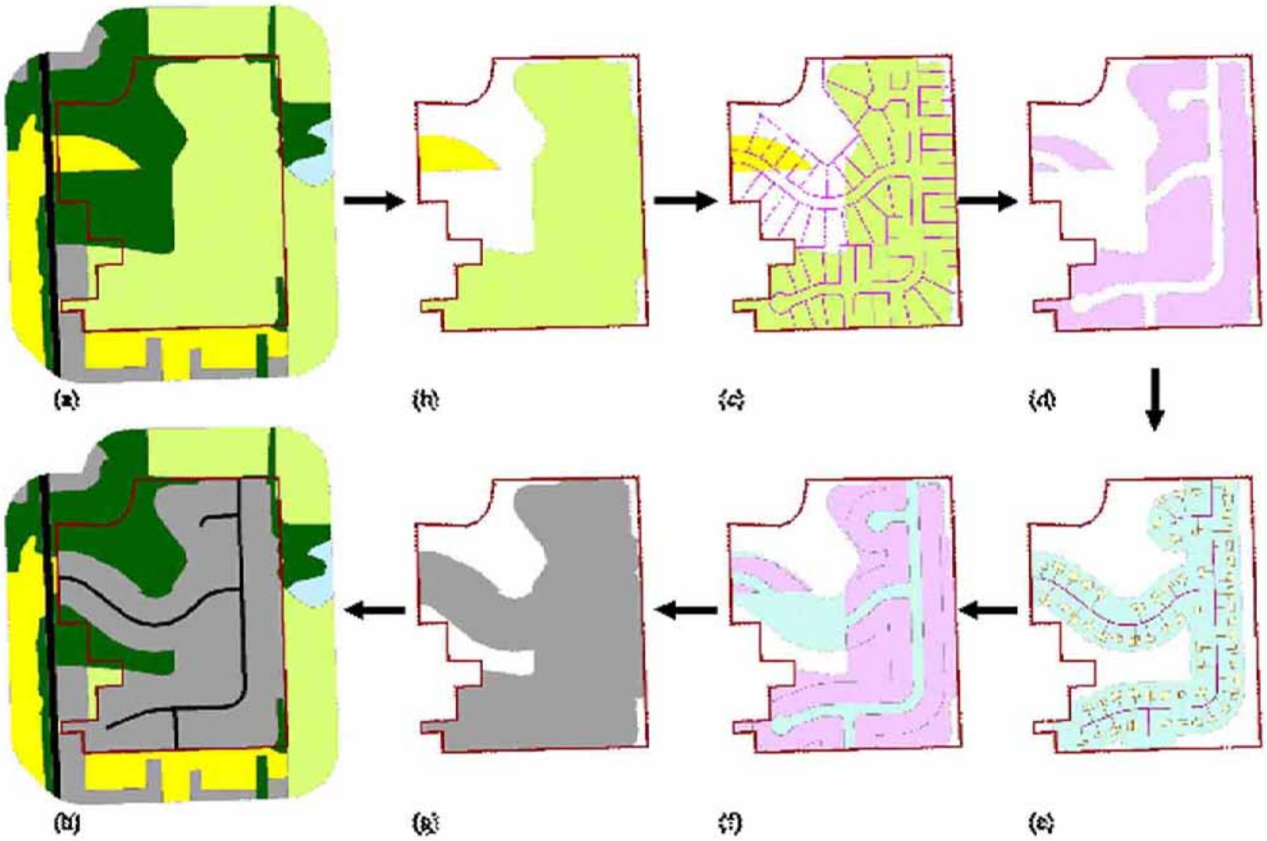

Figure 5: Illustration of the cross-tabulation results for McCully Lake Estates subdivision. (a) The actual residential developed results compared to the (b) predicted results and (c) the cross-tabulation outcome. RD is correctly predicted (1|1), where ND was predicted as RD (2|1), where RD was predicted as ND (1|2), and where ND was correctly predicted (2|2). Note that within the cross-tabulation output both correctly predicted categories are colored in blue.