Journal of Maps
Vol. 8, No. 4, December 2012, 327–333

SOCIAL SCIENCE

A tale of two land uses in the American West: rural residential growth and energy development

Timothy J. Assal[a*] and Jessica M. Montag[b]

[a]*U.S. Geological Survey, Fort Collins Science Center, Fort Collins, Colorado, USA;* [b]*Graduate Degree Program in Ecology, Colorado State University, Fort Collins, Colorado, USA*

(*Received 26 March 2012; Resubmitted 24 October 2012; Accepted 29 October 2012*)

This paper describes a spatiotemporal land use map for a rural county in the western United States. Sublette County, Wyoming has undergone recent land use change in the form of heightened rural residential development on private land and increased energy development on both public and private land. In this study we integrate energy production data, population census data, ownership parcel data, and a series of Landsat Thematic Mapper and Enhanced Thematic Mapper scenes (over a 25-year period) to create a map that illustrates the changing landscape. Spatial change on the landscape is mapped at 30 square meters, congruent with a Landsat pixel. Sublette County has a wealth of wildlife and associated habitat which is affected by both types of growth. While we do not attempt to quantify the effect of disturbance on wildlife species, we believe our results can provide important baseline data that can be incorporated into land use planning and ecological-wildlife research at the landscape scale.

Keywords: rural; energy; development; landsat

1. Introduction

Past research on energy development in rural areas have indicated that during ‘boom’ times there is increased community growth as energy development increases (Helmericks, 1994; Isserman & Merrifield, 1987). While this research has discussed these patterns, spatially explicit data on this phenomenon rarely exist (Shrestha & Conway, 2011). In this article we utilize Sublette County, Wyoming (Figure 1) to spatially and temporally examine rural residential growth and energy development over a 25-year period by combining coarse filter (well data, parcel data) and fine-scale (remote sensing) approaches. Specifically, in our analysis we integrate energy production data, population census data, ownership parcel data, and a series of Landsat Thematic Mapper and Enhanced Thematic Mapper scenes to create a map that illustrates the changing landscape. The results serve as important baseline data that can be incorporated into land use planning and ecological-wildlife research at the landscape scale (Radeloff, Hammer, & Stewart, 2005; Theobald, 2004).

Sublette County, Wyoming provides an excellent area for analysis given its rural nature, the patchwork of public and private lands, the world-class wildlife that exists there and the increasing amount of energy development that is occurring. The County covers 1295 square kilometers of diverse topography and land cover given that it is bounded by the Wind River Mountains and the North American Continental Divide on the north and east sides while Bridger-Teton National Forest bounds it on both the west and east sides. Eighty percent of Sublette County is under public land ownership with the remaining 20% of private land ownership occurring largely along valley bottoms and state highway corridors. Higher elevation land cover is dominated by coniferous forests while the lower elevation land cover is dominated by sagebrush, aspen and riparian areas. A recent study found that Wyoming big sagebrush was the most

*Corresponding author. Email: assalt@usgs.gov

ISSN 1744-5647 online

http://dx.doi.org/10.1080/17445647.2012.745381
http://www.tandfonline.com

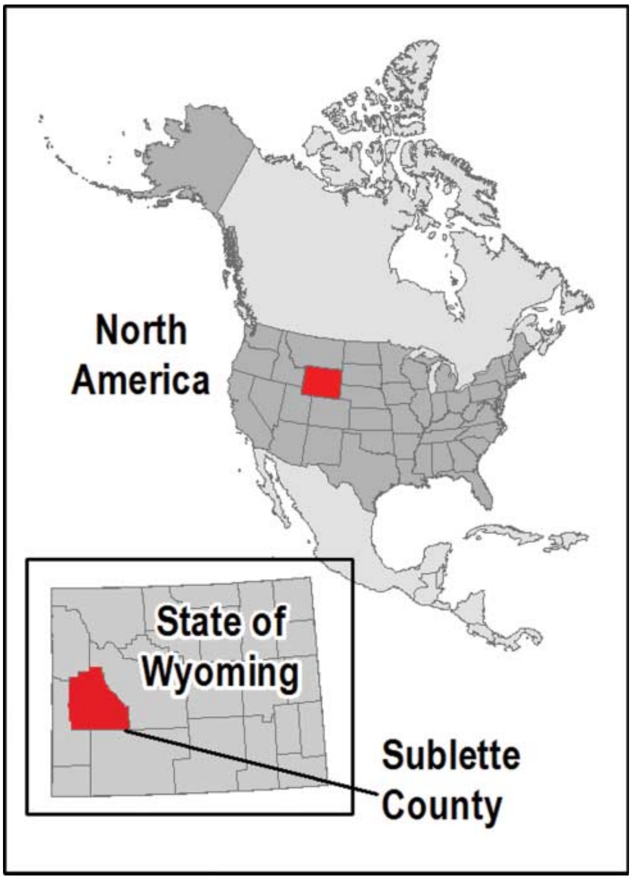


Figure 1. Vicinity map of Sublette County, Wyoming.

impacted landcover type in one of Sublette County's natural gas fields (Walston, Cantwell, & Krummel, 2009).

The land cover in Sublette County provides critical winter, summer, and migration habitat for ungulates (mule deer, pronghorn, moose*, elk, bighorn sheep*) as well as habitat for a variety of other species (grizzly bear, wolf, Canada lynx*, pygmy rabbit*, snowshoe hare, greater sage-grouse*, northern goshawk*, boreal owl* and many more) (Wyoming Game and Fish Department, 2010). The asterisked species are species of greatest conservation need (SGCN), as designated by the Wyoming Game and Fish Department, which are found within the county. SGCN merit more focused management and consideration in land use (Wyoming Game and Fish Department, 2010), hence SGCN provide a basis for the discussion of the value of understanding the spatial extent of rural residential growth and energy development.

The County has a population of 10,247 (US Census, 2010a) with 36% of the population residing in the towns of Big Piney, Marbelton, and Pinedale. The remaining 64% reside in unincorporated areas which we refer to as areas for possible rural residential growth. We are using the US Census definition of rural, meaning all areas outside of 2500 or more people (US Census, 2010b). Although none of the towns mentioned above have a population greater than 2500, we are focused on the rural areas outside of the towns. There has been a 125% increase in population from 1980 to 2010, with the population expected to grow over 70% by 2030 (Wyoming Department of Administration and Information, 2010).

In addition to increasing population and the associated residential rural growth that goes with it, energy development, as determined by the number of producing wells, has increased by 588% from 1980 to 2010 within Sublette County (Wyoming Oil and Gas Conservation Commission, 2012). Much of the increased energy production has occurred in two Natural Gas Fields, Jonah and the Pinedale Anticline (PAPA). The remaining portion of this paper outlines and illustrates how we have attempted to show the changes in rural residential growth and energy development.

2. Methods

2.1 *Satellite imagery*

We used Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) for our analysis because the imagery provides fine-scale spatial resolution (30-meter pixels), a long temporal record (the archive extends from 1984 to the present) and has a large ground footprint (185 km swath) that covers the majority of Sublette County in one scene. Furthermore, Landsat data are available from the United States Geological Survey's EarthExplorer archive (US Geological Survey, 2010) at no cost. We conducted a search of the EarthExplorer archive to acquire cloud-free scenes during the same time of year (June–August). Six scenes were acquired over a 25-year time frame, effectively creating five time periods for which analysis was conducted (Table 1). All of the scenes obtained were preprocessed by the US Geological Survey to level 1T (terrain corrected data). The footprint of this image series covers the vast majority of Sublette County including the two energy fields of interest and all but four residential parcels. We omitted acquisition of an additional six images to minimize analysis time and the complications of obtaining adjacent temporal imagery.

Radiometric calibration of imagery is an important step for creating a consistent, high-quality temporal image series for use in change detection analysis. We converted Bands 1–5 and 7 of each image (Band 6, 60 m thermal band was omitted) from Digital Numbers to absolute units of at-sensor spectral radiance. The spectral radiance values were converted to Top-Of-Atmosphere reflectance (Chander, Markham, & Helder, 2009) to account for differences in sensor and viewing angle. We did not apply an absolute atmospheric correction or relative normalization between images because there did not appear to be any obvious cloud cover and we did not feel this process was necessary for the edge detection methods to be used later.

Ground control points were selected from 2009 aerial photography (considered truth in this analysis) and geometric registration of each image was considered. All images were registered and snapped to the 2009 Landsat image with a root mean square error of less than 0.5 pixels.

We conducted exploratory analysis of various image processing functions to determine which would provide the best detection of development in our analysis using Landsat data. Since both residential and energy development create linear disturbances on the landscape, we used a non-directional edge enhancement algorithm on each image. The non-directional edge enhancement algorithm creates an output for each of the six bands associated with each image. After assessing the utility of each band edge image, we decided to retain all six bands for maximum information about the landscape and summed for each year to create a yearly edge image. Both natural (e.g. rock outcrops, streams, vegetation patches, etc.) and anthropogenic (e.g. roads, well pads, driveways, fence lines, agricultural fields, etc.) features are identified in the edge enhancement process. We reasoned that by comparing each image date with the subsequent image date that this would cancel out natural edge features leaving only the artificial edge features created on the landscape during that time period.

2.2 *GIS data*

In an effort to reduce noise in the edge detection data, we created a coarse filter using GIS data for both the rural residential and energy development analyses. Several factors contribute to noise in these data. Legitimate edge changes over time include the changing extent of irrigated agriculture fields or vegetation differences due to timing of vegetation green-up. For example, the only image available for 1984 was acquired in early June before peak green up for vegetation. We obtained parcel ownership data from the Sublette County GIS Server (Sublette County, 2010) and removed parcels located within the town limits of Pinedale, Marbleton and Big Piney, so that the rural residential parcels remained. We then queried the parcel database for residential property types and parsed the data into the five time periods based on the 'year built' attribute (e.g. Period 5 = year built

Table 1. Satellite imagery sensor types, scene information and acquisition date used in the analysis.

Satellite	Sensor	Scene Path/Row	Acquisition date (year-month-day)
Landsat 5	Thematic Mapper	37/30	19840602
Landsat 5	Thematic Mapper	37/30	19890718
Landsat 5	Thematic Mapper	37/30	19940716
Landsat 7	Enhanced Thematic Mapper +	37/30	19990706
Landsat 5	Thematic Mapper	37/30	20050831
Landsat 5	Thematic Mapper	37/30	20090709

between 2005 and 2009). The assumption was made that a structure or some type of land change occurred in the year indicated by this attribute. A qualitative assessment of 2009 aerial photos and the satellite imagery indicated that this was a fairly safe assumption. Residential parcels that were built on earlier than 1984 were omitted as well as four parcels from the southern part of the County. These outlier parcels were outside of the footprint of the Landsat scenes acquired, and were omitted to reduce imagery acquisition and processing time. The residential parcel footprint data set for each time period was used as the mask to confine the change detection analysis.

We obtained a geodatabase of Wyoming energy well activity (identified as point features) from 1900 to 2010 for this analysis (Biewick, 2011). All oil and gas well types were subset for the Jonah and PAPA Natural Gas Fields separately. For both energy fields, the wells were assigned to one of the five time periods based on the 'start year' attribute. A qualitative analysis of energy wells and 2009 aerial photos indicated that a 200-meter buffer around each well point was appropriate to capture the footprint of the disturbance associated with each well. The buffered well data for each time period served as the mask to confine the change detection analysis.

2.3 *Change detection analysis*

In an effort to minimize differences between each time period, each respective edge stack was scaled so that the maximum edge value did not exceed a value of one for each time period (Table 2). This was accomplished by dividing the edge image by the maximum value associated with that time period. Next, image differences were created by subtracting each adjacent time period (e.g. Period $5_{\text{edge difference}} = 2009_{\text{edge}} - 2005_{\text{edge}}$). To objectively measure change across time periods, we classified change as pixels with a value greater than one positive standard deviation from the mean (Figure 2). Pixel values that hover within one standard deviation of the mean typically do not represent real change. Pixel values that dramatically increased in edge value between time periods will be represented in the right tail of the histogram. This was calculated for each time period and the classification was applied to the area within each respective area (i.e. residential parcels, Jonah and PAPA energy fields).

3. Conclusions

3.1 *Sublette County development map*

Compilation of the change data for each time period for both the rural residential development and energy development analyses represents the combined development map for these areas of Sublette County. We present results on the amount of added units (wells and rural residential parcels) with the amount of classified change area (Table 2, Figure 3). The results indicate that the area of disturbed footprint measured from changes in the edge metric correlate well with the number of additional houses and energy wells added to the landscape. Furthermore, the amount of change on the landscape markedly increased during the last 10 years of this study (1999–2009) which correlate to time periods four and five. The amount of rural residential parcels developed on the landscape nearly doubled during this time period. The number of wells located in both energy fields increased nearly tenfold between periods three and four, with another large increase between periods four and five. The results also indicate that the area of change associated with each energy field is substantially larger than rural residential development. The map clearly indicates that the Jonah energy field is more densely developed than the PAPA. Although concentrated in small areas, the impact from rural residential development is much less obvious on the landscape at the county level.

Given the diverse habitats and wildlife species that occur in Sublette County, the ability to detect change in increased energy development and rural residential growth provides baseline data in which wildlife resource

Table 2. Results of the change detection analysis.

		Residential development		Jonah development		PAPA development	
Time period	Image dates	No. of parcels	Area km^2	No. of Wells	Area km^2	No. of Wells	Area km^2
1	1984–1988	155	0.77	2	0.1	10	0.0
2	1989–1993	328	2.36	6	0.25	10	0.0
3	1994–1998	577	4.97	107	5.03	27	0.76
4	1999–2004	1065	6.79	557	11.46	370	12.34
5	2005–2009	2039	13.04	1583	28.16	1871	24.78

Figure 2. A hypothetical histogram of an image edge difference between two time periods. The red lines indicate one standard deviation on either side of the mean (not shown). In this analysis, pixels located in the right tail of the histogram represent increasing edge in the landscape, indicative of disturbance.

managers and researchers can overlay spatial wildlife population or habitat data. This can be especially useful for species migration in order to highlight potential areas of overlap. While we did not add this additional analysis, we believe that our baseline data would be useful.

3.2 *Challenges and future work*

A rigorous accuracy assessment was not conducted at this time. The main challenge with this effort is the lack of spatially explicit mapped data for the entities over time (i.e. home and energy development footprints). Furthermore, aerial photos do not exist at each time period. A qualitative assessment of time period five was conducted using 2009 and 2006 aerial photos (in lieu of 2005 imagery which was unavailable). This assessment indicated that these methods worked very well for identifying the footprint of disturbance associated with energy wells. Application of the GIS mask reduces noise in the change detection data. However, since it limits change to the 200-meter buffer around well points, it is susceptible to missing change associated with new roads located outside of the well buffer. Results were not as strong, but still promising for this method applied to mapping rural residential development. Although the exact footprint was not captured as clearly as with the energy development, this method shows great promise for flagging areas of change (Figure 4). This could be viewed as a coarse filter approach to identify hot spots of change, upon which ground visits or analysis of aerial photos could be supplemented if more rigorous results are desired (if available).

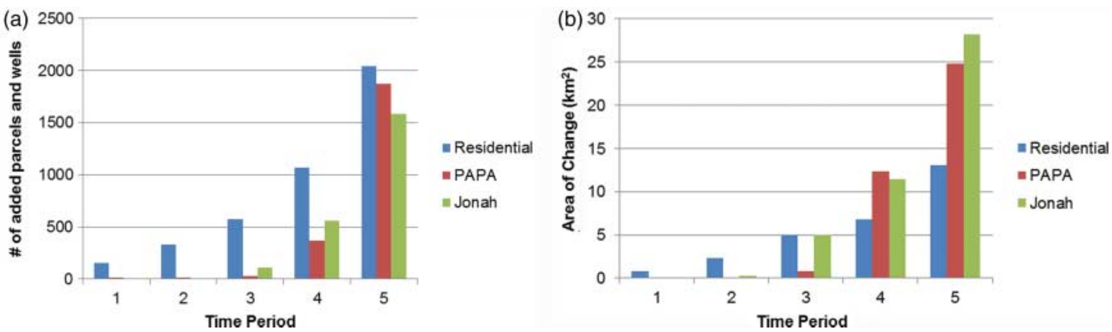


Figure 3. The number of added units (residential parcels or wells) during each period (left) and the amount of classified change for each group over time (right).

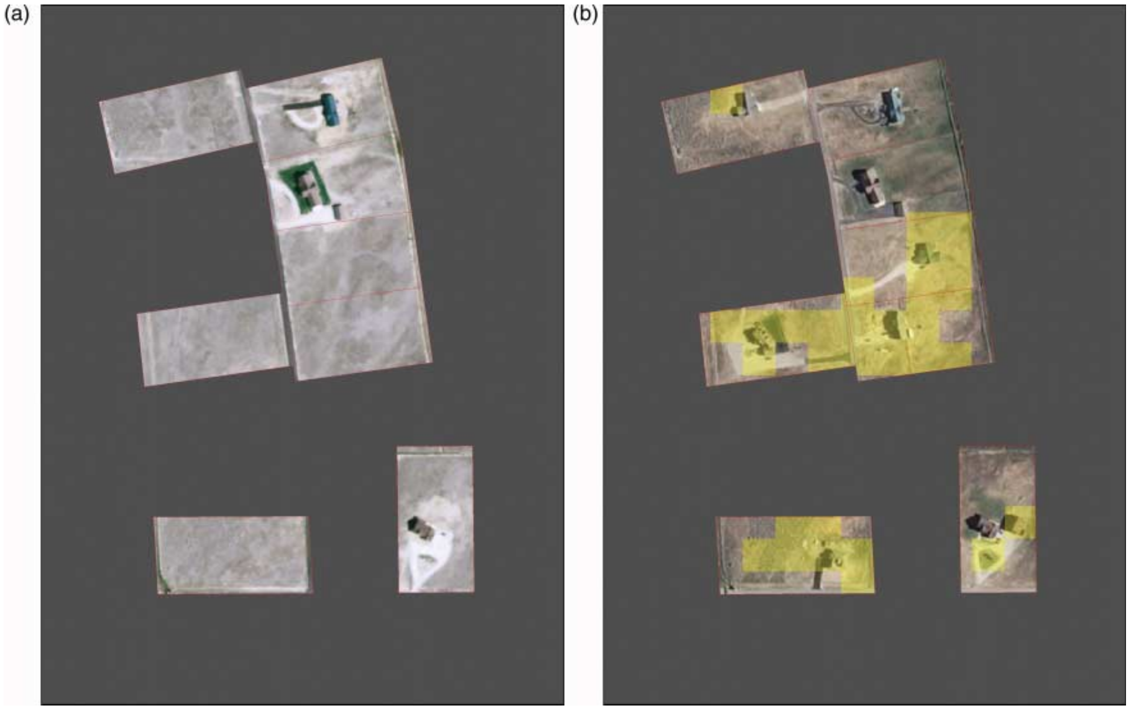


Figure 4. Eight parcels that were built on in time period five are displayed with 2006 aerial photo (left) and 2009 aerial photo (right). Yellow pixels in right image correspond to 30 m^2 Landsat pixels classified as new rural development change during that time period. New development or additional structures in six of the eight parcels was identified correctly. No change was identified in the two parcels in top right. These were possibly misclassified, incorrectly attributed in the GIS database or built in the time period between satellite image (August 2005) and aerial photo (September 2006) acquisition. Aerial photos obtained from US Department of Agriculture Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/). Area outside of parcels is shaded gray to provide anonymity.
Note: The analysis is cumulative over time.

A preliminary comparison of the number of units (e.g. wells or residential parcels) with the amount of landscape change (e.g. pixels or acreage) indicates that a strong linear relationship ($R^2 > 0.84$) exists between the number of wells or residential parcels and the amount of landscape change. However, the development of a landscape model was not the intent of our work at this time and a more rigorous accuracy assessment should be conducted on these methods before future work is implemented in this realm. If satisfactory results are obtained this could prove very useful for developing a method to model the amount of expected landscape change given an increase in wells or residential parcels.

Software

The GIS analysis was conducted in ESRI ArcMap 10. The satellite imagery processing and creation of edge maps were conducted using ERDAS Imagine version 11 software. Graphs were produced using Microsoft Excel. The map was also produced using ESRI ArcMap 10.

Acknowledgements

We would like to thank the US Geological Survey and other Wyoming Landscape Conservation Initiative (www.wlci.gov) partners for providing logistical support for this project. We thank Robert McDougal, Cynthia Melcher, Janine Powell and three anonymous reviewers for helpful comments and revisions to the article.

References

Biewick, L.R. H. (2011). Geodatabase of Wyoming statewide oil and gas drilling activity to 2010. U.S. Geological Survey Data Series 625.

Chander, G., Markham, B.L., & Helder, D.L. (2009). Remote Sensing of Environment Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, *113,* 893–903. doi: 10.1016/j.rse.2009.01.007

Helmericks, S.G. (1994). Social and attitudinal change in a boomtown: Craig, Colorado 1970-1990. Thesis PhD, Colorado State University, p. 419.

Isserman, A.M., & Merrifield, J.D. (1987). Quasi-experimental control group methods for regional analysis: An application to an energy boomtown and growth pole theory. *Economic Geography*, *63,* 3–19. doi: 10.2307/143847

Radeloff, V.C., Hammer, R.B., & Stewart, S.I. (2005). Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and its relation to forest fragmentation. *Conservation Biology*, *19,* 793–805. doi: 10.1111/j.1523-1739.2005.00387.x

Shrestha, N., & Conway, T.M. (2011). Delineating an exurban development footprint using SPOT imagery and ancillary data. *Applied Geography*, *31,* 171–180.

Sublette County (2010). Sublette County GIS Server. Retrieved November 15, 2010, from http://records.sublettewyo.com/mapserver/map

Theobald, D.M. (2004). Placing exurban land-use change in a human modification framework. *Frontiers in Ecology and the Environment*, *2,* 139–144.

U.S. Census (2010a). Table DP-1-Profile of general population and housing characteristics: 2010, Retrieved February 2, 2012, from http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?fpt=table

U.S. Census (2010b). 2010 Census urban and rural classification and urban area criteria. Retrieved September 1, 2011, from http://www.census.gov/geo/www/ua/2010urbanruralclass.html

U.S. Department of Agriculture (2010). Geospatial gateway. Retrieved December 15, 2011, from http://datagateway.nrcs.usda.gov/

U.S. Geological Survey (2010). EarthExplorer archive. Retrieved December 15, 2011, from http://edcsns17.cr.usgs.gov/NewEarthExplorer/

Walston, L.J., Cantwell, B.L., & Krummel, J.R. (2009). Quantifying spatiotemporal changes in a sagebrush ecosystem in relation to energy development. *Ecography*, *32,* 943–952. doi: 10.1111/j.1600-0587.2009.05852.x

Wyoming Department of Administration and Information (2010). Population for Wyoming, counties, cities, and towns: 2010 to 2030. Retrieved February 2, 2012, from http://eadiv.state.wy.us/pop/wyc&sc30.htm

Wyoming Game and Fish Department (2010). Wyoming Game and Fish Department, Cheyenne, WY. Retrieved February 3, 2012, from http://gf.state.wy.us/web2011/wildlife-1000407.aspx

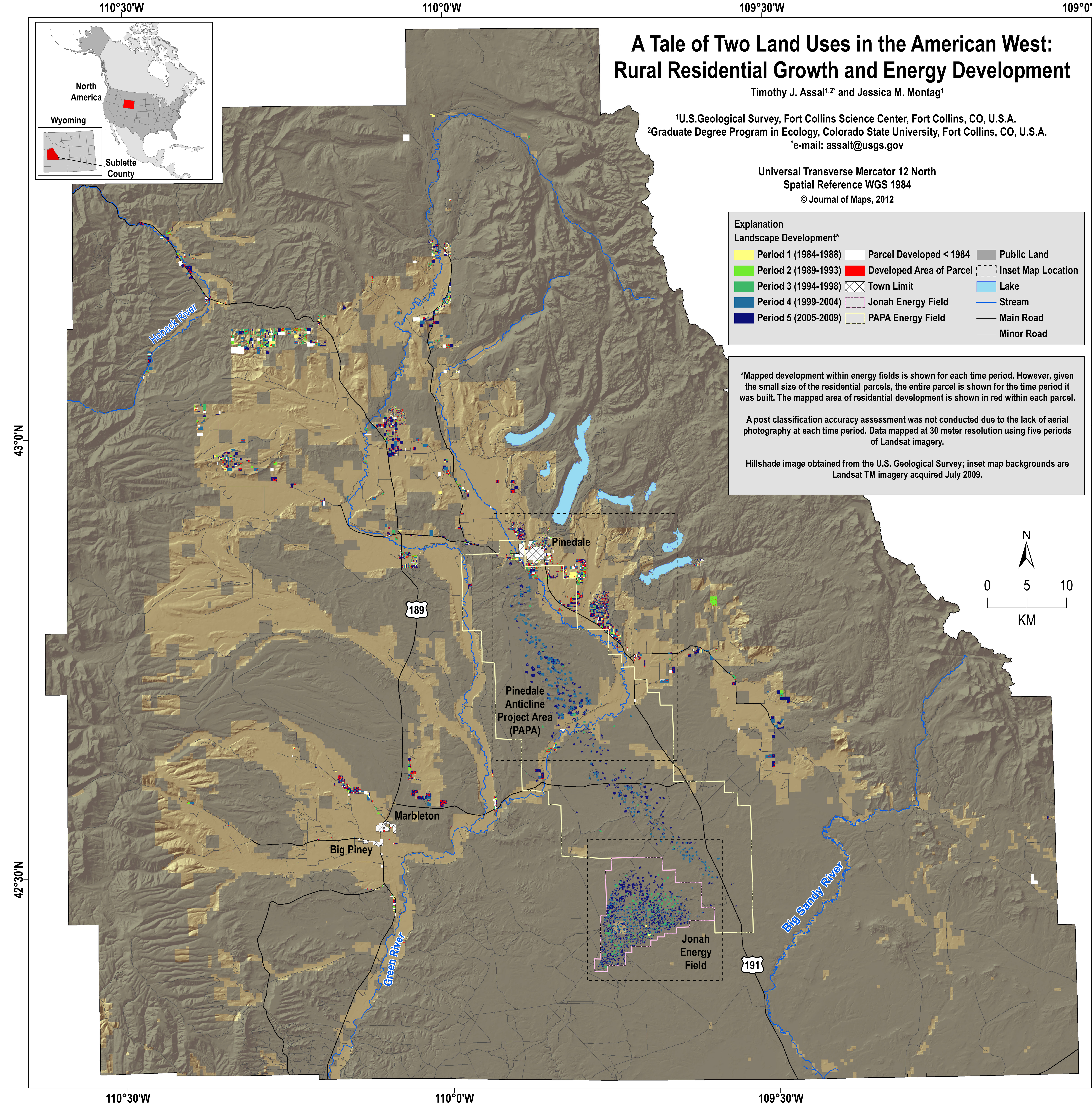
Wyoming Oil and Gas Conservation Commission (2012). Wyoming oil and gas conservation commission. Retrieved February 3, 2012, from http://wogcc.state.wy.us/

A Tale of Two Land Uses in the American West: Rural Residential Growth and Energy Development

Timothy J. Assal[1,2*] and Jessica M. Montag[1]

[1]U.S.Geological Survey, Fort Collins Science Center, Fort Collins, CO, U.S.A.
[2]Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO, U.S.A.
*e-mail: assalt@usgs.gov

Universal Transverse Mercator 12 North
Spatial Reference WGS 1984



Explanation

Landscape Development*

- Period 1 (1984-1988)
- Period 2 (1989-1993)
- Period 3 (1994-1998)
- Period 4 (1999-2004)
- Period 5 (2005-2009)
- Parcel Developed < 1984
- Developed Area of Parcel
- Town Limit
- Jonah Energy Field
- PAPA Energy Field
- Public Land
- Inset Map Location
- Lake
- Stream
- Main Road
- Minor Road

*Mapped development within energy fields is shown for each time period. However, given the small size of the residential parcels, the entire parcel is shown for the time period it was built. The mapped area of residential development is shown in red within each parcel.

A post classification accuracy assessment was not conducted due to the lack of aerial photography at each time period. Data mapped at 30 meter resolution using five periods of Landsat imagery.

Hillshade image obtained from the U.S. Geological Survey; inset map backgrounds are Landsat TM imagery acquired July 2009.