Bridging metropolitan growth and regional zoning in Greater Des Moines, Iowa U.S.

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Abstract

The Greater Des Moines Iowa region is currently undertaking regional planning efforts aimed at promoting sustainable development. We examined metropolitan growth in the region from 2000-2010 using remote sensing techniques. Morphological image analysis was applied to create a map of robustly classified new development, which was analyzed with respect to a Regional Unified Zoning created from individual municipal codes. Our results indicate that built-up land increased 15 percent over the decade. The greatest share of new development took place in western and northern suburbs, which are known to make use of Planned Unit Developments (PUD). Indeed, 37 percent of all new development was observed in PUDs. Our results indicate that growth was primarily expansive in nature. In addition to having implications for regional planning in Greater Des Moines, this study makes broader contributions by linking remote sensing and land use planning.

1. Introduction

Planning at the regional level can have many positive effects on sustainability-related issues. For example, minimizing urban sprawl and reviving declining central cities has been effectively pursued by implementing policies at the regional level (Swanstrom, 2001). Likewise, evidence suggests that planning for equity should occur at a regional scale because local governments typically do not effectively address inequality issues in their agendas (Pastor and Benner, 2011). From an environmental perspective, “green regionalism” has the potential to bring reduction of energy and resource consumption, limitation of pollutants, and conservation of nature (Beatley, 2011, p. 140).

A few stable and successful cases of regional planning exist in the U.S. In Oregon, for instance, Portland’s Metropolitan Planning Organization is responsible for regional transit and land use planning. It has integrated these processes, creating transit-oriented development that has yielded denser development and increased transit use (Metro, 2010). In Minnesota, the Twin Cities are home to a unique tax-base sharing program that has been in existence since 1971. Participating municipalities pool 40 percent of their commercial and industrial tax base growth. The pool is then redistributed to communities according to their fiscal capacity, such that communities with less commercial development receive more from the pool (Metro Council, 2013).

Many initiatives to promote regional planning are taking place in the U.S., mainly because of the sustainability dimension that such approaches bring. Federally funded initiatives indicate that regional planning for sustainability is indeed important. Well known regional federal strategies come from the Department of Transportation (DOT) and the Environmental Protection Agency (EPA). As well, during his first term, President Obama launched the “Sustainable Communities” program, which is primarily administered by Department of Housing and Urban Development (HUD). The objective of this initiative “is to stimulate more integrated and sophisticated regional planning to guide state, metropolitan, and local investments in land use, transportation and housing, as well as to challenge localities to undertake zoning and land use reforms” (HUD, 2013). However, as Knaap and Lewis (2011) alert, success of the Sustainable Communities initiative “depends specifically on the physical, cultural, and political context of a given metropolitan area, its sources and strength of leadership, the breadth of organizational participation, the technical capacity of the combined organizational team, and the institutional governance structure” (p. 205).

Achieving consensus to plan at the regional level is the biggest challenge facing supporters of regional planning, an important issue when considering the political context described by Knapp and Lewis (2011). Weir et al. (2009) alerts horizontal collaboration alone cannot empower regional decision making processes. Based on their research, there is a need to include vertical power, which is essential to building regional capacities. “Only by exercising power at multiple levels of the political system can local reformers launch a virtuous cycle of reform that begins to build enduring regional capacities" (p. 455). The Portland and Twin Cities cases described above are examples of such successful power sharing. However, most cities in the U.S. struggle with the establishment of these essential horizontal and vertical collaborations. The Greater Des Moines, Iowa metropolitan area is one such location. According to the 2012 State of the Region report for Greater Des Moines, several existing organizations currently participate in regional oversight, including the Des Moines Area Regional Transit Authority and the Greater Des Moines Partnership. However, the report also points out that "past efforts for government consolidation or establishment of a regional governing body" have not been successful (p. 25).

In 2010, the Des Moines Area Metropolitan Planning Organization (DMAMPO) was awarded a grant from the Sustainable Communities initiative to plan for sustainable development in Greater Des Moines. The plan document, and the planning process itself, has come to be known as *The Tomorrow Plan*. One of the goals of the partnership between HUD and DMAMPO is to "coordinate policies and leverage investment" so as to "align federal policies and funding to remove barriers to collaboration, leverage funding and increase the accountability and effectiveness of all levels of government to plan for future growth" (TTP, 2013, p. 7). More specifically, one of the Tomorrow Plan's 15 draft objectives is the "increased use of compact development as a tool for regional planning to accommodate population growth, to utilize infrastructure efficiently, and to preserve productive agricultural land and natural areas for environmental and recreational purposes" (The Tomorrow Plan 2012). In other words, the Greater Des Moines region would like to limit urban sprawl and promote compact development.

Based on the findings of Knaap and Lewis (2011), there is a need to study the physical context of the area to ensure regional planning is successful. We believe two important components of the physical context are past trends in metropolitan growth, and the relationship between growth and current land use planning/development regulations. This paper has two main objectives designed to address these needs: 1) examine spatial patterns of development in Greater Des Moines over the period 2000-2010; and 2) analyze the types of zoning categories in which this development occurred. In addition to contributing valuable information to the Tomorrow Plan, this study makes broader contributions by explicitly evaluating growth as it relates to land use planning; the literature on empirical remote sensing rarely explores such linkages.[1]

2. Methodology

In this section, in addition to briefly introducing our study area and the data we used for the remote sensing analysis, we describe the three main steps we took to address the objectives. First, we classified the land covers, then we identified areas of new development, and finally we developed a regional unified zoning.

2.1. Study area

A 1,304 km^2 study area was defined for this paper (Figure 1) based on the area of interest identified by the Tomorrow Plan. The study area covers 17 incorporated cities covering ~712 km^2, as well as ~590 km^2 of unincorporated land (four counties). The region is home to a wide range of land uses from intensive row-crop agriculture in the rural areas, to mixed uses in the peri-urban region, and high density urban in the center of the city.

Unlike many Iowa communities, the population of Greater Des Moines has undergone a steady increase over the last decade. According to the State of the Region report, "between 1960 and 2010, Greater Des Moines grew in population by over 235,000 people, increasing from nearly 323,600 persons to nearly 558,700 persons. On an average annual basis, the growth rate was 1.1 percent. The nation grew at the same annual rate during this period, while the State of Iowa population increased at a much slower annual rate of 0.2 percent" (p. 25).

[1] See Munroe et al. (2005) and York and Munroe (2010) as examples of papers that do explore these linkages.

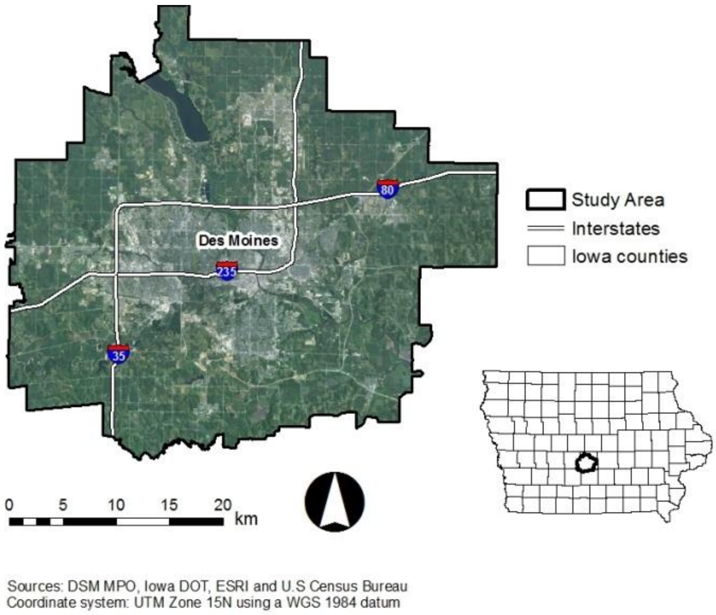

Figure 1. Map of the study area and its location in the State of Iowa (basemap is a 2010 natural color orthophoto).

2.2. Remotely sensed data

To address this paper's first objective, we created land cover maps of the study area for 2000 and 2010 based on remotely sensed satellite data. Many studies have demonstrated the benefits of using multi-temporal imagery for land cover classifications (e.g. see Yuan et al. 2005). This may be particularly important for the Greater Des Moines region given the seasonal variation of crop cover in the area. Therefore, a total of four satellite scenes – one from the summer and one from the fall of each year – were used in the classifications. These were collected by the Landsat 5 Thematic Mapper (TM) sensor on 1-Jun and 24-Nov 2000, and 15-Jul and 3-Oct 2010.

The images were geometrically corrected by the USGS with their Level 1T Product Generation System and georeferenced to UTM zone 15 north using a WGS 1984 datum. Atmospheric correction was deemed unnecessary since minimal interference was observed for the study area and spectral classes were identified independently for the 2000 and 2010 data.

Six bands of spectral data (TM bands 1-5 and 7) were obtained for the Landsat scenes, all with spatial resolutions of 30 m. The summer and fall data from each year were stacked into 12-band composite images and clipped to the study area. These composite datasets were used as inputs to the unsupervised classification procedures described below.

Additional remotely sensed data in the form of high-resolution National Agriculture Imaging Program (NAIP) orthophotos of the study area were used to guide the classifications. These were obtained from the Iowa Department of Natural Resources GIS Library and had collection dates of 2002 and 2010; the closest years available relative to the Landsat collection dates.

2.3. Land cover classifications

We generated 2000 and 2010 land cover maps using unsupervised classifications. Five informational land cover classes were targeted based on the project needs and first-hand knowledge of the study area (Table 1). While distinguishing between different types of development (i.e. commercial, residential, etc.) would have been ideal, undertaking a higher level classification was beyond the scope of this paper. Finally, cloud and cloud shadow "classes" had to be introduced in the 2010 scheme.

Table 1. Land cover classes and their definitions

Land cover class	Definition
Built-up land	All land that is covered by human-built structures, including pavement, buildings, and other artificial structures.
Seasonally flooded land	Land that was seasonally flooded (i.e. covered with water only in the summer or the fall images, but not both).
Trees	All deciduous and evergreen trees, including natural forests, managed forests, and trees that exist in the urban landscape.
Crop land and grasses	All areas used for agricultural production, including row crops and fallow fields; and land covered with grasses, including native prairie, unmanaged grasslands, managed pastures, and urban/recreational grasses.
Water	All natural and man-made water bodies, including lakes, rivers, streams, ponds, and pools.

Land cover classifications were carried out separately for the 2000 and 2010 data using ENVI 5.0 remote sensing software. An Iterative Self-Organizing Data Analysis Technique (ISODATA) approach was used based on the work of Yuan et al. (2005), who classified land cover in the Minneapolis-St. Paul, Minnesota area. This approach was deemed appropriate for the Greater Des Moines region given similarities in the types of land cover present for the two regions. All land cover classifications were based on the 12-band composite rasters described above.

The ISODATA classifications used a change threshold of one percent, a maximum class standard deviation of 0.5, and 60 iterations. A total of 100 spectral classes were identified for each year, which were then manually recoded as belonging to one of the five informational classes. In the absence of ground-truthing data, this process was guided by visual examinations of the high-resolution orthophotos and natural and false color composites of the Landsat data.

Initial examinations of the recoded land cover maps revealed problems sorting roads into the built-up class. To address this, we obtained road centerline data from the Iowa Department of Transportation for 2000 and 2010, converted the vector data to raster format, and appended these to existing pixels in the built-up classes. Finally, the 2000 built-up class was “burned into” the 2010 map based on a non-reversal rule that once a pixel was developed, it could not revert back to an undeveloped state. Other studies of land cover change have used similar ancillary data overlays and non-reversal strategies (e.g. see Riitters et al. 2004, Powell et al. 2008, and Suarez-Rubio et al. 2012). Pixels counts were used to compute estimated areas (km^2) in each land cover class.

Accuracies of the final land cover maps were assessed using a stratified sampling method. For both years of data, at least 50 pixels from each land cover class were randomly selected and examined in the high-resolution orthophotos. Sample sizes were chosen based on Congalton and Green’s (2009) guideline for studies with fewer than 12 classes and/or areas smaller than 1,000,000 acres (~4,047 km^2). The pixels were then assigned as belonging to the land cover class dominant in the 30 m square area, and compared to the classification result at the same location. The data were compiled in error matrices and used to compute user’s and producer’s accuracies, total accuracies and Kappa statistics.

2.4. New development

A map of new development was created by first analyzing change in land cover from 2000 to 2010 using post-classification change detection. While a sub-pixel or segment based approaches to identifying new developments may be preferable, such analyses were beyond the scope of the project. The post-classification change technique analyzes pixel-by-pixel changes in independently derived land cover maps (Lu et al. 2004). Pixels representing "new development" (i.e. transition from an undeveloped class in 2000 to the built-up class in 2010), were isolated for further analysis. All other pixels were labeled "no development".

Accuracy of the resulting development map was assessed by comparing reference data from the two times points at radomly selected validation points in the "no development" and "new development" extents. Specifically, orthoimagery and satellite composites collected in 2000 (and 2002), were compared with images collected in 2010, and pixels were assigned to the appropriate class. Accuracy measures were computed based on the resulting change detection error matrix.

To isolate reliably identified legitimate new development pixels from erroneously identified pixels, we used Morphological Spatial Pattern Analysis (MSPA) to partition pixels by their morphological characteristics. MSPA is an image processing technique used to analyze the shape and connectivity of map elements (Vogt et al. 2007a, b). Pixels were sorted into seven morphological categories – core, islet, loop, bridge, perforation, edge, and branch – and percentages of pixels belonging to each class were evaluated. As explained further in the results section, this information was used to develop a final new development map and address the second objective.

2.5. Regional Unified Zoning

To address this paper's second objective, we utilized a Regional Unified Zoning (RUZ) spatial dataset created for the DMAMPO in support of the Tomorrow Plan. The basis for the RUZ was a collection of the zoning codes of each of the seventeen communities in the MPO region, in addition to three county-wide zoning codes.

The creation of a uniform zoning classification (UZC) allowed all zoning districts in the codes of all communities in the MPO to be included. Every zoning district can be described as falling into one of the districts in the UZC. The purpose of the UZC was to allow for comparisons of zoning code districts across communities. The first step, which the description is not part of the scope of this paper, was to evaluate the theoretical maximum development density across the MPO region using existing zoning standards. The UZC was created through an iterative four step process.

<u>High level scan of zoning codes:</u> A high-level scan of each community's zoning code was conducted to look for general similarities among zoning districts primarily in terms of allowable land uses and prescribed densities.

The results of this scan led to the initial creation of twenty general zoning districts classified into the following district types: Agricultural (1 district), Residential (6), Commercial (7), Industrial (2), Planned Unit Development (1), Planned residential development (1), Government (1), and Open Space (1).

Populate districts – examine for outliers: After the high-level scan was completed, each zoning district in each community was then examined in detail. An attempt was made to associate each zoning district with one of the twenty general zoning classifications in the UZC, based on metrics of allowable land uses and density. Approximately 80 percent of all the zoning districts in the MPO region fit neatly into the twenty zoning classifications initially identified. However, several districts defied easy classification, and refinements to the general zoning classifications were therefore necessary.

Refine generalized classifications: The "outliers" that could not be placed into one of the initial twenty zoning classifications fell into one of three categories. The first category of outliers was caused by the initial zoning classifications being based on incorrect parameters. The original six residential districts were based on what initially appeared to be logical groupings of density minimums found in the codes (R-1 = 1-4 units/acre, etc). Closer examination resulted in the creation of seven residential classifications instead of six. A classification was added for districts with <1 unit/acre minimums, and the densities for the other classifications were adjusted, resulting in much more logical groupings of residential districts. For similar reasons, a second agricultural category was added to capture a clear difference in agricultural districts based on a break point of 1 dwelling unit/10 acres.

The second category of outliers was caused by unusual use restrictions. Specifically, a third industrial/manufacturing district was added, and a second Planned Unit Development –Residential Only (PUD-R) district was added because several communities had these distinctive districts in their codes.

The third category of outliers was caused by zones that were simply unique in one way or another. For example, an Urban Core CBD classification was added to accommodate the unique characteristics of the zoning district regulating downtown Des Moines.

The reevaluation and refinement resulted in a final UZC with twenty-four separate zoning classifications, shown in Table 2.

Table 2: Defined Unified Zoning Classification System

Zone	Name	Classification
A-1	Agriculture	Agricultural zones with residential densities of one housing unit per 10 acres or lower densities
A-2	Agricultural Transition	Agricultural zones with residential densities greater than one housing unit per 10 acres
C-1	Neighborhood Commercial/Professional Office	Small areas for offices, professional services, and shopfront retail. In scale with surrounding neighborhood
C-2	Office Park/Clean Industry	Business and industry complexes, including research, high tech, corporate HQ, regional distribution
C-3	General Commercial	A catch-all classification. Allows a broad range of general commercial operations
C-4	Highway-Oriented Commercial	Located along major arterials. Big box retail with ample parking. Allows auto-oriented services
C-5	Large Scale Commercial	Regional shopping centers, power centers, the agglomeration of numerous retail/commercial services in a single complex under single ownership
C-6	Downtown	Concentrated downtown retail, service, office and mixed uses in existing central business districts
C-7	Urban Core CBD	The extreme CBD character of downtown Des Moines
GOV	Government	Government zones and land
M-1	Limited Industrial	Light and limited types of industrial uses
M-2	General Industrial	General industrial uses
M-3	Heavy Industrial	Heavy industrial uses
MU	Mixed-Use	Non-PUD zones which allow a mix of land-uses on the same parcel
OS	Open Space	All types of open space such as floodways, conservation areas, etc.
PUD_R	Planned Residential Development	PUD zones which allow only residential development
PUD_MU	Planned Unit Development	PUD zones which do not restrict development to just residential

R-A	Residential Agricultural	Residential areas with <1 Housing Units/Acre
R-1	Residential Estate	Residential areas with 1-3 Housing Units/Acre
R-2	Low-Density Residential	Residential areas with 4-7 Housing Units/Acre
R-3	Moderate-Density Residential	Residential areas with 8-11 Housing Units/Acre
R-4	High-Density Residential	Residential areas with 12-19 Housing Units/Acre
R-5	Urban High-Density Residential	Residential areas with 20+ Housing Units/Acre
R-6	Mobile Home Residential	Mobile Home Park

Assign each zoning district to one UZC zoning classification: In the final step, each of the 21,967 zoning districts found in the MPO communities' zoning codes was assigned to one of the twenty-four classifications in the UZC. For instance, the R-1 from the UZC classification was assigned to the districts as follows: from Dallas County codes, Suburban Residential District (R-1), One and Two-Family Residential (R-2), Suburban Estate District (RE-1); from Des Moines codes, Large Lot One Family Residential (R1-90), etc.

Analyze land area of new development in RUZ districts: The final RUZ and final new development map were used to address this paper's second objective. Specifically, we used zonal statistics function from the ArcGIS Spatial Analyst extension, which summarizes the values of a raster within the zones of another dataset. In our case, the zones were the 24 unified zoning classes, and the other dataset was the final development map. By doing that, we were able to identify what type of zoning classes received more new development between 2000 and 2010. We also applied zonal statistics for the 17 incorporated cities in the study area to understand which municipalities received more new development. The municipal boundary data were obtained from the U.S. Census Bureau's TIGER/Line® database.

3. Results

3.1. Land cover

Before considering the classification results, it is important to understand how closely they represent true conditions on the ground. The final 2000 and 2010 land maps had estimated total accuracies of 94%, and Kappa statistics of 0.92. The Kappa measure reflects the agreement between the classified and reference data relative to the agreement that would be expected simply by chance.

In addition, we also computed user's and producer's accuracies for each of the land cover classes. User's accuracy measures the probability that features shown on the map are true representations of features on the ground. Conversely, producer's accuracy measure's the probability that a feature on the ground is labeled correctly on the map.

User's and producer's accuracies were consistently high for both years (Table 3). Notably, accuracies of the built-up class were lower for 2010 than 2000. This is to be expected given that the 2000 data were burned into the 2010 map, creating a potential for error propagation. However, all together, these statistics suggest that the individual land cover maps are of high quality.

Table 3. Summary of classification accuracies (%) for 2000 and 2010

	2000		**2010**	
	User's	**Producer's**	**User's**	**Producer's**
Built-up	96	93	98	93
Seasonally flooded	N/A	N/A	100	96
Trees	94	88	84	91
Crop land & grasses	95	96	96	93
Water	92	100	90	98
Total accuracy	94		94	
Kappa statistic	0.92		0.92	

Based on the unsupervised classification results, the dominant land cover in 2000 and 2010 was crop land and grasses; however, the area covered by this cover decreased 19 percent over the decade (Table 4). All other land cover classes increased over the same period. A total of 82 km^2 of new built-up land was observed in 2010, a 25 percent increase relative to 2000. This corresponds to an average annual growth rate of 8.2 km^2 for the decade.

The largest percent change in land cover was observed for water, which increased 37 percent. This is likely caused by high precipitation levels in 2010 that resulted in the swelling of natural waterways such as Saylorville Lake and the Des Moines River.

Table 4. Summary of land cover area statistics for 2000 and 2010

	Area (km^2)		**Change 2000 to 2010**	
	2000	**2010***	**Absolute (km^2)**	**Relative (%)**
Built-up	327	409	+82	+25
Seasonally flooded	0	24	+24	–
Trees	177	197	+20	+11
Crop land & grasses	762	619	-143	-19
Water	38	52	+14	+37

*A 4 km^2 area was obscured by cloud and cloud shadow in 2010

As seen in the final land cover maps (Figure 2), in both 2000 and 2010, the greater Des Moines region had a compact urban core surrounded by lower density built-up lands in peri-urban and rural areas. The core urban area corresponds to the City of Des Moines, and to a lesser degree, West Des Moines. Surrounding this urban core were lower density built-up lands in the peri-urban region (e.g. suburbs of Clive and Urbandale to the west), and in several outlying cities (e.g. Ankeny to the north and Altoona to the northeast). Rural built-up land also existed beyond the peri-urban fringe. Based on visual comparison of the two maps, much of the new development occurred radially outward in the peri-urban regions.

In both 2000 and 2010, tree cover was observed scattered throughout the urban and peri-urban areas, adjacent to water bodies, and in a few other open space areas (Figure 2). Crop land and grasses were observed throughout the region, especially in the rural areas, but also interspersed with built-up lands in the form of lawns and other fields. Finally, in 2010, high summer precipitation levels caused flooding along the Des Moines River and its smaller tributaries. Effects of the flooding were observed in the 2010 summer Landsat images and identified as separate spectral classes during the classification procedure (Figure 2).

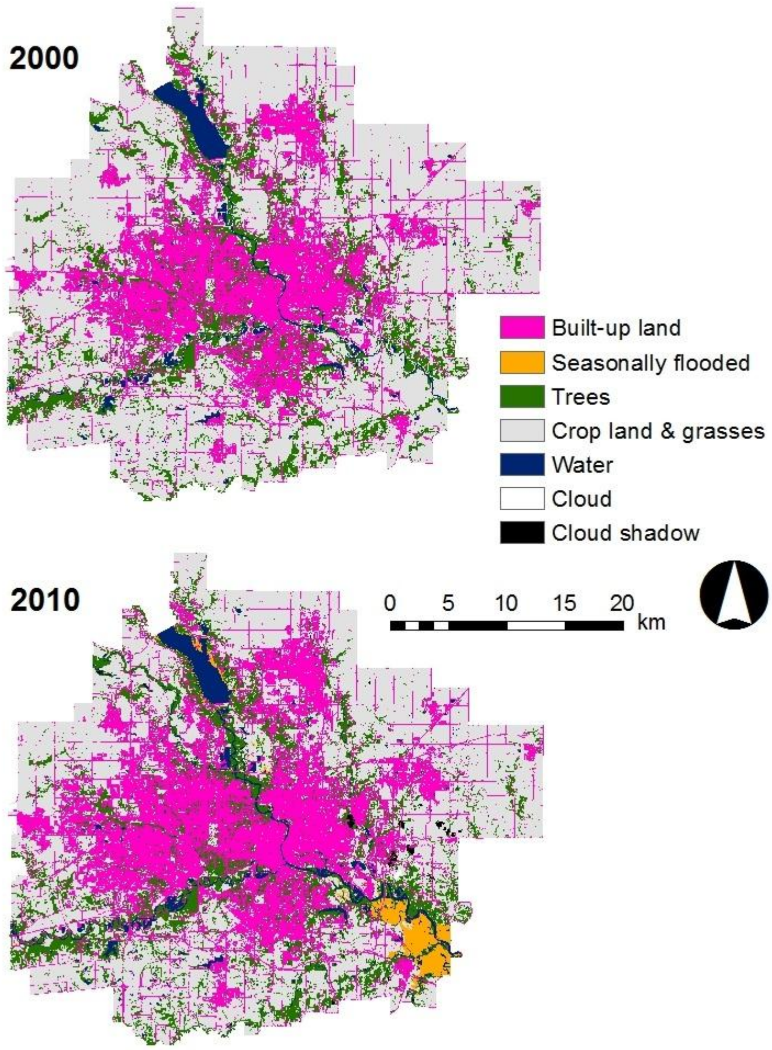

Figure 2. Final land cover maps of the greater Des Moines region for 2000 and 2010 based on Landsat images and ancillary road data.

3.2. New Development

As explained above, we used a five stage process to identify robustly classified new development pixels for use in our zoning analysis. First, we computed a post-classification change matrix from the final 2000 and 2010 land cover maps. Second, we extracted all pixels that were built-up land in

2010 but undeveloped in 2000 and labeled these “new development”. Third, we assessed the accuracy of the new development pixels and found that the estimated total accuracy was 85 percent with a Kappa statistic of 0.71 (Table 5).

These relatively low accuracy statistics were likely caused by error propagation through the two maps, but are well within the range of change detection errors reported in the literature (e.g. see Alberti et al. 2004, and Yuan et al. 2005). However, we were particularly concerned with the low user’s accuracy for new development pixels, which indicates an estimated 28 percent of the pixels were erroneously labeled “new development”.

Table 5. New development error matrix for 2000 to 2010

Classification	Reference data		User’s accuracy (%)
	New development	No development	
New development	273	106	72
No development	6	378	98
Producer’s accuracy (%)	98	78	
Total accuracy: 85%	Kappa statistic: 0.71		

Since our zoning analyses required robust new development data, we refined the change map in two final stages. In the fourth stage, MSPA was used to partition the new development pixels into seven morphological classes according to their shape and form (Figure 3). Finally, in the fifth stage we determined which morphological categories the erroneously identified pixels belonged to, and compared these to the MSPA output and full sample of validation pixels.

As shown in Figure 3, only ~40 percent of all new development and validation pixels were islets, while over 90 percent of the erroneous pixels were islets. These occurred primarily in regions where “mixed pixels” were observed and expected (i.e. low density built-up land, rural roads, etc.). Mixed pixels are cells in which more than one land cover are present in the 30 m by 30 m area.

Based on Chi-square tests, the percentage of erroneous pixels in the morphological classes were significantly different than the percentages of validation pixels in each class ($p<0.001$).[2] These results illustrate that

[2] Distributions of erroneous pixels versus all new development pixels were also significantly different ($p<0.001$), but there was no difference between validation pixels and all new development pixels ($p=0.967$).

some morphological classes were overrepresented (i.e. islet) and others were underrepresented in the erroneous pixels.

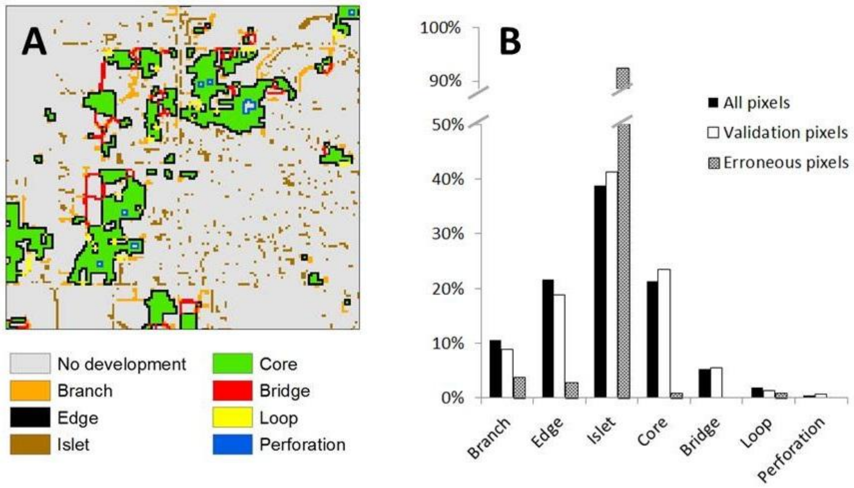

Figure 3. A) Example of MSPA output for a subset of the study area illustrating classification of new development pixels into the seven different morphological classes. B) Graph showing the percentage of pixels in each morphological class for all new development pixels (All), validation pixels randomly selected for the change accuracy assessment (Validation), and validation pixels found to be erroneously labeled new development (Erroneous).

To account for the apparent overrepresentation of erroneous islet pixels, we removed all pixels belonging to this class from the new development results. This resulted in a 40 percent reduction of land classified as new development, a decrease from 82 km^2 to 50 km^2. We believe this approach was warranted despite the fact that the sample did not include all erroneous pixels, and also included correctly identified new development. To illustrate, total accuracy of the new development data increased to 95 percent with a Kappa of 0.91 when the erroneous islet pixels were removed from the results. Likewise, user's accuracy of new development increased to 92 percent, and the producer's accuracy of no development increased to 93 percent.

3.3. Development and zoning

The second objective of this paper was to analyze the types of zoning categories in which new development occurred. We addressed this by computing zonal statistics for new development within the 24 zones included in the RUZ. To help make sense of overall patterns of development, we also calculated the area of built-up and "vacant" land (union of the tree and crop land/grass covers) by zoning category. These calculations were repeated for municipalities within the study area. Results for the five zoning categories and five municipalities with the greatest share of new development are presented in Figure 4 and Tables 6 and 7 and below.

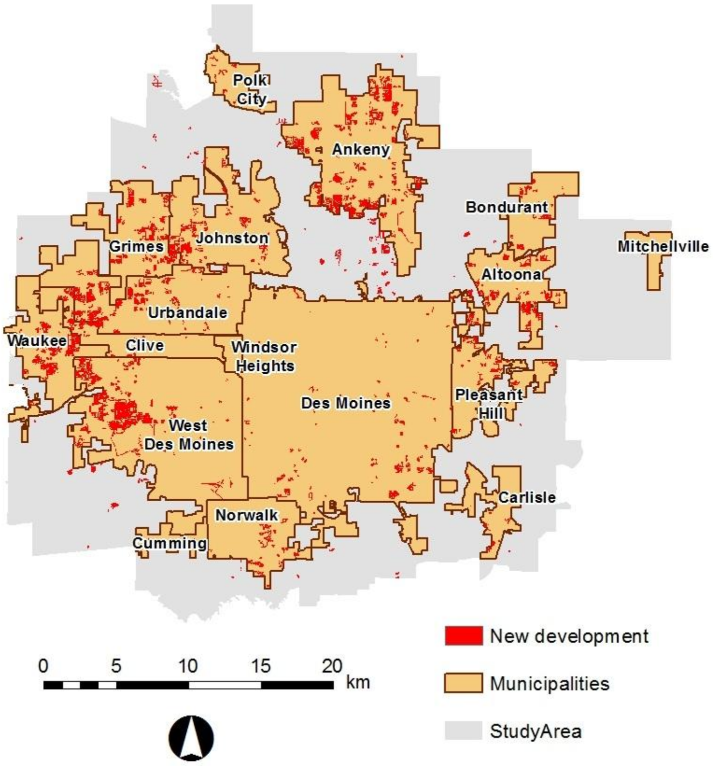

Figure 4. Map of new development identified for 2000-2010 overlaid on municipality boundaries in the study area.

As expected, the greatest share of new development in the ten-year period took place in Des Moines' growing northern and western suburbs. As shown in Table 6, Ankeny had the largest total share of new development at nearly 37 percent. This was followed by West Des Moines, Urbandale, Johnston, and Waukee. Together they accounted for ~65 percent of all new growth in the region, but only ~24 percent of land area in the region. In 2000, all five municipalities were a mix of vacant and built-up land, and together were home to only ~22 percent of vacant land in the study area.

Table 6. Summary of land cover statistics for the five municipalities that had the largest shares of new development

Municipality	Percentage of total for the study area: New development 2000-2010	All land	Vacant land 2000
Ankeny	20.3	5.8	5.5
West Des Moines	18.3	7.8	6.6
Urbandale	11.5	4.4	3.6
Johnston	7.7	3.6	3.4
Waukee	7.5	2.3	2.5

Table 7. Summary of land cover for the five zoning categories that had the largest shares of new development

Generalized zoning category*	Percentage of total for the study area: New development 2000-2010	All land	Vacant land 2000
PUD_MU	36.9	6.9	6.8
R-2	19.3	11.3	9.7
Not defined	9.2	10.5	9.0
M-1	6.4	3.1	2.2
R-5	5.2	2.1	2.2

*Full descriptions can be found in table 2 above.

Some of these suburbs - West Des Moines, Urbandale, and Ankeny – were known to make extensive use of PUDs to direct the density, form and mix of uses in new development (personal communication). Indeed, PUD_MU received the highest share of new development, followed by R-2, M-1, and R-5. As well, over 9 percent of total new development occurred in areas with no defined zoning (Table 7). In total, ~77 percent of all new development in the study area occurred in these five categories, even though they make up only ~34 percent of the study area. In regards to the state of the land in 2000, the five categories were home to less than 30 percent of all the vacant land in 2000. These observations are important because they suggest that development in these locations was purposeful. In other words, development did not just occur here because there was no other vacant land on which to build.

4. Conclusions and Recommendations

In this paper we combined a variety of spatial methodological steps to understand metropolitan growth in Greater Des Moines, relying mostly on remote sensing techniques. Our remote sensing analyses exhibited very high accuracy. Both the 2000 and 2010 land cover classifications had total accuracies of 94 percent. As well, the use of selected morphological categories to refine a new development map also contributed to an estimated user's accuracy of 96 percent for this important land cover transition. With these indicators in mind, the conclusions and recommendations presented below can be taken with confidence.

During the period of study (2000-2010), there was a 15% increase in the built-up area of the region, and a decrease in crop land & grass land cover. The majority of new development occurred in the peri-urban region, principally in the western and northern suburbs. Likewise, most development appeared to be in the form of urban expansion. However, it is important to note that we did not explicitly test for or address infill development in our analyses.

Five communities experienced most of the new development: Ankeny, West Des Moines, Urbandale, Johnston, and Waukee. Our results suggest that development in these communities was purposeful; development did not happen in these locations simply because there was nowhere else to build. Extraneous factors such as population pressure and changes in the economic structure of the region affect spatial patterns of development (York and Munroe 2010). This is an important area that should be targeted for future research.

Considering the types of zoning categories in which new development occurred, the results were not surprising. PUDs, which are a special category of zoning that provide a lot of flexibility to the city and developers, was the predominant class. One of the limitations of our work was that we were unable to incorporate information about zoning code dates and recent changes. As a consequence we could not infer what role zoning played in farm land preservation.

In creating the RUZ we observed that there is a mosaic of local governments working independently to plan for their own future growth. This may confirm that there is no horizontal collaboration with vertical power in the region. There are already indications that the Tomorrow Plan will not create a future regional land use (personal communication). This means it is very unlikely that component localities will undertake land use and zoning reforms. At the time of writing this paper it is difficult to say with any confidence that the Tomorrow Plan will result in a more robust regional approach to land use planning and regulation. It is more likely that the plan will act as a catalyst for further conversations about collaboration among the region's municipalities.

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