Effects of Urbanization on Ecological Services in a Semi-Arid Region of the United States

Year 1 Project Report

for

NASA Land Cover-Land Use Change Program (NRA-00-OES-08

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Abstract

Changes with land cover and land use are closely integrated with water processes at the land surface. Nowhere is that more apparent than in the Edwards aquifer region of south-central Texas. The Edwards aquifer covers approximately 4,350 square miles in parts of 12 counties in Texas and includes San Antonio and Austin, the nation's eighth and nineteenth largest cities, respectively. Water is discharged at several natural points and through hundreds of pumping wells, particularly municipal supply wells in the San Antonio region and irrigation wells in the western extent. Because of its highly permeable nature in the fresh water zone, the Edwards aquifer responds quickly to changes and extremes of stress placed on the system. The semi-arid climate and highly variable rainfall in the region create large differences in recharge and discharge rates from year to year.

Population growth in this region has been high with county population increases (1990 – 1999) ranging from 11.1% in Kinney County to 72.6% in Williamson County. While this growth has directly increased the demand on the aquifer, of greater significance has been the impact on the region's ecological services. Of particular interest is the dynamic between water resources, carbon sequestration, and wildlife habitat. For example, reduction of brush and other woody plants in the Edwards aquifer recharge zone has been shown to increase water resources in the artesian zone, where the water is discharged for public use. However, the elimination of woody plants reduces wildlife habitat. Additionally, the increased biomass of woody plants sequesters more carbon than the grasslands that would replace them, so brush removal reduces sequestration of carbon. Clearly the goals of increasing water availability, increasing carbon sequestration, and increasing wildlife habitat are in conflict. Policy instruments have addressed these conflicting goals individually and as a result have failed to achieve a sustainable balance between them.

The overall goal of the research is to determine the impacts of past land cover and land use change (LCLUC) on regional ecological services and to apply that knowledge to evaluate public policy instruments to enhance these services in the future. Specific ecological services targeted are water resources, vegetation for carbon sequestration, and refugia for wildlife habitat. A strong multi-disciplinary research team has been assembled to accomplish this goal through evaluation of LCLUC in the region from LANDSAT satellite images, determination of the changes in ecological services arising from LCLUC, utilization of spatial information from these analyses to establish and evaluate different policy instruments to control LCLUC, and optimization of policies to maximize ecological services through management of LCLUC. The outcome of this research will be an understanding of LCLUC and the effects on ecological services in a semi-arid region, a determination of the effectiveness of policies to enhance ecological services, and an optimization of ecological services through policies that appropriately manage LCLUC.

Keywords: Agriculture; Image Processing; Land Cover Classification; Rangeland Management; Runoff, Streamflow; Urbanization; Water Management; North America; Savanna; Semi-arid; LANDSAT; Regional Scale; Time Series Analysis

Questions, Goals, and Approaches

NASA ESE Scientific Questions

This project is addressing three of NASA's ESE scientific questions:

Where are land cover and land use changing, what is the extent and over what time scale?

Juniper and mesquite encroachment in rangelands in the drainage area and urbanization has been shown to have a significant effect on aquifer recharge. **Change detection** of LANDSAT images will be used to determine the amount and rate of brush encroachment (**carbon sequestration**) and urbanization (**human dimension**) in the region over the past 30 years. (25% effort)

What are the causes and what are the consequences of LCLUC?

The consequences of LCLUC in the aquifer drainage and recharge zones on surface water hydrology and aquifer recharge will be modeled for each watershed in the region so that an overall impact on **water availability** can be determined. (25% effort)

The consequences of LCLUC on ecosystem services (e.g. **carbon** sequestration, **water** availability, **wildlife** refugia) will be evaluated from a socio-economic basis. The **social science** basis is essential in establishing effective strategies to optimize brush control programs with respect to water quantity and carbon sequestration concerns. (25% effort)

What are the projected changes of LCLUC and their potential impacts?

The effectiveness of programs to manage brush removal will be evaluated with respect to the needs of the landowners and other stakeholders in the region. The **human dimension** is critical to establish optimal solutions to rangeland management. (25% effort)

Project Goals

This is an ambitious project with multiple components. In order to develop and test the methodology, first year efforts have been focused on two watersheds in the region; Sabinal River and Leon Creek. The goals have been to (1) develop the LANDSAT image library for the region, (2) develop image classification methods for identification of brush species and urban areas, (3) develop the watershed modeling data inputs, (4) identify and interview stakeholders in the study areas, (5) develop the survey questionnaire, and (6) develop the landholder data necessary to distribute and evaluate the questionnaire.

Table 1. Project Timeline from the proposal - Year 1

Quarter/Year	Activity	Status
3rd Quarter 2001	Project Begins	
	Equipment and images ordered	Complete
	Ground truth data collection begins	Complete
4th Quarter 2001	Initial ROI images developed for current time	Complete
	Initial classifier developed and validated	Complete
	Historic weather and aquifer data collected	Complete
	Identify focus groups	Complete

Quarter/Year	Activity	Status
1st	ROI images for time series developed	Complete
Quarter	Initial classification and validation of LCLU	Complete
2002	Initial LCLUC maps developed	Complete
	Initiate focus group meetings	Complete
2nd	Current image set ordered	Complete
Quarter	Additional ground truth data collected	In progress
2002	Classifier performance reviewed	In progress
	Time series of LCLUC images completed	In progress
	Continue focus group meetings	In progress
	Develop and test mail survey questionnaire	In progress

The primary area of concern is the recent flooding that has occurred in the entire Edwards Aquifer region. All of the counties contained n the study area have been declared Federal Disaster areas and have suffered significant damage from heavy rains that occurred in the first week of July. At this time it is uncertain what effect this will have on the study.

Approach and Methods

The approach to this study has relied on close interdisciplinary cooperation between engineers and social scientists. To facilitate this, regular team meetings are held and the study site was visited by the entire team in May.

Progress

First year efforts have been focused on two watersheds in the region; Sabinal River and Leon Creek. Sabinal River is an area where land use is primarily farming and ranching but is undergoing significant changes in land ownership and land use. Traditional agricultural activities are being supplemented or replaced by recreational uses (e.g. leased hunting) of the land. This project will explore the implications of these changes on brush removal programs and landowner incentives. Leon Creek is located in the northwest of corner of San Antonio (Bexar county) and extends into Bandera county. It is an area that has undergone extensive urbanization over the previous 15 years.

Image processing of LANDSAT TM and ETM+ data has been a primary achievement of the first year. A study on land cover classification of Bandera, Real and Uvalde Counties (details at http://baen.tamu.edu/users/josh/baen.616/) focused on the unsupervised and supervised classification of a portion of the study area. Results indicated that supervised classification produced better results than unsupervised classification when determining land cover classes. However, development of well defined training data was essential in successful classification. An example of the classified product is shown in Figure 1.

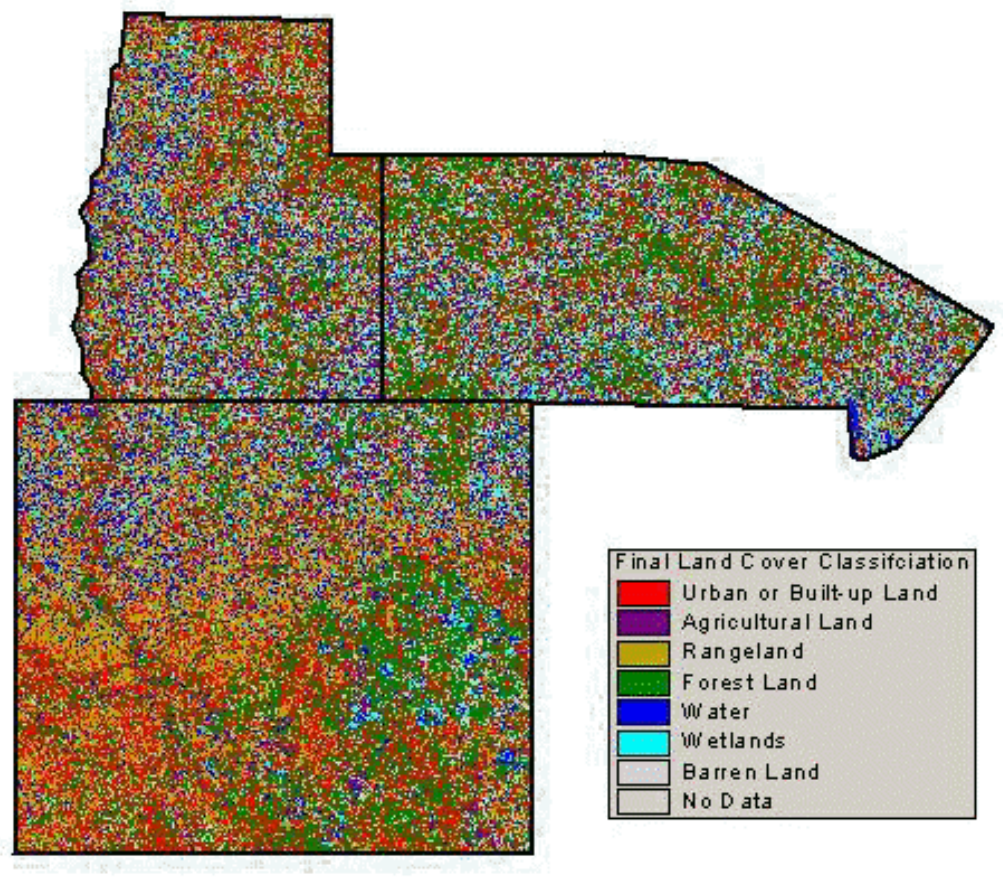

Figure 1. Clipped binary encoded classification of land cover in Ulvade, Real, and Bandera counties, Texas from a LANDSAT ETM+ image for December 14, 1999.

A second aspect of this project has been to create land cover input datasets for the SWAT 2000 Model (details at http://baen.tamu.edu/users/josh/Peschel/peschel.htm). A supervised neuro-fuzzy sub-pixel classification method was developed to create land cover input grids for the SWAT 2000 Model. The input grids were based on remotely sensed data. Through the use of digital elevation model (DEM) data files, an approximate boundary of the Leon Creek watershed was located. A LANDSAT Thematic Mapper (TM) image of the watershed taken in September 1987 and an Enhanced Thematic Mapper+ (ETM+) image October 1999 was superimposed onto the delineated watershed. Select data from the extracted TM and ETM+ image subsets was coupled with corresponding ground-truth data to create an Adaptive Neuro-Fuzzy Inference System (ANFIS) model. Results of this study indicate that neuro-fuzzy classification of land cover is highly dependant on the correct selection of membership functions. Preliminary results are shown in Figure 2. The final land cover classification did not accurately reflect the ground truth data. Possible sources of error may include not enough training data or incorrect membership function selection. Work is continuing on this approach.

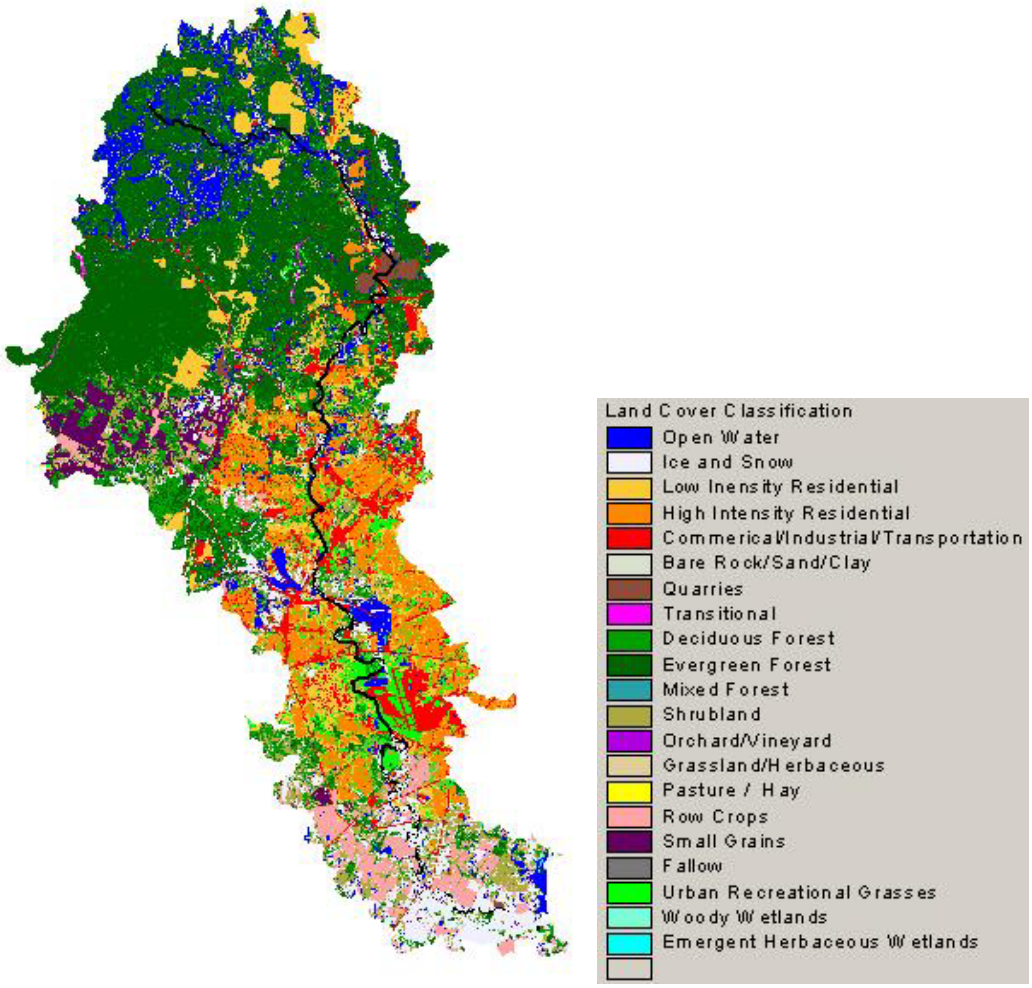

Figure 2. Generated land cover grid for October 20, 1999 Landsat image of the Leon Creek watershed

There are several socio-economic forces in the region that are creating changes in land use. As noted in the abstract, the large growth in regional population has generated a corresponding increase in urbanization. A depressed agricultural economy has made other land uses more attractive and profitable. While many of the properties have been in families for several generations, inheritance taxes and changing owners have created shifts in land use. Inheritance taxes have caused some landowners to sell off parcels of land to pay the taxes on the remaining land. Often, heirs of generational land are not interested in managing the inherited land and realize the profitability of selling the land in smaller tracts.

With the increased urban population there is an increased demand for hunting and other recreational activities. Many of these activities (e.g. leased hunting) favor an increase in trees and brushy cover. Since hunting and recreation are often more profitable than the traditional livestock operations, the landowners have altered their brush control practices. The wildlife, particularly exotics introduced for hunting, can devour large fields of crops, particularly desirable grasses, forcing the remaining farmers and ranchers to change to species that are resistant to wildlife.

Next Steps

The project will continue to follow the original timeline as shown in Table 2. Once the methodology is fully tested for the two watersheds, the effort will be extended to include all of the watersheds in the Edwards aquifer region.

Table 2. Project timeline - Years 2 and 3.

Quarter/Year	Activity
3rd Quarter 2002	Parameterization of SWAT and CityGreen Finalize mail survey questionnaire, print questionnaire, reply envelopes, etc.
4th Quarter 2002	Scenario development Conduct mail survey questionnaire
1st Quarter 2003	Scenario analysis Conduct follow up on mail survey questionnaire
2nd Quarter 2003	Analyze mail survey data
3rd Quarter 2003	Analyze landowner responses for implementation of alternative policy instruments
4th Quarter 2003	Management strategy optimization Estimate costs of implementing alternative policy instruments that incorporate appropriate landowner incentives
1st Quarter 2004	Determination of optimal combination of policy instruments for enhancing ecosystem services and social welfare
2nd Quarter 2004	Final Report prepared Final publications prepared and submitted

Conclusions

The first year of this project has been successful at establishing the basis for the subsequent years. Some key findings are:

- Supervised classification methods have the highest potential for success; however, it will be essential to develop a comprehensive set of training data to develop the final classifier.
- Remotely sensed data will be used to create a direct data input to the Soil and Water Assessment Tool (SWAT), a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS).
- Land use patterns are changing dramatically from traditional agricultural uses. This will be an important factor in developing good stakeholder feedback.

Publications

Kreuter, U. P., H. G. Harris, M. D. Matlock and R. E. Lacey 2001. "Estimated change in ecosystem service values in San Antonio area, Texas." *Ecological Economics* **39**: 333-346.