WATER, RURAL LIVELIHOODS AND GLOBAL TRANSFORMATIONS: GEOGRAPHIES OF PERI-URBAN AREAS IN MEXICO

by

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A Dissertation Submitted to the Faculty of the

SCHOOL OF GEOGRAPHY AND DEVELOPMENT

In Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY
WITH A MAJOR IN GEOGRAPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

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ACKNOWLEDGEMENTS

Many thanks are in order to the members of my committee, Drs. Margaret Wilder, Christopher Scott, Carl Bauer and Scott Whiteford. Their dedicated guidance and prompt response provided a sound base for the completion of this work.

A special thanks and recognition goes to my advisor, Dr. Margaret Wilder who guided devotedly my education since I started graduate school at The University of Arizona in 2005. Her clever guidance and enthusiastic advice has had a great impact in my formation. I appreciate the financial support of Dr. Wilder and the Climate Assessment of the Southwest Program during my doctoral studies and the research opportunities they provided on water and climate in northwest Sonora and southern Arizona. I am grateful to the Climate Assessment of the Southwest (CLIMAS) Program of the National Oceanic and Atmospheric Administration (NOAA) for supporting this dissertation research.

Many thanks to the Consejo Nacional de Ciencia y Tecnología (CONACYT) for the scholarship granted to pursue my Ph.D. studies. Thanks to the members of the scholarship evaluation committees for their confidence vote to invest in my formation.

I am grateful to Dr. Erick Sánchez, professor of the Universidad Autónoma de Ciudad Juárez, and his collaborator Lic. Mónica Velo Olivas for providing valuable data for this study. Thanks to all people who collaborated in different aspects of my dissertation: Dr. Edella Schlager contributed significant revisions during the planning of this work. Drs. José Luis Moreno, Nicolás Pineda, and Ernesto Camou provided guidance to understand the region of Hermosillo. Ecol. Maribel Pallánez, Antrop. Carolina Romero, and Ecol. Guadalupe Morales contributed insightful comments during the field work. Special mention goes to Linda Koski, Liz Cordova and John Moeller, from the School of Geography and Development, and Julieta González, from the Center of Latin American Studies, for their always prompt and kind administrative and technical support during my studies.

My deep appreciation goes to ejidatarios of the peri-urban area of Hermosillo for their patience and willingness in telling me their lives and realities.

Thanks to my parents and brothers for their example in undertaking every single mission with courage and joy. Thanks for their strengthening motivation from home.

A very special recognition goes to my family. My wife and my children always showed me their loving support and patience all these years. Thank for joining in this journey.

Rolando Díaz

DEDICATION

To truth and life

To Yadira, Rodrigo and Diego

Whose single smile is an inspiration.

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ABSTRACT

The population in developing-country cities is expected to double in the next thirty years. In Mexico, urban population is projected to increase by around 25 percent in the next 20 years. Peri-urban areas have long been a source of food, natural resources, and labor to sustain growing cities. The urban/peri-urban phenomenon is frequently studied as a territorial landscape for urban expansion, and a good deal of scholarship chronicles aspects of land annexation, housing construction, and infrastructure. But the question of how peri-urban water resources have been reallocated to serve urban needs has not received sufficient scholarly attention. Peri-urban water reallocation demands examination in arid regions where water is a critical resource. Mexico's northwest region represents one of the most critical examples; the most-drought prone region in Mexico, it is characterized by over-drafted groundwater sources and rapid urban growth. In this research, I develop three distinct, yet related themes to examine the peri-urban phenomenon. The studies are based on research in the peri-urban and urban areas of Hermosillo, the capital city of Sonora, in northwest Mexico. Sonora borders the U.S. state of Arizona along a 390-mile length.

First, this work draws on the notion of the "hydrosocial cycle" (Swyngedouw, 2004) to examine geographies of power at the urban-rural interface. Following Swyngedouw, we argue that urban water augmentation strategies reveal a distinct set of urban-rural relations of uneven social power where peri-urban water resources are “metabolized” in urban areas, reflecting the demands of powerful, politically connected

urban individuals and populations over more disparate and marginalized rural producers. The Hermosillo case indicates that small-scale farming communities or *ejidos* are the most vulnerable water users because of their lack of political power in the governmental decision making process. This research demonstrates how small farmers are losing access to their water resources via intensive processes of urbanization, while large-scale, politically-connected irrigators have successfully resisted efforts to metabolize their water to serve urban growth.

Second, although a considerable number of studies examine how livelihoods are affecting natural resources, particularly in rural forest-dependent communities in Latin America, few studies have examined how the transfer of natural resources from the peri-urban to urban areas affects peri-urban livelihoods. In this work, I examine how peri-urban rural livelihoods have been reshaped by cities' water reallocation causing ejidatarios in many cases to lose their livelihoods, but without creating new urban jobs as an alternative means of subsistence, resulting in a net negative outcome for ejido members.

Finally, this research evaluates the land use/cover change dynamics and their effects in the peri-urban area of the city of Hermosillo. This study demonstrates that urban expansion causes at least two other types of land use/cover changes (LUCC) beyond the urban fringe that are not usually considered in LUCC studies. First, the study documents the loss of agricultural land due to water transfers from peri-urban communities to the city and, second, it provides evidence for the transformation of grazing lands to recreational ranchettes (known as *lotes campestres*) acquired by urban

families. The research demonstrates that urban expansion in the peri-urban land is a broader and more complex phenomenon than previously understood and examines how water transfers act as a driver of land use/cover change.

CHAPTER 1. INTRODUCTION

Explanation of problem and its context

Ejidos are small-scale communal lands that were created as part of Mexico's massive land reform in the postrevolutionary decades of the 1930s and 1940s to satisfy the demand by landless campesinos for land. By the 1980s, approximately half of the national territory and as much as 80% of Mexico's forests were in the hands of ejidos and indigenous communities (Bray et al., 2003). There are approximately 28,000 ejidos in Mexico (Cornelius, 1992).

Ejido communities are the most marginalized and impoverished in Mexico. According to DeJanvry and his co-authors (1997), 47 percent of ejidal households nationally are in conditions of poverty, and 34 percent are in extreme poverty. Although the ejido system has experienced many transformations during its existence, such as the so-called green revolution and agricultural modernization, until the 1980s it experienced a certain stability regarding the rules of organization and the governmental support for its activities (De Janvry et al., 1997; Hewitt de Alcántara, 1978). However, the 1990s marked a critical turning in which ejidos have been challenged by neoliberal transformations in agricultural supports, trade arrangements and land and water tenure.

Regarding the economic transformations, the North American Free Trade Agreement (NAFTA), signed in 1994 by Mexico, the U.S. and Canada, is of particular importance. An iconic illustration of these transformations is the case of wheat, a

commodity where Mexico had traditionally been a net exporter. While in 1990, Mexico imported US$46. 3 millions in wheat, in 2002, the value of imported wheat increased to US$236.8 millions, an increment of 411% (Mella & Mercado, 2006). Integration of the NAFTA region involves national-level reforms in agricultural policies, such as elimination of subsidies and price supports that expose the agricultural sector, especially smallholders, to market volatility and fluctuating prices. Rural scholarship has amply shown how free trade and liberalization strategies lead to economic hardship for Mexico's agricultural producers (see, for example, Wilder & Whiteford, 2006; Schwentesius & Gómez, 2001).

The "Article 27" constitutional reforms of 1992 changed the land tenure of ejidos from inalienable property (e.g., land that could not be sold) to individual titles in which the ejidatarios are able to sell their land. Prior to the 1992 ejido reforms, ejidatarios had only usufruct rights to the land.

In keeping with neoliberal reforms, dramatic revisions to the nation's water policy in a new National Water Law were introduced in 1992 (Wilder 2009). The law established new aspects such as decentralization of urban water management and irrigation districts. This law also established the National Commission of Water (CONAGUA) as the authority responsible for the administration of all national water issues and all the hydraulic work (NWL, 1992, p. 2). The new law also address some aspects of water markets, such as now users are free to transfer their rights when only the user changes or within the irrigation districts and aquifers (Garduño, 2005: 104). Since water market requires legal security, the new law also codified water rights through the

Public Registry of Water Rights (Registro Público de Derechos de Agua, REPDA). Prior to REPDA, many ejidos had water rights but lacked any specific volume of water; since the establishment of REPDA, many ejidos and other farmers have assigned volumetric rights.

In addition to these neoliberal reforms, climate variability and climate change create vulnerability for cities and farmers alike. The northwest region of Mexico is a semi-arid area characterized by low annual precipitation levels that average only 450 mm. According to the Comisión Nacional del Agua (CONAGUA), the northwest is the country's most drought-prone region (CONAGUA, 2007). The most recent 10-year drought caused huge economic losses in the ranching and agriculture sectors, and caused some cities to ration water for the first time (Wilder & Romero, 2006). These global economic transformations coupled with climate change leads to a situation of regional water and land use intensification known as *double exposure* (Leichenko & O'Brien, 2008). Nonetheless, an additional challenge—that of urbanization-- exists for ejidos located close to cities at the peri-urban area. Although ejidos in this region have traditionally had access to water since ejido communities were formed, in the last decade, these communities have had to compete with the city of Hermosillo's growing demand for water, which has proven a powerful and unbeatable rival.

The principal question that emerges is how has urban expansion in the context of drought affected small farming communities (ejidos) in peri-urban areas? More specifically, this work seeks to answer the following questions: (1) what is the process shaping water transfers from peri-urban areas to the urban area of Hermosillo, Sonora?

(2) How has the increasing water demands of the city of Hermosillo interacted with the farming-based livelihoods of peri-urban ejidos? And (3) what is the link between water transfers and land use/cover changes in peri-urban areas?

Review of the literature

In order to examine this set of questions, I draw upon three principal areas of scholarly literature, including the scholarship on understanding the concept of the "peri-urban;" political ecology, especially the scholarship on water, development, and the hydrosocial cycle; and land use/land cover change.

I. Understanding the Concept of the "Peri-urban"

Peri-urban regions resist easy definition (McGregor et al., 2006; Tacoli, 2006; Brook & Davila, 2000), but following the sense of the prefix peri, can be defined as the immediate zone that surrounds a city's existing boundaries. However, this territorial definition does not satisfy many scholars because according to them, the peri-urban is best understood as a series of flows or processes or interface of good and services between the rural and urban areas (Narain & Nischal, 2007; Allen, 2003; Brook et al., 2003). Each peri-urban area has properties unique to its context, and may manifest urban, rural characteristics a mix of both. The peri-urban area may be a kind of transition zone with more urban characteristics in the area closest to the city boundary and a more rural character at its

edge farthest from the city boundary. Alternatively, peri-urban areas may have sketchy patches of both, the urban and rural dotting the peri-urban zone's landscape, or in some cases, there may be a crisp edge to the urban boundary that marks a clear demarcation with an essentially rural area beyond the boundary. The peri-urban transition zone between urban and rural areas defies universal definition and is best understood as context-specific. A peri-urban region can best be understood as an area of transition along an 'urban-rural gradient' (McGregor et al., 2006, p. 10).

Existing scholarship has chronicled the urban-peri-urban phenomenon in terms of land annexation, housing construction, and infrastructure issues, but the question of mining peri-urban water resources to serve urban needs has not received much scholarly attention. For example, three recent edited volumes on the peri-urban interface do not address urban/peri-urban water transfer (McGregor et al., 2006; Tacoli, 2006; Brook & Davila, 2000), nor does a World Bank study on the implications of urbanization for peri-urban areas (Lavadenz & Deininger, 2001). Lavandez and Deininger (2001) found that urban expansion of Mexico's 110 major cities "represents one of the greatest challenges for the agrarian sector during the coming decades" (p.18). It is forecast that these major urban centers will require 700,000 new housing units each year, and that over two-thirds of the land required for this expansion will come from the ejido sector—specifically, from peri-urban ejidos located at the edges of cities (Lavadenz & Deininger, 2001, pp. 18-19). Undoubtedly, land use change from agricultural to urban use is one of the most important effects of urban sprawl on rural livelihoods. However, the link between rural livelihoods and water use due to ejido-urban transfers is critical as well. Water use for

economic livelihoods in peri-urban areas is quite important because many income activities, such as agriculture and horticulture, depend on the availability of water (Allen et al., 2006; Treminio, 2004). For those involved in these activities, lack of water due to urban water demand poses a serious threat to their livelihoods.

II. Political Ecology of Water and the Hydrosocial Cycle

Recently, significant scholarly attention has focused on the developing "crisis" in water availability and water quality. The World Water Vision Report states that one in five persons worldwide lacks access to safe and affordable drinking water, and one half of the world's population has no access to sanitation (Cosgrove & Rijsberman, 2000, p. XX). The report also argues that without considerable innovations in technology, institutions, and investment, the world in 2025 will likely face an estimated 1.3 billon people without access to safe drinking water, and 2.6 billion without adequate sanitation (Conca, 2006).

Political ecology has become firmly established as a dominant field of human-environmental research in geography. One of the most significant contributions to human-environment research is that political ecology provides, in contrast to the more positivists human-environment approaches, theoretical tools to address the larger political and economic factors that contribute to environmental change (Walker, 2005; Robbins, 2004; Zimmerer, 1996).

There is a growing body of scholarship on water governance and new water management paradigms that are critical to address the shortcomings of water

management (Scott & Banister, 2008; Lara et al., 2005, Bauer, 2004; Gleick, 1996). Beyond water governance, the political ecology of water framework is directed at the social vulnerability and unequal power relations of water users in particular contexts (Wilder & Romero, 2006; Castro 2006). Political ecologists utilize water as an analytical lens through which to examine relations of power, shifting access to resources under processes of economic restructuring and political transformation, and the complex interplay of multi-scaled forces (such as markets and government/civil society institutions) in particular contexts. One of the most prominent conceptual innovations in political ecology of urban water is the called hydrosocial cycle (Swyngedouw, 2004; Bakker, 2003). The hydrosocial cycle emphasizes the idea that "the circulation of water – as a physical and social process – brings to light wider political economic, social, and ecological processes" (Swyngedouw, 2004, p. 2). Unlike the hydrological cycle, which is focused on the physical environment, the hydrosocial cycle highlights how water should not be abstracted from the social ends and power relations that give it meaning (Budds, 2008; Bakker, 2003). In doing so, not only is human agency lost but processes that inherently involve the physical, the spatial, the social, the institutional and the economic are viewed in incomplete, even misleading terms (Díaz-Caravantes & Wilder, n.d.). Swyngedouw (2004) draws on the concept of the hydrosocial cycle to analyze processes of urbanization and transferences of water in the case of Guayaquil, Ecuador. Similarly, for this research, the hydrosocial cycle sheds light on the urban/peri-urban unequal power relations in Hermosillo and its environs, in which urban interests have prevailed over peri-urban water rights.

The peri-urban area of a city is immediately implicated in a city's drive to expand. Swyngedouw (2004) anticipates this focus on the water resources of peri-urban areas as the city is driven to expand, and urban expansion necessarily requires pushing on the urban water frontier (pp. 37-38). Peri-urban areas are an integral part of the urbanization of water. Since water is expensive to transport across long distances, cities attempt to find water sources as close as possible to existing urban boundaries. In this dissertation (see Article in Appendix A), my co-author and I argue that this process of urban areas, such as Hermosillo seeking to augment water supply, promotes a new peri-urban water landscape--or "waterscape-- in which a new socionatural space is constructed that reflects the uneven relations of power within urban/peri-urban linked communities.

III. Peri-urban Livelihoods

The literature on livelihoods in rural Latin America illuminates significant interactions among communities and the natural resources they depend on to survive. As Latin American cities have expanded outward, the literature on the increasing phenomenon of peri-urban areas has also grown. However, this literature reflects insufficient understanding of how water and livelihoods in peri-urban areas are affected by urbanization. In my second article (see Appendix B), I address the interaction among households, livelihoods, and climate and structural drivers in peri-urban areas. This work depends, first, on a vast scholarship on household livelihoods in Latin America, and

second, on a small body of research on peri-urban land transformations, both of which I review briefly below.

In Latin American studies, household-level analysis of livelihoods has received significant attention in part because it sheds light on key socio-ecological processes, often in fragile ecological environments (Chowdhury & Turner II, 2006; Fox, et al., 2003; Perz & Walker, 2002; Liverman et al., 1998). In these studies, there is a particular interest in how biophysical variables such as forest cover and soil quality are related to population variables (e.g., household size, on-farm population density, and migration). Perz and Walker (2002), for example, have examined the interaction of household life cycles and land use allocation in the Amazon. Based on a quantitative-household survey analysis they conclude that land and capital availability as well as the numbers of dependent children, labor availability, and generational transitions influence the likelihood of adopting productive conservation programs in this agroforestry systems.

The environmental perspective states that population dynamics can cause significant environmental impacts, such as deforestation, with implications for the sustainability of natural resources and biodiversity conservation (McShane & Wells, 2004; Sayer & Campbell, 2003; Hardin, 1968). Political ecologists, on the other hand, seek structural and political explanations for the causes of environmental degradation (Robbins 2004). Changes in the quality and quantity of natural resources (i.e. drought and natural disaster) can also have important impacts on household and demographic dynamics, such as harming sources of income (de Sherbinin et al., 2008).

Several structural changes are producing environmental degradation on the peri-urban areas. Allen (2003) identifies three processes of environmental change in the peri-urban interface, including a change in land use, such as from agricultural to residential or industrial uses; a transfer of natural resources such as forest, water and pollution from peri-urban to urban areas; and a change in the generation of waste and use of environmental services, such as increased solid and liquid waste in the peri-urban zone.

According to the peri-urban literature, peri-urban livelihoods might potentially be benefited by their geographical location near the city through their access to jobs and urban markets for peri-urban agriculture (McGregor et al., 2006b; Douglas, 2006; Lynch & Poole, 2006; Brook & Davila, 2000). Peri-urban residents may benefit by employment for the jobless, access to health and education, and opportunities provided by urban infrastructure. Finally, peri-urban farmers can benefit from the availability of urban food waste they employ as livestock feed or fertilizers (Douglas, 2006). Lynch and Poole (2006), for example, study the mechanism by which smallholder producers overcome the informational constraints in fruit and vegetable market systems. They conclude that although peri-urban smallholders have access to urban markets, the smallholders have significant limitations in access to market information and are also limited in their ability to respond to risks of entering new markets (Lynch & Poole, 2006, p. 91).

With a focus on peri-urban water resources, Allen et al. (2006) analyze the link between peri-urban livelihoods and water resources, but just in relation to water and sanitation services in the peri-urban areas. However, as the authors also argue, water use for economic livelihoods in peri-urban areas is quite important because many income

activities, such as agriculture and horticulture, depend on the availability of water. For those involved in these activities, lack of water due to growing urban demand, poses a serious threat to livelihoods (Allen et al., 2006; Treminio, 2004). DeJanvry et al. have shown that ejido access to irrigation water is one of the most critical indicators for moving out of poverty (1997, p. 197).

IV. Land Use/Cover Change in Peri-Urban Areas

Among the scientific community and the society in general there has been a growing concern about the complex environmental problems caused by human alteration of ecosystems. Land cover changes, in particular, have major effects on the environmental and socio-economic sustainability of communities (Watson et al., 2000). Land cover change itself represents one of the most substantial ways of ecosystem alteration and is linked commonly to other forms of environmental degradation such as erosion, habitat and biodiversity loss, and groundwater depletion (Lambin & Strahler, 1994).

Land cover change linked to urbanization processes is one of the most insidious manifestations of ecosystem deterioration (Dewan & Yamaguchi, 2009; Batisani & Yarnal, 2009; Yuan, 2008; Hasse & Lathrop, 2003). In fact, urbanized landscapes are the most critical expression of land cover alteration (Forman, 1995). As an example, impervious surface directly impact the amount of runoff to water bodies (Ridd, 1995). As is well-known, the augmentation of runoff causes significant problems of flooding and pollution (Conway, 2007; Booth et al., 2002).

If we consider the global trends, we can see the magnitude of this problem. According to a report published by the Transport and Urban Development Department of the World Bank, urban built-up areas in the world consumed some 400,000 square kilometers in 2000 and cities are now expected to grow 2.5 times in area by 2030, consuming some 1 million square kilometers (Angel et al., 2005). Although, according to Angel et al. (2005) this area is just 1.1 percent of the total land areas of countries, urban areas have marked effects on environmental conditions at both local and global scales (Herold et al., 2003).

A considerable number of studies have examined the land-livelihoods relationship on the peri-urban area (Jaiyebo, 2003; Narain, 2009; Smith, 2007; Brook et al., 2006; Kelly, 2006; van den Berg et al., 2003). Brook et al. (2006), for example, based in the case of the city of Hubli-Dharwad, India study how the size of the landholding is related to the dairy markets from the peri-urban area to the city. In this study, they showed that the dairy production is more profitable in villages near to the city where access to markets is better regardless of the size of landholding. However, small landowners and the landless need to buy more pasture for the livestock, reducing its economic benefits gained from proximity to the market. Focused on the process of land conversion from agricultural to urban uses, van den Berg et al. (2003) examine the agricultural transformation of the peri-urban area of Hanoi, Vietnam, to show that farmers who lose their land due to urban development receive a fixed non-market based compensation by government. Some farmers have the strategy of using this compensation to invest in farmland farther from the city.

Nonetheless, there is a more limited research regarding the water-livelihoods-land interrelationship, a gap which my research proposes to fill. Urban water supply strategies have negatively impacted livelihoods of ejidatarios (small-scale communal farmers) by harming or even obliterating their traditional means of subsistence based on agriculture and livestock (Díaz-Caravantes, n.d.). In the case of Hermosillo, Sonora, the extension of urban water infrastructure into peri-urban ejido areas during a decade of drought has also produced significant land use/cover change in the peri-urban area. One is the transformation of ejido grazing lands to recreational ranchettes (known as *lotes campestres*) by urban families. Another is the loss or abandonment of agricultural land due to the water transfers from peri-urban communities to the city. In my third article (Appendix C), I specifically address how urban water transfers are linked to land use/land cover change in peri-urban areas of Hermosillo.

Explanation of dissertation format

The research presented in this dissertation is organized in three related studies testing different aspects of the problem focused on questions I identify in the introduction. The objectives, methods and main findings of each study are summarized in Chapter 2 (Present Study). Individual studies were prepared in the form of publishable papers and included as appendices in this dissertation. Each paper consists of an introduction, methods, results and discussion, and conclusion sections.

Appendix A, titled, "Water, Cities and Peri-Urban Vulnerabilities in Northwest Mexico" was prepared for submission to *Geoforum*. This paper, co-authored with Dr. Margaret Wilder, draws on the notion of the hydrosocial cycle (Swyngedouw, 2004) to examine geographies of power at the urban/peri-urban interface to answer the question of how access for urban water resources has been carried out. In this work we argue that urban water augmentation strategies reveal a distinct set of urban-rural relations of uneven social power where peri-urban water resources are “metabolized” in urban areas, reflecting the demands of powerful, politically connected urban individuals and populations over more disparate and marginalized rural producers. The results of this study are connected with Appendix B in providing the broader context of the research problem.

Appendix B, titled, "Balancing Urban and Peri-Urban Exchange: Rural Livelihoods in Mexico" was prepared for submission for the *Geographical Journal.* This paper examines how the transfer of natural resources from the peri-urban to urban affects peri-urban livelihoods. This evaluation is critical because the livelihoods of Mexican peri-urban ejidos are being drastically reconfigured by urban expansion. In the case of Hermosillo, a tremendous pressure on water resources of peri-urban ejidos due to urban demand has been demonstrated. Based on semi-structured interviews and structured surveys with ejidatario producers and water managers, this paper examines how peri-urban rural livelihoods have been reshaped by Hermosillo’s water reallocation causing ejidatarios in many cases to lose their livelihoods, but without creating new urban jobs as an alternative means of subsistence, resulting in a net negative outcome for ejido

members. The primary data developed for this research are a sample of household surveys, are also used for the article in Appendix C.

Appendix C, titled, "Peri-Urban Land Use/Cover Changes and Water Transfers: New Geographies of Land Studies" was prepared for submission for *Journal of Latin American Geography*. This research evaluates the land use/cover change dynamics and their effects in the peri-urban area of the city of Hermosillo, Sonora (Mexico). We utilize a mixed methods approach including image classification based on Land-sat imagery, household surveys and semi-structured interviews. This study demonstrates that urban expansion causes at least two other types of land use/cover changes beyond the urban fringe that are not usually considered in land studies. The first one is the loss of agricultural land due to water transfers from peri-urban communities to the city. The second one is the transformation of grazing lands to recreational ranchettes (known as *lotes campestres*) acquired by urban families. By doing this, we demonstrate that in the peri-urban area, water is itself a critical driver that produces land use/cover changes. In this research, a new land use type, recreational ranchettes, emerged as a phenomenon linked to urbanization processes.

CHAPTER 2. PRESENT STUDY

The methods, results, and conclusions of this study are presented in the three appendices of this dissertation. The first paper is focused on theoretical engagement with the concept of the "peri-urban" and the implications of Swyngedouw's "hydrosocial cycle" for understanding uneven power relations in the urban/peri-urban area of Hermosillo, Sonora, with compelling empirical evidence from field interviews and surveys. The second paper is focused on empirical analysis to understand how urban water transfers affect peri-urban farming livelihoods in the context of drought and water scarcity in Hermosillo. The final paper utilizes a mixed methods approach of remote sensing and qualitative interviews and surveys to examine how land use and land cover change are linked to changing access to water in peri-urban areas of Hermosillo. The following is a summary of the most important findings in this document. The three studies integrated as a whole explored how urban expansion in the context of drought has affected small farming communities (ejidos) in peri-urban areas. In the case of Hermosillo, the peri-urban area is the most negatively affected region due to the strategies the city of Hermosillo has pursued to supply water to the city in a context of growing water scarcity due to drought and use patterns. Dams, wells and water policy and management have been the means of transference from peri-urban agricultural uses to urban domestic uses. The scope of the individual studies comprising this dissertation is described briefly as follows.

Appendix A- "Water, Cities and Peri-Urban Vulnerabilities in Northwest Mexico"

Based on evidence from our NOAA-funded research,[1] this paper draws on the notion of the hydrosocial cycle (Swyngedouw, 2004) to examine geographies of power at the urban/peri-urban interface to answer the question of how access for urban water resources has been carried out. More specifically, this paper seeks to answer the following questions: What is the process shaping water transfers from peri-urban to urban areas? Why is water transferring from particular peri-urban areas rather than other areas? Why are peri-urban areas more vulnerable?

In this paper, we demonstrate that urban water supply projects have been disproportionately focused on ejidos in the peri-urban area. Of the 16 proposed strategies, 10 were proposed and implemented in the peri-urban area. This disproportionate emphasis on the peri-urban area is not based only on technical or physical conditions, but is also based on power relations as the hydrosocial concept suggests. In order to substantiate this argument, we contrast the water transfer projects that affected the peri-urban ejidos with proposals made to transfer water resources from major irrigation districts. We refer to these in this paper as "counterpoint cases", because these cases reflect how powerful water users were successful in resisting the city of Hermosillo's

[1] This study was part of two larger projects, both funded by the National Oceanic and Atmospheric Administration (NOAA) on water, urban growth, and adaptation to climate change in southern Arizona and northwest Mexico, including Climate Assessment of the Southwest (CLIMAS) Program; and a NOAA Sectoral Applications Research Program (SARP), Moving Forward: Adaptation and Resilience to Climate Change, Drought, and Water Demand in the Urbanizing Southwest and Northern Mexico.

demand for new water resources, while the peri-urban ejidos were largely unable to resist and lost access to water and farming livelihoods, as a result.

Additionally, we suggest the notion of the peri-urban "waterscape" is a distinct concept from the peri-urban landscape which is a fixed and bounded area of territory on the outskirts of a city. By contrast, a peri-urban waterscape develops when the water resources of even distant peri-urban areas are accessed and utilized for the benefit of the city. For example, although some ejidos are located nearly 30 kilometers from Hermosillo, its water can be accessed by the city, therefore making this rural farming area part of the peri-urban phenomenon. We propose that this is an important conceptual advance in understanding how water is a distinct commodity with transformative capacities.

Appendix B- "Balancing Urban and Peri-Urban Exchange: Rural Livelihoods in Mexico"

The second paper examines the question of how has the city of Hermosillo interacted with livelihoods of peri-urban ejidos? As discussed in the literature review above, the linkage of water to the land and livelihoods debate is an important area. A separate yet related innovation is examining this three-way relationship in the context of peri-urban (rather than rural) areas. In other words, is there a trade-off such that these ejidos have obtained a benefit from urban jobs as a way of balancing the loss of traditional livelihoods in agriculture and ranching?

I classify the 16 ejidos by the location and type of urban water supply impact resulting in five groups. In order to examine all of the types of impact on ejidos by urban water supply, one ejido of each group was selected.

As examined in this paper, livelihoods of peri-urban ejidos have been reconfigured by many aspects, such as changes in crop pattern and labor alternatives. Climate conditions, specifically a prolonged drought, are affecting the livestock production by affecting the heads of cattle that can be maintained in the grassland. Urban expansion has produced urban land speculation, particularly in the grassland of ejidos, where ejidatarios have decided to divide and sometimes sell the grassland to be used as a recreational ranchettes (lotes campestres in Spanish) by Hermosillo residents. The selling of agriculture and grassland has been allowed, and sometimes encouraged by the Article 27 land reform.

On the other hand, drought has also contributed to the production of urban water scarcity (coupled with over-drafting of groundwater aquifers by nearby irrigators). Thus, drought, joined with urban expansion, has negatively affected the availability of water in the peri-urban ejidos; farmers have shifted their crop patterns and even stopped cultivating their land. Agricultural free-trade has also impacted the price of wheat and therefore driven changes in crops from wheat and grains to cattle.

As I argue in this work, livelihoods are not only modified by farm changes, but also are transformed by labor strategies. In this case, farm and off-farm labor strategies are considered. Off-farm is divided in two types: local and migration; local refers to the people who works in the city of Hermosillo and migration to the people that looks for

work outside of the farm community or Hermosillo, which could be at national or international level. I analyzed the jobs from ejido families in Hermosillo and I found that only 8 percent of ejidatarios work in Hermosillo and that just 20% of the ejidatarios families had one member working on Hermosillo. I argue that these numbers are not enough to establish that ejido households have a high degree of dependency on urban jobs.

In order to examine in more detail the relationship between the peri-urban livelihoods and the city, in this paper I compare wealth ranking[2] of household with a variable that represents Hermosillo benefits (income) and Hermosillo detrimental outcomes (water impact level[3]).

As shown in the results, when contrasting this variable with the number of household with at least one member of the family working in Hermosillo, I obtained that in almost all households in the high and medium wealth levels, the percentage of households with income from Hermosillo is lower than those in which no household member has a job in Hermosillo. Based on this, I conclude that there is not a substantial relationship between these two variables, that is, level of wealth is not related with income from employment in Hermosillo.

On the other hand, when comparing, wealth ranking with water impact level, I found a substantial association between level of household wealth and the availability of a high quantity of irrigation water. This is completely evident in the case of Ejido La

[2] Wealth ranking is a composite index based on principal component analysis that I use for combining four household characteristics: model of farm tractor, the model of truck or cars, number of head of cattle, and housing quality.

[3] Water impact level is calculated based of the number of years negatively affected in the irrigation activity by reducing the irrigated surface in some cases or reducing the number of irrigations in other cases.

Yesca, where virtually all households in the high wealth category reported no- or very low-water-impact and all medium households in the medium wealth category reported no water impact. The opposite case is ejido La Victoria, where all the households in the low wealth categories reported a very high water impact.

This exercise indicates that, at least in the current structure of the household, the negative impacts of new infrastructure to address Hermosillo's urban expansion are more severe for ejidos than the benefits available to peri-urban residents from living near Hermosillo. Thus, the net trade-off between these two processes is negative for the ejidos.

Appendix C- "Peri-Urban Land Use/Cover Changes and Water Transfers: New Geographies of Land Studies"

This paper examines the question of how has urban expansion impacted water and land resources of peri-urban ejidos?

Academic efforts to link household surveys with the examination of land use/cover changes are not new (Fox et al., 2003; Liverman et al., 1998). However, my contribution to this understanding is to add a new key component in examining urban expansion impacts: the peri-urban/urban water transfers. We utilize a mixed methods approach including on a post-classification approach to compare the main land use/cover types extracted from a multispectral Landsat imagery dataset, 52 household surveys and about 30 semi-structured interviews in 4 small farm communities to demonstrate that urban expansion when associated with water transfers produces at least two other types of

land use/cover changes in the peri-urban area that are not detected with just a traditional remote sensing based study.

The first change is illustrated by the ejido La Victoria. This ejido was very negatively affected by urban water facilities. According to the water impact level, about 90 percent of the total respondents in La Victoria reported a very high impact level and 70 percent have stopped cultivating their agricultural land. In order to substantiate the survey findings and make them more robust I analyzed land use/cover change based on remote sensing analysis. According to this analysis, agricultural land has diminished from 67 percent in 1987 to 24 percent in 2007, which is about 181 hectares.

The other case is in the ejido Molino de Camou. Due to the lack of jobs in Hermosillo and the agricultural production problems caused by water scarcity, the ejidatarios of the Molino de Camou have sold part of the grazing land to be used as recreational ranchettes by urban residents. Some urban residents remove part of the vegetation when they buy a lot. The level of deforestation can vary from parcel to parcel. We found that about 24% of the recreational ranchettes now are barren soil, which in 1995 this land cover type was almost zero. These findings indicate that employing mixed methods can contribute to uncovering new land uses (e.g., the recreational ranchettes), while the methods can mutually reinforce one another for a more robust set of findings. The principal finding of this research is to demonstrate how water can be a specific driver of land use/land cover change.

Summary

As shown in the Hermosillo case, the peri-urban water transfers occurred under a very specific set of political processes that privileged large, politically connected commercial irrigation districts dominated by private growers who sell to export markets over small-scale, marginalized ejido communities who produce for personal consumption and sell to regional markets. Peri-urban rural livelihoods have been reshaped by Hermosillo's water reallocation causing ejidatarios in many cases to lose their livelihoods, but without creating new urban jobs as an alternative means of subsistence, resulting in a net negative outcome for ejido members. A physical condition, the diminution of water availability in the Sonora River basin, combined with an uneven set of power relations has produced the transformation of the peri-urban waterscape, causing significant land use/cover changes, specifically in the agricultural land and grazing land of several ejidos.

The main findings of this research can be summarized in the following points:

- As some scholars have demonstrated, small-scale producers have generally experienced increased economic vulnerability due to neoliberal reforms and water markets (Bauer, 2004; Wilder & Romero, 2006). In this case, a water market may have benefited the ejidatarios by providing at least compensation for their loss of their resources, but still would fail to compensate for long-term loss of livelihoods.
- In March of 2006, Mexico hosted the Fourth World Water Forum, which invited the world community to observe its "new water culture"—or la *nueva cultura de*

agua. Supposedly, this model for water management moved from a highly-centralized, state-controlled water sector to a decentralized model based upon principles of water user participation and markets. Although Mexico's national water reform promotes a new culture of water in which public participation is a keystone, in this case, urban water transfers did not involve consultation with ejidatarios.

- The consequences of urban expansion on quality of life and sustainability have usually been examined as an essential input of urban policy making and planning; however, the effects of urban expansion from the perspective of peri-urban areas have largely been neglected (Banzhaf et al., 2009; McGregor et al., 2006). This study demonstrates the necessity of a comprehensive urban policy that considers a more sustainable peri-urban/urban trade-off.
- Urban water transfers occurred under a very specific set of political processes that privileged large, politically connected commercial irrigation districts over small-scale, marginalized ejido communities. As shown, the large and powerful irrigation districts were able to successfully resist attempts by the city to usurp their irrigation water for urban consumption. On the other hand, the city of Hermosillo increasingly sought to augment water supply from peri-urban sources, most of which efforts resulted in extremely adverse consequences for ejidos such as major diminution in or even total loss of irrigation water.
- Drawing on the notion of the hydrosocial cycle, I have demonstrated that urban water is extracted from the peri-urban area not only based on physical or

hydrological aspects, but also that peri-urban ejidatarios were unable to stop or negotiate these water transfers. According to the results, of 16 initiatives to increase water supply, 10 of them were directed at and implemented in the peri-urban region. Conditions of drought and water scarcity exacerbated the city's drive for peri-urban water resources, a condition that is likely to worsen under projected impacts of climate change.

- Hermosillo's water scarcity has not been solved; instead, urban water policy has produced new and critical problems in the peri-urban area. According to CONAGUA, Hermosillo is one of the four Mexican cities in water crisis in 2010 (Montoya, 2010). For that reason the governor, in the beginning of 2010 declared a state of emergency for the city of Hermosillo due to the water scarcity (Reza, 2010).
- Drought, combined with institutional and economic transformations and urban water policy, has significantly affected peri-urban ejidos causing a triple exposure in which ejidatarios in many cases have lost their livelihoods, but without creating new urban jobs as an alternative source of income—resulting in a net negative trade-off for the ejidatarios.
- Surface water users (e.g. La Yesca) had an advantage relative to groundwater users (e.g., La Victoria) since visibility of surface water apparently conveyed more negotiating ability with the local water utility, and they were able to achieve some degree of compensation. Groundwater also varies interannually and temporally in terms of its storage capacity, but the variability is difficult to

measure. It is very well recognized that Mexican aquifers have been subject to few water balance studies (Carabias & Landa, 2005).

- Conceiving of the peri-urban landscape as a peri-urban waterscape there is a clear three-dimensional water-livelihoods-land interface, where water plays a critical, but usually neglected, role. As analyzed, through the integration of remote sensing and household surveys we identified a new land use that has emerged in the peri-urban region, recreational ranchettes for use by city residents. This land use is exacerbated by a combination of factors in which water scarcity is a critical element.

REFERENCES

Allen, A. (2003). Environmental planning and management of the peri-urban interface: perspectives on an emerging field. *Environment and Urbanization,* 15(1), 135-147.

Allen, A., Dávila, J. D., & Hoffman, P. (2006). *Governance of Water and Sanitation Services for the Peri-urban Poor. A Framework for Understanding and Action in Metropolitan Regions.* Development Planning Unit, UCL, London. Retrieved April 14, 2009, from http://www.ucl.ac.uk/dpu/pui/publications/index.html

Angel, S., Sheppard, S. C., & Civco, D. L. (2005). *The Dynamics of Global Urban Expansion. Transport and Urban Development Department of the World Bank*. Retrieved May 11, 2009, from http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/0,,contentMDK:20970341~pagePK:148956~piPK:216618~theSitePK:337178,00.html

Arnold, C., & Gibbons, C. (1996). Impervious surface coverage - The emergence of a key environmental indicator. *Journal of the American Planning Association,* 62(2), 243-258.

Bakker, K. J. (2003). *An Uncooperative Commodity: Privatizing Water in England and Wales.* New York: Oxford University Press.

Banzhaf, E., Grescho, V., & Kindler, A. (2009). Monitoring urban to peri-urban development with integrated remote sensing and GIS information: a Leipzig, Germany case study. *International Journal of Remote Sensing,* 30(7), 1675-1696.

Batisani, N., & Yarnal, B. (2009). Urban expansion in Centre County, Pennsylvania: Spatial dynamics and landscape transformations. *Applied Geography,* 29(2), 235-249.

Bauer, C. J. (2004). *Siren Song: Chilean Water Law as a Model for International Reform.* Washington, DC: Resource for the Future Press.

van den Berg, L., van Wijk, M., & Van Hoi, P. (2003). The transformation of agriculture and rural life downstream of Hanoi. *Environment and Urbanization*, 15(1), 35-52.

Booth, D., Hartley, D., & Jackson, R. (2002). Forest cover, impervious-surface area, and the mitigation of stormwater impacts. *Journal of the American Water Resources Association,* 38(3), 835-845.

Bray, D. B., Merino-Pérez, L., Negreros-Castillo, P., Segura-Warnholtz, G., Torres-Rojo, J. M., & Vester, H. F. M. (2003). Mexico's Community-Managed Forests as a Global Model for Sustainable Landscapes. *Conservation Biology*, 17(3), 672-677. doi:10.1046/j.1523-1739.2003.01639.x

Brook, R. M., Bhat, P., & Nitturkar, A. (2006). Livelihoods from Dairying Enterprises for the Landless in the Peri-Urban Interface around Hubli-Dharwad, India. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 94-103). UK: Earthscan Publications Ltd.

Brook, R., Purushothaman, S., & Hunshal, C. (Eds.). (2003). *changing frontiers – The Peri Urban Interface Hubli-Dharwad, India.* Bangalore, India: Books for Change.

Brook, R., & Davila, J. (2000*). The Peri-Urban Interface: A Tale of Two Cities*. UK: Natural Resources Systems Programme.

Budds, J. (2008). Whose Scarcity? The Hydrosocial Cycle and the Changing Waterscape of La Ligua River Basin, Chile. In M. K. Goodman, M. Boykoff, & K. Evered (Eds.), *Contentious Geographies* (pp. 59-78). Ashgate Publishing, Ltd.

Carabias, J., & Landa, R. (2005). Agua, medio ambiente y sociedad: hacia la gestión integral de los recursos hídricos en México. México: UNAM, El Colegio de México, Fundación Gonzalo Río Arronte.

Carlson, T. N., & Arthur, S. T. (2000). The impact of land use -- land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective. *Global and Planetary Change*, 25(1-2), 49-65.

Chowdhury, R. R., & Turner II, B. (2006). Reconciling Agency and Structure in Empirical Analysis: Smallholder Land Use in the Southern Yucatán, Mexico. *Annals of the Association of American Geographers*, 96(2), 302-322.

CONAGUA. (2007). *Estadísticas del Agua en México*. Comisión Nacional del Agua. Retrieved April 1, 2009, from http://www.agua.org.mx/content/view/3649/28/

Conca, K. (2006). *Governing Water: Contentious Transnational Politics and Global Institution Building* (illustrated edition.). The MIT Press.

Cornelius, W. A. (1992). The politics and economics of reforming the ejido sector in Mexico: an overview and research agenda. *LASA Forum*, 23(3), 3–8.

Cosgrove, W. J., & Rijsberman, F. R. (2000). *World Water Vision: Making Water Everybody's Business*. Earthscan Publications Ltd.

Conway, T. (2007). Impervious surface as an indicator of PH and specific conductance in the urbanizing coastal zone of New Jersey, USA. *Journal of Environmental Management*, 85(2), 308-316.

Dewan, A. M., & Yamaguchi, Y. (2009). Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Applied Geography*, 29(3), 390-401.

de Janvry, A., Gordillo, G., & Sadoulet, E. (1997). *Mexico's Second Agrarian Reform: Household and Community Responses, 1990-1994.* La Jolla, CA: Center for U.S.-Mexican Studies University of California.

Díaz-Caravantes, R. E. (n.d.). *Balancing Urban and Peri-Urban Exchange: Rural Livelihoods in Mexico.* Unpublished manuscript.

Díaz-Caravantes, R. E., & Wilder, M. (n.d.). *Water, Cities and Peri-Urban Vulnerabilities in Northwest Mexico.* Unpublished manuscript.

Douglas, I. (2006). Peri-Urban Ecosystems and Societies: Transitional Zones and Contrasting Values. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 18-29). UK: Earthscan Publications Ltd.

Gleick, P. H. (1996). Basic water requirements for human activities: meeting basic needs. *Water International*, 21(2), 83.

Forman, R. T. T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions.* Cambridge University Press.

Fox, J., Rindfuss, R. R., Walsh, S. J., & Mishra, V. (Eds.). (2003). *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS* (1º ed.). Kluwer Academic Publishers.

Garduño, H. (2005). "Lessons from implementing water rights in Mexico," in Bryan Bruns et al, *Water Rights Reform*, pp.85-112.

Hasse, J. E., & Lathrop, R. G. (2003). Land resource impact indicators of urban sprawl. *Applied Geography*, 23(2/3), 159.

Herold, M., Goldstein, N. C., & Clarke, K. C. (2003). The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sensing of Environment*, 86(3), 286.

Hasse, J. E., & Lathrop, R. G. (2003). Land resource impact indicators of urban sprawl. *Applied Geography*, 23(2/3), 159.

Hewitt de Alcántara, C. (1978). *La Modernización De La Agricultura Mexicana: 1940-1970* (1º ed.). México: Siglo Veintiuno.

Jaiyebo, O. (2003). Women and household sustenance: changing livelihoods and survival strategies in the peri-urban areas of Ibadan. *Environment and Urbanization*, 15(1), 111-120.

Kelly, P. F. (2006). The Politics of Urban-Rural Relations: Land Use Conversion in the Philippines. In C. Tacoli (Ed.), *The Earthscan Reader in Rural-Urban Linkages* (pp. 265-284). UK: Earthscan Publications Ltd.

Lambin, E., & Strahler, A. (1994). Indicators of land-cover change for change vector analysis in multitemporal space at coarse spatial scales. *International Journal of Remote Sensing*, 15, 2099-2119.

Lara, A. A. C., Whiteford, S., & Marquez, M. C. (2005). *Seguridad, agua y desarrollo. El futuro de la frontera Mexico-Estados Unidos*. Colegio de la Frontera.
Hardin, G. (1968). The Tragedy of the Commons. *Science*, 162(3859), 1243-1248.

Lavadenz, I., & Deininger, K. (2001). *Mexico Land Policy - A decade after the Ejido Reform.* Washington, DC: World Bank.

Leichenko, R., & O'Brien, K. (2008). *Environmental Change and Globalization: Double Exposures.* Oxford University Press, USA.

Liverman, D., Moran, E. F., Rindfuss, R. R., & Stern, P. C. (Eds.). (1998). *People and Pixels: Linking Remote Sensing and Social Science.* Washington, D.C: National Academy Press.

Lynch, K., & Poole, N. (2006). Horticulture and Market Information at the Peri-Urban Interface: Agricultural Marketing in Tanzania. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 74-93). UK: Earthscan Publications Ltd.

Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing*, 25(12), 2365-2401.

McGregor, D., Simon, D., & Thompson, D. (2006). The Peri-Urban Interface in Developing Areas: The Research Agenda. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 313-325). UK: Earthscan Publications Ltd.

McShane, T. O., & Wells, M. P. (Eds.). (2004). *Getting Biodiversity Projects to Work: Towards More Effective Conservation and Development*. Columbia University Press.

Mella, J. M., & Mercado, A. (2006). La economía agropecuaria mexicana y el TLCAN. *Comercio Exterior*, 56(3), 181-193.

Montoya, N. (2010, January 21). Es Hermosillo de las 4 ciudades en crisis del agua. El Imparcial, 1/A.

Narain, V. (2009). Growing city, shrinking hinterland: land acquisition, transition and conflict in peri-urban Gurgaon, India. *Environment and Urbanization*, 21(2), 501-512.

Narain, V., & Nischal, S. (2007). The peri-urban interface in Shahpur Khurd and Karnera, India. *Environment and Urbanization*, 19(1), 261-273.

NWL (National Water Law). (1992). Mexican Congress.

Perz, S. G., & Walker, R. T. (2002). Household life cycles and secondary forest cover among small farm colonists in the Amazon. *World Development*, 30(6), 1009-1027.

Reza, F. (2010, January 22). Solicita Gobernador declarar emergencia por agua en Sonora. El Imparcial, 1/A.

Ridd, M. (1995). Exploring a V-I-S (Vegetation-Impervious Surface-Soil) Model for Urban Ecosystem Analysis through Remote-Sensing - Comparative Anatomy for Cities. *International Journal of Remote Sensing*, 16(12), 2165-2185.

Rindfuss, R. R., & Stern, P. C. (1998). Linking Remote Sensing and Social Science: The Need and the Challenges. In D. Liverman, E. F. Moran, R. R. Rindfuss, & P. C. Stern (Eds.), *People and Pixels: Linking Remote Sensing and Social Science*. Washington, D.C: National Academy Press.

Robbins, P. (2004). *Political Ecology: A Critical Introduction*. Wiley-Blackwell.

Sayer, J., & Campbell, B. (Eds.). (2003). *The Science of Sustainable Development: Local Livelihoods and the Global Environment.* Cambridge University Press.

Sánchez-Flores, E., & Yool, S. R. (2007). Sensitivity of change vector analysis to land cover change in an arid ecosystem. *International Journal of Remote Sensing*, 28(5), 1069-1088.

Schwentesius, R., & Gómez, M. Á. (2001). El TLCAN y el sector agroalimentario de México. *Comercio Exterior*, 51(6), 545-554.

Scott, C., & Banister, J. (2008). The dilemma of water management “regionalization” in Mexico under centralized resource allocation. *International Journal of Water Resources Development*, 24(1), 61–74.

de Sherbinin, A., VanWey, L. K., McSweeney, K., Aggarwal, R., Barbieri, A., Hunter, L. M., et al. (2008). Rural household demographics, livelihoods and the environment. *Global Environmental Change*, 18(1), 38-53.

Smith, M. (2007). Urban Expansion in Oaxaca, Mexico: Research on the Fringe. *Yearbook of the Association of Pacific Coast Geographers*, 69, 88-100.

Swyngedouw, E. (1999). Modernity and hybridity: Nature, Regeneracionismo, and the production of the Spanish waterscape, 1890-1930. *Annals of the Association of American Geographers*, 89(3), 443-465.

Swyngedouw, E. (2004). *Social Power and the Urbanization of Water: Flows of Power*. Oxford: Oxford University Press, USA.

Tacoli, C. (2006). *The Earthscan Reader in Rural-Urban Linkages*. UK: Earthscan Publications Ltd.

Treminio, R. (2004). *Experiencias en Agricultura Urbana y Peri-Urbana en America Latina y el Caribe, Necesidades de Políticas e Involucramiento Institucional*. Food and Agriculture Organization of the United Nations. Retrieved April 14, 2009, from http://www.rlc.fao.org/es/agricultura/aup/pdf/expe.pdf

Turner, B. L., Lambin, E., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences*, 104(52), 20666-20671.

Walker, P. A. (2005). Political ecology: where is the ecology? *Progress in Human Geography*, 29(1), 73-82. doi: 10.1191/0309132505ph530pr

Watson, R., Noble, I., Ravindranath, N., Verardo, D., & Dokken, D. (2000). Special report on land use, land-use change in forestry. *Intergovernmental Panel on Climate Change.*

Weng, Q. (2007). *Remote Sensing of Impervious Surfaces* (1º ed.). CRC.

Wilder, M. (2009). Political and economic apertures and the shifting state-citizen relationship: Reforming Mexico's national water policy. In *Water Policy Entrepreneurs: A Research Companion to Water Transitions Around the Globe*, ed. Dave Huitema and Sander Meijerink, 79-96. Cheltenham: Edward Elgar Publishing

Wilder, M. & Romero, P. (2006). Paradoxes of Decentralization: Water Reform and Social Implications in Mexico. *World Development*, 34(11), 1977-1995.

Wilder, M. & Whiteford, S. (2006). Flowing Uphill Toward Money: Groundwater Management and Ejidal Producers in Mexico's Free Trade Environment. In L. Randall (Ed.), *Changing structure of Mexico: political, social, and economic prospects* (pp. 341-358). Armonk, N.Y.: M.E. Sharpe.

Yuan, F. (2008). Land-cover change and environmental impact analysis in the Greater Mankato area of Minnesota using remote sensing and GIS modelling. *International Journal of Remote Sensing*, 29(4), 1169-1184.

Zimmerer, K. (1996). Ecology as Cornerstone and Chimera in Human Geography. In C. Earle, K. Mathewson, & M. S. Kenzer (Eds.), *Concepts in Human Geography* (pp. 161-187). Lanham, Maryland: Rowman & Littlefield Publishers.

APPENDIX A

WATER, CITIES AND PERI-URBAN VULNERABILITIES IN NORTHWEST MEXICO

Rolando E. Díaz-Caravantes and Margaret Wilder[4]

(For submission to Geoforum)

Abstract

There is growing consensus that the "sustainability" of urban expansion has been accomplished at the expense of the peri-urban zone. This urban/peri-urban interaction is frequently studied with a focus on the urban expansion necessities, and a good deal of scholarship chronicles aspects of issues concerned with land annexation, housing construction, and infrastructure. However, in arid regions such as Mexico's northwest, which is the most-drought prone region, research on urbanization must increasingly focus on the under-examined question of how access for urban *water* resources has been carried out.

Increasing interest in the political ecology of water in urban areas has developed in recent years. This paper draws on the notion of the "hydrosocial cycle" (Swyngedouw, 2004) to examine geographies of power at the urban-rural interface. We suggest that the notion of the "peri-urban" needs to be reconceptualized in the context of water—the peri-urban 'waterscape' is a broader concept defined by hydrological and geographic contours as well as political possibilities. Empirical research in the peri-urban region outside Hermosillo demonstrates that the ability to capture water flows and channel them to cities

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that may be at some geographic remove creates an ample 'peri-urban' phenomenon that is not as finitely bounded as in the case of land. Swyngedouw analyzes the way in which water is urbanized showing the flows of power in the process. Following this, we argue that urban water augmentation strategies reveal a distinct set of urban-rural relations of uneven social power where peri-urban water resources are “metabolized” (Swyngedouw 2004) in urban areas, reflecting the demands of powerful, politically connected urban individuals and populations over more disparate and marginalized rural producers. The Hermosillo case indicates that small-scale farming communities or *ejidos* are the most vulnerable water users because of their lack of political power in the governmental decision making process.

I. Introduction

Over the past two decades, small-scale farming communities or *ejidos* in Mexico have been challenged by a barrage of neoliberal transformations to land tenure, water policy, agricultural supports, and trade arrangements. Ejido members have turned to off-farm sources of income, renting and selling their land, and also to migration as strategies to maintain their livelihood. Now a new challenge looms for ejidos located close to cities at the urban fringe or in peri-urban regions.

Worldwide, peri-urban areas are affected by a growing demand for land. In Mexico, the demand for urban land annexations is aimed squarely at peri-urban ejidos. A World Bank document forecasts that two-thirds of the required land by major urban Mexican centers will come from peri-urban ejidos (Lavadenz & Deininger, 2001). Mexico’s northwest is the most drought-prone region, characterized by intensive commercial agriculture, severely over-exploited groundwater sources, and rapid urban growth. While the urban-peri-urban nexus has been examined in the context of land, limited scholarship analyzes the intensification of water demand from peri-urban areas.

Based on evidence from our NOAA-funded research,[5] this paper draws on the notion of the hydrosocial cycle (Swyngedouw, 2004) to examine geographies of power at the urban/peri-urban interface to answer the question of how access for urban water resources has been carried out. More specifically, this paper seeks to answer the following questions: What is the process shaping water transfers from peri-urban to urban areas? Why is water transferring from particular peri-urban areas rather than other areas? Why are peri-urban areas more vulnerable?

Following our findings, we argue that the notion of the 'peri-urban' should be reconceptualized in the context of water. We posit that the peri-urban 'waterscape' is a broader concept defined by hydrological flow, geographic contours, and political possibilities. The ability to capture water flows and channel them to cities that may be at some geographic remove creates a 'peri-urban' phenomenon that does not have as well-defined a boundary as in the case of peri-urban land. Ejidos in this region have historically had access to water when ejido communities were formed as part of Mexico's massive land reform program in the post-revolutionary period. Many of these ejidos are now being eyed by expanding cities for their water resources as well as opportunities for land expansion. Urban water augmentation strategies reveal a distinct set of urban/peri-urban relations of uneven social power where peri-urban water resources are 'metabolized' in urban areas, reflecting the demands of politically connected urban populations over more disparate and marginalized rural producers.

This paper draws on research conducted in 16 ejidos in the peri-urban region outside the urban boundaries of the city of Hermosillo, the state capital of Sonora. Sonora is a northwest state that shares a 390-mile border with the state of Arizona in the United States. The research was carried out in a 10-month period from June 2008 to March 2009; the study of the ejido Molino de Camou was initiated in 2000-2001 and updated in the

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[5] This study was part of two larger projects, both funded by the National Oceanic and Atmospheric Administration (NOAA) on water, urban growth, and adaptation to climate change in southern Arizona and northwest Mexico, including Climate Assessment of the Southwest (CLIMAS) Program; and a NOAA Sectoral Applications Research Program (SARP), Moving Forward: Adaptation and Resilience to Climate Change, Drought, and Water Demand in the Urbanizing Southwest and Northern Mexico.

recent fieldwork period. First, we conducted around 60 open-ended and semi-structured interviews with ejidatarios and approximately 20 semi-structured interviews with federal, state, and local water officials, as well as academics from the region, in order to determine how urban water infrastructure has affected peri-urban ejidos. After that, we conducted 82 intensive written surveys with ejido members. Basically, the survey was divided in 6 sections: agricultural diversification, livestock production, land tenure and water rights, climate risk strategies, household information, and labor and migration of household's members[6].

Based on our results, we suggest that the notion of the peri-urban 'waterscape' is more flexible—more fluid!—than the peri-urban landscape due to the specific properties of water that allow flows to be transported from distant peri-urban regions to a major city. As more powerful cities reach into politically marginalized rural communities and gain access to their water resources, peri-urban farming communities risk loss of their access to water resources under conditions of intensified urban demand. The empirical evidence presented in this study demonstrates how this risk is exacerbated under conditions of drought, scarcity (whether discursive or 'natural'), and projected climate change.

II. Water Policy on the Urban/Peri-Urban Interface

Increased scholarly attention has focused on the developing "crisis" in water availability and water quality, shifts in international water policy, and the growing need for implementing water conservation strategies. In general terms, long-term population and economic growth drive this water management transformation. Increasing demand has made water a relatively scarce resource. Such scarcity, in turn, has ratcheted upward conflicts and disputes among competing water user groups.

Distinct strategies to deal with the water scarcity problems exist. One emphasis on the water scarcity debate highlights the necessity of implementing water markets (Briscoe, 1996; Thobani, 1995). This approach has received broad attention since the

[6] For a broader description of the survey process see Díaz-Caravantes (n.d.)

1990s. Particularly significant was the International Conference on Water and the Environment, held in Dublin in 1992, from which emanated the "Dublin Principles." The fourth Dublin principle states: "[w]ater has an economic value in all its competing uses and should be recognized as an economic good" (Global Water Partnership Technical Advisory Committee (TAC), 2000, p. 14). Water as an economic good has been the subject of much controversy. The principal argument against this approach is that water is a basic human right, therefore applying market forces and pricing to its allocation is as an unacceptable approach (Bauer, 2004; Gleick, 1996). A middle point is that water should be recognized as a scarce resource, which means that water resources are insufficient to be suitable for all demands, and therefore trade-offs are necessary (Bauer, 2004: 10).

On the other hand, many scholars and practitioners have emphasized that water scarcity is a problem of water governance (Conca, 2006; Bauer, 2004; Bakker, 2003; Global Water Partnership Technical Advisory Committee (TAC), 2000). For example, the Integrated Water Resources Management (IWRM) approach, promoted by the Global Water Partnership (GWP), is focused on providing a broad set of guidelines that "promotes the coordinated development and management of water, land and related resources" (2000, p. 22). The process of decentralization is a permanent concern in regard to water governance issues as well. In the case of Mexico, water decentralization has been crystallized in the implementation of River Basin Councils, the *transfer* of irrigation districts to management by water users, and the privatization and decentralized management of urban water systems (Scott & Banister, 2008; Wilder & Romero, 2006; Lara, Whiteford, & Marquez, 2005).

The international water debates and approaches also have an important influence in the Mexican water policy. Wilder (2009) argues that the 1992 water policy shift in Mexico, was marked by a free market agenda and driven by the government's inability to fix a broken water system during the late 1980s. The new policies derived from a context of global water reform prescribed by the World Bank and other international financial institutions for developing countries around the world, with the. World Bank and the Inter-American Development Bank providing close to 50 percent of the total projected costs of

the water reform program in irrigation districts (Wilder and Whiteford 2006). From the outset the water policy reform has been aligned with free market and privatization agendas but also linked to decentralization and sustainability. It is this context the National Water Law (NWL) was established in 1992, directed by the *Comisión Nacional del Agua* (CONAGUA).

In April 2004, a new National Water Law was enacted, which modified the NWL of 1992. Some issues of the NWL of 1992 (and 2004) address water markets. One of this is that now users are free to trade their rights within irrigation districts or aquifers with no intervention from the CONAGUA (Garduño, 2005: p.104).

Regarding water governance in cities, the NWL of 1992 and 2004 allows the privatization and decentralized management of urban water systems (Wilder & Romero, 2006; Pineda, 1999). According to Wilder and Romero (2006), cities increasingly acquire water rights as a way to expand urban supply. As an example, they indicate that Mexico City already relies on imported water to meet 30% of its local demand. Examining the case of several cities in Baja California cities, although water management was decentralized, the cities still experience water scarcity due to overexploitation of local aquifers affected by competition from commercial agriculture (Wilder and Romero 2006). Although the state's innovative management scheme led to real efficiency gains and expansion of water services, it did not deal with broader issues such as rural–urban competition for the resource.

This study examines how a decentralized urban agency, as the case of Hermosillo, deals with water scarcity and through which mechanisms, such as water markets, face the competition between the city and other users.

III. Political Ecology of Water

Water governance and economic approaches are critical to find alternatives for addressing the shortcomings of water management. However, particularly regarding peri-urban/urban water issues, the social vulnerability and power relations of water users

associated with growing water problems have been even less scrutinized. These socio-ecological changes can be addressed under the framework of political ecology.

Political ecology has become firmly established as a dominant field of human-environmental research in geography. One of the most significant contributions to human-environment research is that political ecology provides, in contrast to the more positivists human-environment approaches, theoretical tools to address the larger political and economic factors that contribute to environmental change (Walker, 2005; Robbins, 2004; Zimmerer, 1996). Specifically, Blaikie and Brookfield's (1987) work gave to the human-environment approaches a "chain of explanation" from the perspective of a broadly defined political economy. Thus, some of the contributions of political ecology are key concepts such as marginalization, political economy, and markets, which help to study a more comprehensive human-environment interaction. Two key notions especially have a great influence on the development of political ecology: (1) that social and cultural systems are based on historical material conditions and relations, and (2) that capitalist production requires the extraction of surpluses from labor to nature (Robbins 2004: 46).

Political ecology has increasingly focused on water issues in recent years. Political ecologists utilize water as an analytical lens through which to examine relations of power, shifting access to resources under processes of economic restructuring and political transformation, and the complex interplay of multi-scaled forces (such as markets and government/civil society institutions) in particular contexts. One of the most prominent conceptual innovations in political ecology of urban water is the called *hydrosocial cycle* (Swyngedouw, 2004; Bakker, 2003). The hydrosocial cycle emphasizes the idea that "the circulation of water – as a physical and social process – brings to light wider political economic, social, and ecological processes" (Swyngedouw, 2004, p. 2). Unlike the hydrological cycle, which is focused on the physical environment, the hydrosocial cycle highlights how water should not be abstracted from the social ends and power relations that give it meaning (Budds, 2008; Bakker, 2003). In doing so, not only is human agency lost but processes that inherently involve the physical, the spatial, the social, the institutional and the economic are viewed in incomplete, even misleading

terms. For this research, the hydrosocial cycle sheds light on the urban/peri-urban unequal power relation, in which urban interests prevail over peri-urban water rights.

The hydrosocial cycle not only highlights the fact that natural resources are appropriated through social processes, but also brings to light the notion that social processes produce the transformation of nature (Swyingedouw, 1997). The separation of "nature" and "society" or "culture" into two distinct domains have been considered problematic because in many cases have been demonstrated that nature's results is inseparably associated with societal issues (Swyngedouw, 2004). For that reason nature and society should not be considered as separable, but should be reconceptualized as a hybrid, as a socio-nature (Swyngedouw, 2004). Drawing on this idea, the hydrosocial cycle aims to examine how new socionatural landscapes are constructed by the negotiation and mediation of differential political power relations in specific contexts.

The inseparability of nature and society implies that nature to some degree has been transformed or metabolized by society/culture. In the same way a living organism metabolizes nutrients into energy via processes of circulation, exchange and transformation of material elements, urban expansion metabolizes water through processes of social-natural transformation reflective of differential power relations (Swyngedouw, 2004, p. 16).

IV. Peri-Urban Areas and the Hydrosocial Cycle

The peri-urban area of a city is immediately implicated in a city’s drive to expand. Swyngedouw (2004) anticipates this focus on the water resources of peri-urban areas as the city is driven to expand, and urban expansion necessarily requires pushing on the urban water frontier (2004, pp. 37-38). Peri-urban areas are an integral part of the urbanization of water. Since water is expensive to transport across long distances, cities attempt to find water sources as close as possible to existing urban boundaries. This process promotes a new peri-urban water landscape or "waterscape," in which is

constructed a new socionatural space that reflects the relations of power inscribed therein (Swyngedouw, 1999).

Peri-urban regions resist easy definition (McGregor, Simon, & Thompson, 2006; Tacoli, 2006; Brook & Davila, 2000), but following the sense of the prefix peri, can be defined as the immediate zone that surrounds a city's existing boundaries. However, this territorial definition does not satisfy many scholars because according to them, the peri-urban is best understood as a series of flows or processes or interface of good and services between the rural and urban areas (Narain & Nischal, 2007; Allen, 2003; Brook, Purushothaman, & Hunshal, 2003). Each peri-urban area has properties unique to its context, and may manifest urban, rural characteristics a mix of both. The peri-urban area may be a kind of transition zone with more urban characteristics in the area closest to the city boundary and a more rural character at its edge farthest from the city boundary. Alternatively, peri-urban areas may have sketchy patches of both, the urban and rural dotting the peri-urban zone's landscape, or in some cases, there may be a crisp edge to the urban boundary that marks a clear demarcation with an essentially rural area beyond the boundary. The peri-urban transition zone between urban and rural areas defies universal definition and is best understood as context-specific. A peri-urban region can best be understood as an area of transition along an 'urban-rural gradient' (McGregor et al., 2006, p. 10).

In the case of the peri-urban zone of Hermosillo, most of the ejidos manifest distinctly rural characteristics. However, we classify them as peri-urban ejidos because of two characteristics. First, there is a geographical feature. Although the concept of a peri-urban waterscape is broader and more flexible than that of a peri-urban landscape, the relative proximity of the ejidos to the city continues to be a fundamental characteristic that make a distinction from other ejidos located in distant rural areas. Second, peri-urban processes of exchange and transfer (of labor, goods and services) continues to be a key feature of these ejidos Such exchanges may be regarding natural resources such as forest, land, or pollution (Allen, 2003), or as the Hermosillo case discussed here, water. The peri-urban is the place in which the rural-urban interface is more intense in economic

good and services such as peri-urban agricultural products to urban markets or urban jobs for the peri-urban residents (Douglas, 2006; Lynch & Poole, 2006).

Existing scholarship has chronicled the urban-peri-urban phenomenon in terms of land annexation, housing construction, and infrastructure issues, but the question of mining peri-urban water resources to serve urban needs has not received much scholarly attention[7]. For example, three recent edited volumes on the peri-urban interface do not address urban/peri-urban water transfer (McGregor et al., 2006; Tacoli, 2006; Brook & Davila, 2000), nor does a World Bank study on the implications of urbanization for peri-urban areas (Lavadenz & Deininger, 2001). Lavandez and Deininger (2001) found that urban expansion of Mexico's 110 major cities "represents one of the greatest challenges for the agrarian sector during the coming decades" (p.18). It is forecast that these major urban centers will require 700,000 new housing units each year, and that over two-thirds of the land required for this expansion will come from the ejido sector—specifically, from peri-urban ejidos located at the edges of cities (Lavadenz & Deininger, 2001, pp. 18-19). Undoubtedly, land use change from agricultural to urban use is one of the most important effects of urban sprawl on rural livelihoods. However, the link between rural livelihoods and water use due to ejido-urban transfers is critical as well. Water use for economic livelihoods in peri-urban areas is quite important because many income activities, such as agriculture and horticulture, depend on the availability of water (Allen, Dávila, & Hoffman, 2006; Treminio, 2004). For those involved in these activities, lack of water due to urban water demand poses a serious threat to their livelihoods.

When peri-urban land is targeted for urban expansion of housing or infrastructure, those land areas are brought into the urban area via annexation. They change in status from peri-urban to officially urban; jurisdiction of the area may move from one set of government arrangements to another, more local, government; residents of the peri-urban area become citizens of the urban area with the privileges and responsibilities that obtain

[7] A significant exception is the volume *Wastewater Use in Irrigated Agriculture: Coordinating the Livelihood and Environmental Realities* (Scott et al., 2004), in which peri-urban wastewater use in agriculture in arid and semi-arid regions is discussed.

to that status.[8] In the case of peri-urban water resources, the equation is quite different. The city's professional staff of engineers and planners, appropriately make plans for increasing the growing city's water supply, and design the most cost-effective strategies that lead them to look as nearby as possible for new water sources close to the urban boundaries. The politicians weigh the political ramifications of the proposed set of alternatives, and factor in where they are likely to meet greater acceptance or resistance. The city takes an action that turns off the spigot for the peri-urban water user, and diverts those water resources to new urban uses. The peri-urban water user stays in place, while his or her water resources are transported and used within the city boundaries, in many cases, kilometers away. The peri-urban water user's status does not change; he or she remains a resident of the same community under the same governmental authority. But the water that supported the livelihood of that water user is no longer available. The hydrosocial cycle thus works to produce a new non-productive social landscape in the peri-urban area. But peri-urban areas are not without agency; some can organize to resist the urbanization of water successfully, while others cannot. Given uneven power geometries that exist in the urban-peri-urban interface, some peri-urban areas are able to resist the urbanization of water, while others are more vulnerable.

Ejido communities are the most marginalized and impoverished in Mexico. Ejidos are small-scale communal lands that were created as part of Mexico's massive land reform in the postrevolutionary decades of the 1930s and 1940s to satisfy the demand by landless *campesinos* for land. By 1980, half of Mexico's cultivated land was in ejidos. During the 71 years of one-party governance by the PRI (Institutional Revolutionary Party), ejidos and campesinos were an important part of the clientelistic structure and were able to negotiate resources in exchange for political support and loyalty. Since Mexico began its neoliberal economic reforms in the late 1980s, ejidos have experienced an economic squeeze based on trade liberalization, loss of subsidies, and scaling back of

[8] Peri-urban areas in the context of the United States would likely be within the local jurisdiction of an unincorporated county, and after annexation, would become part of a city's jurisdiction. In the Mexican case, peri-urban areas are already within the municipality (municipio), which combines the functions of city and county, and therefore would likely not change jurisdictional status after annexation.

state credit and support (Wilder & Romero, 2006; Whiteford & Melville, 2002; De Janvry et al., 1997). Due to processes of urbanization and privatization, and in a context of scarcity, ejidos in Sonora have lost access to water resources in commercial irrigation districts and peri-urban areas (Díaz & Camou, 2005). Over the last two decades of growth and expansion, as cities have reached outward for land, historically rural ejidos have in many cases become part of a peri-urban area (Lavadenz & Deininger, 2001).

Scarcity is a major driver of the process of the urbanization of water in the Hermosillo area as shown in the next section of this paper. Building on Smith's (1984) arguments about the social production of nature, Bakker (2003) illuminates how increased demand or conditions of drought produce water scarcity and drive a "frantic" search for scarce resources by capital, arguing that scarcity benefits capital by fostering the accumulation of 'scarce' resources. Scarcity of water supply, or the perception of scarcity, is a significant driver of processes of urbanization of peri-urban water resources in Hermosillo. Northwest Mexico is a highly vulnerable region, due to rapid population growth, industrial development, and agricultural intensification over the last 30 years, and particularly due to climate-related factors (Liverman & Merideth, 2002; Ray et al., 2007). A semi-arid region with low annual precipitation levels that average only 450 mm, according to Comisión Nacional del Agua the northwest is the country's most drought-prone region (CONAGUA, 2007). The most recent 10-year drought caused huge economic losses in the ranching and agriculture sectors, and caused some cities to ration water for the first time. Sonora is the most highly-irrigated state in Mexico, with 7 major irrigation districts located primarily along its western coast. Its coastal aquifers are among the most severely overdrafted in the country and saline intrusion is a significant problem (CONAGUA, 2007). Due to its location on the Gulf of California coast, Sonora is highly vulnerable to intraseasonal, interannual and interdecadal climate variability that contributes to extreme climate events, including both floods and drought (Hallack-Alegria & Watkins, 2007; Magaña & Conde, 2000; Comrie & Glenn, 1998). In addition to climate variability, climate change is projected to increase temperatures and create drier conditions over the next 25 to 50 years, leading to reduced water supply and severe

and prolonged droughts (Christensen et al., 2007; Seager et al., 2007). Climate change will exacerbate existing problems of increased water demand from growing cities and intensified agriculture, competition amongst water using sectors, and the decline of water quality (Magaña & Conde, 2000).

Because of its rapidly growing urban sprawl, its climate conditions, and the existence of peri-urban ejidos that depend on water resources, the city of Hermosillo and its surrounding countryside illuminate how the peri-urban zone is affected by urban water demand as shown in the following section.

V. Empirical Case Study Findings

In the first part of this section, we present the key turning points of the recent history of Hermosillo's water scarcity. As shown in this section, most of the projects to provide water to Hermosillo were implemented in the peri-urban area, negatively affecting the peri-urban ejidos. This disproportionate emphasis on the peri-urban area is not based only on technical or physical conditions, but is also based on power relations. In order to demonstrate this point, we contrast the water transfer proposals of the peri-urban ejidos with large powerful water users, referred to in this paper as "counterpoint cases", because these cases shown the contradictory water policy that treats favorably powerful water users and in which less influential users, peri-urban ejidos, are the losers.

Key turning points in Hermosillo's contemporary water history

The development of a perception of water scarcity as Hermosillo grew over the past twenty years is key to the increasing focus on peri-urban water resources. With a total population of about 650,000, the city of Hermosillo is the vibrant center of the northwestern state of Sonora, Mexico, which shares its northern border with the United States (see Figure 1). In Mexico in 2005 there were 34 cities with more than 500,000 inhabitants, similar to Hermosillo (INEGI, 2005); 20 are located in states with a strong

pressure on water resources (CONAGUA, 2007). Hermosillo's case illustrates a broader phenomenon occurring in developing countries where rapid population growth is taking place in arid regions.

Figure 1

The economy of Hermosillo is based on the automotive, manufacturing, service, and tourism industry. The *maquila* (foreign-owned assembly plants) industry employs 28 percent of the economically active population and generates 47 percent of Hermosillo's income.

The principal key turning points in Hermosillo's contemporary water history occurred in 1981 and 1996 (in bold italics letter in Table 1).

Table 1

From the time the Abelardo L. Rodriguez dam (ALR dam in Figure 1) began operations in 1948 until 1981, the city's water was supplied by wells located very close to the dam's outlet (del Castillo, 1994, p. 72) and the dam's water was used exclusively for agricultural purposes. However, in 1981 the state government reallocated the water impounded by the ALR dam from agricultural to domestic use (del Castillo, 1994). According to an academic interviewed during the fieldwork, the motivation for the change in water allocation was primarily population growth in concert with increasing industrialization. From 1970 to 1990, Hermosillo's population increased by 130% (about 230,000 inhabitants). This demographic change is explained by Hermosillo's rapid industrialization, especially the Ford plant which opened in 1984 with the capacity to produce 130,000 units per year and which generated 1,200 direct jobs (Ramírez, Conde, & León, 1997, p. 187). From the perspective of this study, 1981 is crucial because it began the era of water transfers from peri-urban agriculture to urban purposes.

The second key turning point came in 1996. Prior to that year, the Sonora River Basin (gray color in Figure 1) had experienced more than a decade of about 45% above

average streamflows. Since the water crisis began, however, from 1996 to 2005 the Sonora River basin registered about 42% below the average streamflows and therefore the city's supplies drastically diminished (see Figure 2).

Figure 2

The 1996 water crisis was the beginning of desperate efforts to provide water to Hermosillo, efforts which did not always achieve complete success because in some years, especially between 1998 and 2005, the city had to ration water to households by means of *tandeos* (staggered turns). According to the municipal water provider, *Agua de Hermosillo* (AGUAHH), with the tandeos water is provided by turns to different sectors of the city, resulting in a sector receiving water for certain hours of the day (AGUAHH, 2007). Although necessary, the strategy was not well accepted by the citizens, especially because some sectors of the city received water for fewer hours than the authorities had designated, which according to the authorities was due to technical limitations in the water distribution network (Salazar, 2005a).

The water shortage of 1996 also triggered a competition between urban and agricultural water users. Figure 3 shows the city's contemporary water supply proposals, in which four main agricultural regions have been proposed as potential water suppliers: a) the Hermosillo Coast irrigation district, b) the Yaqui Valley irrigation district, c) Pesqueira, d) and the Hermosillo's peri-urban area.

Figure 3

What has happened in and among these regions from a hydrosocial perspective speaks to the power relations and differentiation embedded in urban water reallocation during the period from 1996 to the present. This time has been very remarkable in terms of the number of urban water projects; however, these projects have been disproportionately focused on ejidos in the peri-urban area. The city's water transactions

involving the peri-urban ejidos have been either coercive or insensitive to the livelihood needs of the ejidos as shown below.

Peri-Urban Ejidos

As we shown in this section, the peri-urban area is the region most targeted by Hermosillo's water supply strategies and, therefore deserves a detailed examination. This research is focused on the 16 peri-urban ejidos (Figure 4) for several reasons: ejidos are the most prominent representative of the rural sector in Mexico because they represent half of the cultivable land in Mexico and ejidos represent the most visible social sector of the rural population; in other words, one cannot talk about Mexican rural society without talking about ejidos. Second, ejidos are constituted of many producers and therefore many families; thus, by examining effects on ejidos, the social impact of urban water supply strategies on the largest number of the most affected and vulnerable rural people is studied. Third, Hermosillo's water supply augmentation strategies have had severe impacts on ejidos' access to water, more so than on any other regions. Finally, private landowners located inside the peri-urban area have individual land tenure and, in this case, their land is more fragmented than ejidos and it would be a thorny research effort to collect information of each affected person.

Figure 4

As designated in Figure 4, these ejidos can be divided by location: from A to L are the city's upstream peri-urban ejidos and from M to P the downstream ejidos. The downstream peri-urban ejidos belong to the Presa ALR Irrigation District, which has a maximum of 13,000 irrigable hectares and is comprised of private landowners and four ejidos: Villa de Seris, La Manga, La Yesca, and San Miguel. Currently, these users receive Hermosillo's wastewater. The upstream ejidos are not grouped in any water organization. Except for El Molino de Camou and Codorachi (L and G, respectively) that

have surface water, all the ejidos use (or used) groundwater. In fact, as displayed in Table 2, groundwater is the primary source of water in the Sonora River basin, accounting for about 88% of the total water rights.

Table 2

The Sonora River basin embraces a total of 15 municipalities with a total population of 771,342 in 2005, of which 83% live in the city of Hermosillo (CEA, 2008). According to REPDA, inside this basin, the principal water uses are agriculture with more than two thirds of the total volume of water rights and urban with 18 percent. Inside the peri-urban area that embraces the 16 ejidos (the square area that appears in Figure 4), groundwater comprises an even higher percentage of total volume, at with about 97% percent. As in the basin, the major water uses in the peri-urban ejido area are agriculture and urban, but the proportion considerably varies. Of the total assigned rights inside the peri-urban ejido area (158,241,997 m^3) about 38% is for urban purposes (primarily drinking water use). Of this 38% granted for urban use, 94% is assigned to the city of Hermosillo. This data confirms that even inside the peri-urban ejido area the city of Hermosillo is the major water user.

The ejidos examined in this case study have around 32,000 hectares with about 1,000 total ejido members, and were created in the 1930's (with the exception of San Miguel, created in 1987). The following table provides basic characteristics of these ejidos.

Table 3

The principal productive activities in these ejidos are small-scale irrigated agriculture and small-scale cattle ranching. Ejidos that used to grow wheat in the fall-winter growing season and corn and beans in the spring-summer season have now turned primarily to growing grass to feed livestock. The principal destination of the calves is the

U.S. beef market. The ranching ejidos have an average of 11 head of cattle per ranching *ejidatario*. The farming ejidos have an average of 5 irrigable hectares per ejidatario; due to urban water supply strategies that we analyze in this paper, many ejidos have lost their irrigation water and have had to abandon active production. To supplement their incomes, most ejido families have off-farm sources of income from men working as day laborers on private farms in the vicinity or as skilled laborers (brick layers) around the ejidos or in the city of Hermosillo, and multiple family members contributing to total household income (De Janvry et al., 1997). Although this research examined 16 peri-urban ejidos, for analytical purposes, in this paper we discuss in detail three categories of cases (not each individual case) that illuminate specific processes that frame the way ejidal water resources have been 'taken' and with what responses from the ejidos:

A. Reshape and negotiate; B. Passive; and C. Resistance.

A. Reshape and negotiate (Presa ALR irrigation district and Ejido Molino de Camou)

In 1981, the state government decided to use the water of the dam for domestic use (del Castillo, 1994). This water transfer affected the Presa ALR irrigation district (the downstream ejidos), which, until that time was the primary user of the water contained in the ALR dam impoundment. After a couple of years of protest and negotiation, the state government agreed that, as compensation, the irrigation district could use urban wastewater mixed with dam water. Yet, in 1996, all water contained by the ALR dam was designated for Hermosillo's water supply, and since that moment the irrigation district has solely used Hermosillo's untreated wastewater (Pallánez, 2002). Although using residual water has evident disadvantages concerning health and environmental issues, some water users of this district believe this transfer helps them. Before the Presa ALR Irrigation District started to use residual water, the availability of water depended completely on the availability in the ALR dam water, and the irrigated area in the district varied drastically (Moreno, 2006, p. 144). Since 1996, the availability of water depends

entirely on the city's residual water. In this regard, some ejidatarios stated that this water transfer from freshwater to wastewater benefited them because now they have more certainty of water availability. The ejidatarios stated that now they experience water shortages only during vacation periods because most of the city's residents leave town and the residual water significantly decreases. The untreated wastewater is also a limitation on what crops it can be used to irrigate. Ejidatarios stated in interviews that they cannot grow alfalfa and vegetables, for example, because the wastewater will "burn" them.

The ejido Molino de Camou is an additional case where a peri-urban user was able to negotiate with the city. In 1998, the Molinito dam started to be used for the urban water supply. According to the explanation of a CONAGUA's agent, since that time, the Molinito dam is used to store water and release it through the Sonora River to recharge the aquifer Mesa del Seri-La Victoria, which is used to provide water for the city via the urban wells located in that area. The ejido most severely affected by this change was the ejido Molino de Camou because CONAGUA started to restrict the surface water for the ejido with a volume that was not enough even for one growing season (Díaz & Camou, 2005). However, this restriction changed with the most recent city water supply project. In 2008, an aqueduct was implemented to provide 1,500 lps from the outlet of the Molinito dam to the water treatment plants located very close to Hermosillo (AGUAHH, 2007). This project was envisioned at the time of Hermosillo´s water crisis in the mid-1990s; however, by a fortuitous circumstance, the project was actually brought to completion in part due to the fact that the mayor of Hermosillo by that time was of the same (PRI) party as the governor. The ejido Molino de Camou benefited from this project because the aqueduct, due to terrain characteristics, passes through the ejido's land, and AGUAHH had to negotiate with the ejido Molino de Camou. AGUAHH agreed that the ejido can get water from the aqueduct. This ejido also was able to negotiate with CONAGUA to increase its water right from 1.4 to 2.1 Mm^3 (about a fifty percent

increase)[9]. Due to neoliberal reforms, particularly the Article 27 ejido land reform issued in 1992, about half of the ejidatarios of Molino de Camou have sold their lands to wealthy producers from Hermosillo, some of them very influential in state policy, such as one new "ejidatario" who has been secretary of many state agencies[10]. This may explain the ejido's success in negotiating water rights, and that sheds light on the importance of power and social dynamics in negotiating water issues.

B. Passive (Ejido La Victoria and Ejido Mesa del Seri)

Due to the increase of urban water demand in the 1980s, eleven wells were established in 1986 in ejido La Victoria, located in the northeast of the city, very close to the ALR dam (del Castillo, 1994). In interviews, ejidatarios from La Victoria say that during the period from 1986 to the mid 1990s water availability was not a big problem. However, as we established, from 1996 to the present (except for 2006-2007) the Sonora River basin has registered below-average flows. Due to this water shortage, in 1996 the state government constructed an infiltration gallery for collecting sub-surface flows from the river. The structure was located on the outside-edge of the ejido La Victoria's agricultural land. The infiltration gallery provided around 500 lps for two years; yet, because of the lack of streamflows in the Sonora and San Miguel Rivers, it did not operate after 1998. The infiltration gallery now is used as a part of the pumping system, but no longer for its original purpose (AGUAHH, 2007, p. 22). Ejidatarios from La Victoria state that this system was the beginning of a water shortage in their own wells. Before 1996, the ejidatarios had shallow wells that extended to about 40 feet below the surface. After the infiltration gallery was constructed, the ejido wells dried up. The ejidatarios argue that they cannot compete with the city's wells, which go to hundreds of feet below the surface and are located outside yet adjacent to the ejido boundaries. Evidently, the infiltration gallery in conjunction with the installation of urban wells (in 1986) and the water

[9]The water right of 1.4 Mm^3 was verified in a document of the ejido (CONAGUA, 1991). The water right of 2.1 Mm^3 was verified through REPDA.

[10] The changes in ejido land rights was verified through the Registro Agrario Nacional (National Agrarian Registry).

streamflow shortage in the rivers due to the drought were the perfect combination to adversely affect the ejidatarios' wells.

Similarly, in order to fulfill Hermosillo's water demand, 14 wells were established in the summer of 1998 in the so-called Mesa del Seri area, located near the ejido Mesa del Seri, very close to the ALR dam. As was the case with ejido La Victoria case, the ejidatarios of Mesa del Seri said that they had artesian wells and they could find the water at 40 feet below the surface. According to the farmers, these urban wells significantly harm their own water supply and now many agricultural parcels are dried up and abandoned.

These two ejidos exemplify a passive reaction to water transfer because they did not receive any compensation, and they did not react to the taking. The gradualness of the process, which is evident in the case of La Victoria, explains why there was no response. The location of urban wells, which are located outside the ejido's land, also explains this passivity. The location of the urban wells and the uncertainty of groundwater dynamics complicate the empirical evidence of the water transfer. By contrast, surface water users in Presa ALR irrigation district and ejido Molino de Camou had an easier task in making their case.

C. Resistance/agency (Las Malvinas case)

In 2006, for the first time, a project was implemented in which a private company supplied 250 lps of water to the city through an aqueduct of around 17 kilometers from 2 wells located in the Las Malvinas zone in the San Miguel River watershed, situated to the north of Hermosillo (AGUAHH, 2007). This is the basic information that appears in a document of AGUAHH (2007); however, what is not reported is the conflict and resistance to this project by many ejidatarios. The reason behind the protest was clear: these urban wells supplying the aqueduct would take the water used by their agricultural wells. Although the principally affected ejidos were Codorachi, El Torreón, La Labor, and El Carmen, ejidatarios from El Zacatón and Zamora stated that in some degree they

were adversely affected, and for that reason they also participated in the protest. Although they did not protest in their own case, some ejidatarios interviewed in La Victoria and Mesa del Seri said that they also participated in solidarity in this conflict because they did not want to see their own history repeated when, in the 1990s, the city introduced wells in the aquifer of La Victoria-Mesa del Seri and dried up their agricultural wells.

The Malvinas project was announced in 2004 as the first transfer that initiated the age of "water marketing" in Hermosillo (Del Río Sánchez, 2005, p. 93). In 2004, the contract was signed with the water suppliers, who were private land and water owners located very close to the aforementioned ejidos. According to the major, the Malvinas water would ensure Hermosillo´s water provision for the summer of 2005 and beyond. In the contract between AGUAHH and the water suppliers was established that the private company would be responsible for constructing and operating the aqueduct for 20 years, in which AGUAHH would pay to the company, and, at the end of that period, the infrastructure would be transferred to AGUAHH. At the end of 2004 the construction of the aquifer was initiated, yet a month later, around 200 ejidatarios stopped the work with a blockage (Montoya, 2010). The work remained stopped until in May 2005 (5 months after the taking) state and municipal police officers displaced the ejidatarios from the works, and re-established the ejidatarios' new campground far from the construction zone (Salazar, 2005b). After this relocation, the resistance movement started to disappear. By the end of 2005, the resistance was completely dissolved (Figueroa, 2008). According to interviews in one of the affected ejidos, Codorachi, the agricultural ejido´s well dried up when the aqueduct from Las Malvinas started to operate. This information was confirmed by CONAGUA officials in interviews. An urban well, *La Tijera,* which is part of the Malvinas project, the water table descends down to 30 meters every year[11] and this over-pumping dried up the wells of the surrounding ejidos (personal interview conducted in March 20, 2009). As a consequence, the irrigated land of Codorachi was reduced from 120 to 40 hectares. They continue irrigating thanks to a surface water source they have

[11] According to these agents, if the water table descends 1 meter for year is too much.

had since de 1930s, yet, if they had to depend on the groundwater, they would have no water at this time. The resistance to the Las Malvinas project slowed down the state's plan but could not stop it. The power differential between small ejido farmers and major urban interests was too great to be overcome.

In this section, we see that ejidos in the peri-urban area have largely been unable to resist the city's growing demand for water, and have lost access to their water resources in many cases. In this study we demonstrate that the focus on the peri-urban region as a source of water is not a hydrographical or physical coincidence. In an interview, a manager of AGUAHH state that finding water for the city is a "big problem because wherever you look (for water) you find political opposition, particularly from large irrigation districts." This comment let us know that water supply involve political power. The method to demonstrate this point consist of examining two "counterpoint" cases (regions a, b, and c in Figure 3), which are large and influential irrigation districts successful in challenging and ultimately taking advantage of the water augmentation strategies advanced by the city of Hermosillo, unlike to the case of peri-urban ejidos.

Counterpoint cases

A. Desalination Proposal and the Hermosillo Coast Irrigation District

The Hermosillo Coast irrigation district, established in 1945, is located to the southwest of Hermosillo with its western edge near the Gulf of California. The district it is able to irrigate 66,296 hectares. This is the biggest groundwater irrigation district in Sonora. It has a water concession granted by CONAGUA for around 409 Mm^3; the source of district's water is the aquifer of the same name located in the same area[12]. The district is principally a producer of table and industrial grapes, oranges, nuts, and vegetables for

[12] According to CONAGUA (2007) this aquifer has been highly overexploited and is one of the many Mexican aquifers that have the problem of saline intrusion. As an example of this overexploited trend, in 2002, the recharge to the aquifer was 250 Mm^3, but the actual extraction was of 527 Mm^3; more than the recharge, and even more than granted by the water concession (SAGARHPA, 2005).

exporting to the U.S. market. The Hermosillo Coast produces about 31% of the total revenues from agriculture in irrigation districts of Sonora (CEA, 2008). In this district there are 1,957 water users, including people who are very influential in the internal politics of the city of Hermosillo (Moreno, 2006; Martínez, 2002). Over 70% of the total water volume granted in the Hermosillo Coast district is used by large private producers, and just 4.2% by ejidatarios (Martínez, 2002).

After the 1996 Hermosillo water crisis, the state government proposed the construction of a desalination plant to supply water to the city. The project would have established a battery of wells located close to the coast[13]. The Hermosillo Coast irrigators were totally opposed to this proposal, arguing that this project would cause irreversible damage to the aquifer because it would create problems of saline intrusion. In reaction to this protest, the governor changed the project so it would pump groundwater nearer to the coastline, thereby avoiding irrigation district aquifers. The mayor of Hermosillo also opposed the desalination plant, mainly arguing that the cost of the water would be too high and the city had other options to obtain water such as an aqueduct from the Molinito dam. Finally, in 2001, the mayor requested the transfer of the urban water administration from the state to the municipality of Hermosillo. Once urban water management was transferred to the municipality in 2002, the mayor dropped the desalination project (Pineda Pablos, 2006, p. 242). The defeat of the desalination proposal demonstrates the political power of large private producers in the Hemosillo Coast irrigation district, many of whom are or had been elected officials in the city of Hermosillo (Moreno, 2006, pp. 487-500).

The Hermosillo Coast growers even found a way to benefit from the city's water crisis. Among the options Hermosillo's mayor proposed in 2001 was to buy water rights from the Hermosillo Coast irrigation district. This plan was implemented in 2006 by the subsequent mayor. According to the contract agreed between the city and the irrigation district, the irrigation district sold 30 Mm^3 of which 20 Mm^3 was given to the city and 10 Mm3 will be used to recharge the aquifer. As a result, in 2006, 15 wells were established

[13] This battery of wells would have extracted water at a rate of 3 400 lps, desalted the water using reverse osmosis, and transported it to the city through an aqueduct 110 kilometers long (Moreno, 2006).

in the Los Bagotes zone, which supplies 750 liters per second (lps) on average to the city of Hermosillo (AGUAHH, 2007, p. 23).

B. Novillo Aqueduct Proposal

A second long-term project was to supply water to Hermosillo through an aqueduct of around 150 kilometers from the Novillo dam (Figure 3). The Novillo is a hydropower dam constructed in 1964 by the Mexican Power Commission (CFE). This dam, in conjunction with the Oviachic dam, is part of the Yaqui River dam system. The proposed Novillo aqueduct would have diverted water from the Novillo dam, away from the Yaqui River irrigation district. This district, the largest surface water district in Sonora, has an irrigable surface of around 220,000 hectares with nearly 20,000 producers (Wilder & Romero, 2006). The Yaqui River produces about 35.5% of the total revenues from agriculture in irrigation districts of Sonora (CEA, 2008). Officially created in 1951, it is the birthplace of the Green Revolution in wheat production and one of Mexico's most productive breadbaskets, producing about 30 percent of the domestic wheat supply (Wilder & Whiteford, 2006). This is a very well-organized and influential district in Sonora's politics. Fox example, the state governor (2003-2009) is a prominent water user from this district. The Yaqui River, similar to the Sonora River, has experienced below-average streamflows due to a prolonged drought from 1995 to about 2006. The reduction in water supply forced an 8-year hiatus (1999 to 2007) in cultivating most of the district's land in the spring-summer growing season, causing an economic loss of an estimated 40 percent of income during those years (Wilder, 2002). This may explain why, at the end of the 1990s, the irrigation district users rejected the Novillo aqueduct project arguing that any volume of water extracted from the Yaqui River would result in considerable damage for the development and economy of the Yaqui Valley region (Pablos, 1998, p. 106). Although this project has not been implemented, it remains alive as one of the key

planning projects. If this project is ever implemented, the water transfer will not be easy or cheap because the Yaqui Irrigation District is an experienced water trader[14].

In addition to these major proposals, Hermosillo has also explored other augmentation strategies[15].

Table 4 summarizes in chronological order the contemporary water supply strategies in Hermosillo. Whereas between 1981 and 1995 just a few initiatives were proposed and implemented to augment the water supply for the city, from the onset of major drought in 1996 to the present, 12 projects have been proposed (and 9 implemented).

Table 4

As we have demonstrated in the three profiled categories as well as with the data summarized in Table 4, urban water supply projects have been disproportionately focused on ejidos in the peri-urban area (gray lines in Table 4). Of the 16 proposed strategies, two were proposed in the Hermosillo Coast irrigation district, one in the Yaqui Valley irrigation district, one in Pesqueira, two inside the city, and 10 in the peri-urban area. All of the proposed projects in the peri-urban area were implemented, three in the 1981-1995 period, and seven after 1996; whereas, the Yaqui Valley and Pesqueira proposals were

[14] This was clear when I asked to the manager of the Yaqui Valle Irrigation District that if now the city would buy water rights from the district they would be willing to sell, he responded: "it depends of how much money we are talking about".

[15] In 1998, the zone called Pesqueira was proposed as another source of water for Hermosillo (Lagarda Lagarda, 1998). This is located 30 kilometers to the north of Hermosillo (Figure 3). Pesqueira is located in the aquifer of the Rio Zanjón, with a volume granted by CONAGUA of 90 Mm^3. This aquifer is overexploited at about 41.5% of the aquifer's capacity; as an illustration of this, in 2002 the recharge of the aquifer was around 77 Mm^3 and the estimated actual use was about 109 Mm3 (Moreno, 2006, p. 395). This area principally produces table grape by private landowners oriented to the U.S. market. In 2006, around 2,300 hectares of table grape were produced. Although this project has not been realized, it is still considered by the state government as a water supply alternative.

Two additional projects have been implemented inside the city limits of Hermosillo. The first project, in 1987, consisted of about a dozen wells situated in the zone named La Sauceda, very close to the ALR dam outlet. Currently there are 18 wells in this zone that provide 500 lps (AGUAHH, 2007). In 2002, 27 deep wells were installed that provide 1 600 lps. These are El Realito and Sur located within the dam impoundment, and Pueblitos located in northern Hermosillo (AGUAHH, 2007).

not implemented, and of the two projects in the Hermosillo Coast, only one, which was the most economically convenient for the district, was implemented. The intensive water project activity in the post-1996 period of the onset of the water crisis demonstrates how scarcity helped to drive processes of dispossession of ejido water resources by a more powerful urban constituency.

VI. Discussion

This analysis of the city of Hermosillo's water supply augmentation strategies demonstrates how water is accessed by a politically dominant major urban area from marginalized peri-urban farming and ranching communities. In cases carefully documented in 16 peri-urban ejidos, this paper provides evidence for how the flows of water from the marginalized ejidos to the thirsty cities represent hydrosocial flows, capturing not only the material flows of water but the chain of techno-scientific analysis and political decision-making, all directed squarely at accessing ejido water resources. In this analysis, we make four principal arguments.

First, we have mapped the ways in which the hydrosocial cycle is played out in the context of Hermosillo and its peri-urban communities, underscoring the socio-spatial nature of the urbanization of water and expansion of what Swyngedouw (2004) calls the *urban water frontier*. We provide evidence that in the aftermath of the 1996 water crisis and with the advent of a prolonged drought, the Agua de Hermosillo increasingly sought to augment water supply from peri-urban sources, most of which efforts resulted in extremely adverse consequences for ejidos such as major diminution in or even total loss of irrigation water. Subsequently, the analysis of the 'counterpoint cases' of the desalination plant and the Novillo aqueduct provided evidence that powerful, politically connected irrigation districts (Hermosillo Coast and Yaqui Valley) were able to successfully resist attempts by the city to usurp their irrigation water for urban consumption. Of 16 initiatives to increase water supply, 10 of them were directed at and implemented in the peri-urban region and all of them, except for the wells in the Willard

zone, affected peri-urban ejidos. On the other hand, of the 16 initiatives, 2 were implemented inside the city and 4 were proposed in the counterpoint cases, of which just one was implemented, but unlike the ejido cases, with monetary compensation.

Second, Hermosillo's water scarcity has not been solved; instead, urban water policy has produced new and critical problems in the peri-urban area. Decentralization of the municipal water agency Agua de Hermosillo has not resulted in better service or water availability for Hermosillo residents, but it has increased water scarcity in the peri-urban area. Part of the problem is the lack of a long-term plan to supply water to the city. In an interview, a prominent manager of AGUAHH told me that they plan thinking that they will have conditions of drought in the next year. Urban water projects seems to depending of the set of political parties, for example when the major and the governor were from PRI they implemented the Molinito aqueduct, and now (2010) that the major, the governor and the Mexican president are from *Partido Acción Nacional* (PAN) they want to implement a "permanent solution" a plan called "Sonora SI" in which the city of Hermosillo is benefited. In 2010, the governor conducted the first informative public meeting about the plan in the Valle del Yaqui region in order to convince to the residents about the benefits of the Novillo aqueduct (González, 2010).

On the other hand, as examined, water markets have been only implemented between AGUAHH and large-scale private producers from the Hermosillo Coast irrigation district and in the Malvinas project. However, peri-urban ejidatarios have not benefited from water markets. As Bauer (2004) and Wilder & Romero (2006) have demonstrated, small-scale producers have generally experienced increased economic vulnerability due to neoliberal reforms and water markets. In this case, a water market may have benefited the ejidatarios by providing at least compensation for their loss of their resources, but still would fail to compensate for long-term loss of livelihoods.

Third, we argue that the peri-urban 'waterscape' which is fluid and allows transportation of water over sizeable distances is conceptually distinct from the peri-urban landscape which is a fixed and bounded area of territory on the outskirts of a city. By contrast, a peri-urban waterscape can encompass a much broader geographical area

depending on hydrological characteristics and geographic terrain, and is thus a more flexible and, yes, fluid area. For example, although ejido Codorachi is located nearly 30 km from Hermosillo, its water can be accessed by the city, therefore making this rural farming area part of the peri-urban zone. As Karen Bakker (2003) has argued, the specific properties of water make it a uniquely uncooperative commodity and expensive to transport, yet as this case illustrates, if the demands of capital are sufficient—that is, the benefits of urban expansion exceed the costs of infrastructure and transportation-- cities will invest in the necessary infrastructure. Water has the property of flow very easy from the peri-urban zone to the city. In this regard, water is not an uncooperative commodity as examined in the Bakker's work, but is actually too cooperative. Thus, even geographically distant, essentially rural communities may become part of the peri-urban phenomenon as thirsty cities go hunting for increased water supply under conditions of growth, drought, and intensified concerns about climate change.

Four, we examine specific ejidos within both the upstream and downstream basins of the Sonora and San Miguel Rivers to analyze the consequences of Hermosillo's urban water strategies. All the ejidos suffered losses of access to their water resources due to the installation of deep urban wells, the construction of new dams or aqueducts to store and transport water, or simple cutting off of access to traditional sources. In the case of ejido Molino de Camou, ejidatarios were able to negotiate a volumetric assignment of water rights when the municipality needed to gain access to ejido land in order to construct an aqueduct across it, thus giving the ejido Molino de Camou some powerful leverage in the negotiation. Downstream users, the Presa ALR irrigation district, were also able to negotiate their water rights and although they use untreated wastewater, according to them, they have improved their irrigation system in water quantity and timing terms. It is not a coincidence that the ejidos that were not drastically affected in water availability are surface water users. We conclude that the fact of having surface water instead of groundwater gives to these ejidatarios an advantage in negotiating with authorities. Surface water is a more visible source; moreover, groundwater alteration is not as tangible as surface water variation. Groundwater also varies interannually and temporally

in terms of its storage capacity, but the variability is difficult to measure. It is very well recognized that Mexican aquifers have been subject to few water balance studies (Carabias & Landa, 2005). If we add this gap to the implicit uncertainty of groundwater, we have the perfect setting for justifying the uncompensated taking of groundwater such as in the study cases.

The urbanization of water for the city has contributed to the production of a new social landscape for the peri-urban area. Peri-urban ejidos in the study have lost or experienced reduced access to irrigation water that had allowed them to stay on and actively produce on their land. Both livelihoods and communities are made more vulnerable in the process as most households turn to migration as an alternative income strategy. Ultimately, the Hermosillo case demonstrates how hydrosocial politics can protect the city's place within a broad political economic network − of "global circulations of water and money" (Swyngedouw, 2004, p. 29). Focusing the city's expansion of the urban water frontier on capturing the water resources of peri-urban ejidos does not disturb the commodity chains produced by the large commercial irrigation districts, which will still have adequate water to produce wheat for Mexico City conglomerates and grapes for the U.S. market. The commercial irrigation districts and large private corporate farms (such as the Pesqueira grape-producing zone) have had the political leverage to resist and turn back urban challenges for their water, while ejidos have had to give way. In this sense, it is important to recognize that the urbanization of ejido water resources is part of nearly two decades of the neoliberal transformation of the ejido through water policy reforms, land tenure reforms, trade liberalization, and agricultural policy changes.

The uneven outcomes of the hydrosocial processes in the Hermosillo case demonstrate the processes of exclusion and marginalization that Swyngedouw argues are embedded within the hydrosocial cycle as large, commercial irrigators are spared from giving up water or are paid for their surplus water, while small ejido farmers have their water resources pumped out or transported away without any compensation.

Future climate change is projected to have deleterious impacts on water supply in northwest Mexico, with reduced water supply due to higher temperatures, reduced snowmelt, and longer, more severe droughts than those experienced in recent memory. The increasing vulnerability of water supply enhances concerns about scarcity. Given this context of scarcity, the hydrosocial cycle and future processes of urbanization of water are likely to increasingly implicate peri-urban and rural ejido water resources in the future.

VII. Conclusion

As a consequence of the last two decades of water supply augmentation projects, the urban area of Hermosillo is daily "metabolizing" water resources that have been taken from ejido farming communities. Following Swyngedouw, cities metabolize water from outside the urban boundaries via an inseparable infusion of hydrological flows and channels with sociopolitical processes, resulting in new socionatural landscapes. At one level, this represents a simple rural-to-urban water transfer evocative of market forces that dictate that water should flow to its highest and best use and legislative frameworks that privilege urban 'public' consumption over crop consumption, especially in times of scarcity. However, as we have seen in the Hermosillo case, the peri-urban water transfers occurred under a very specific set of political processes that privileged large, politically connected commercial irrigation districts dominated by private growers who sell to export markets over small-scale, marginalized ejido communities who produce for personal consumption and sell to regional markets. On the other hand, the peri-urban waterscape phenomenon does not have as well-defined a boundary as in the case of peri-urban land. The people within the peri-urban waterscape have not received the same benefits of the transfer of water from the peri-urban to urban that those areas where land is incorporated from the peri-urban into the urban area. The peri-urban water user's geopolitical status does not change, but the water resources that supported their livelihoods have been reallocated to the city. A physical condition, the diminution of

water availability in the Sonora River basin, combined with an uneven set of power relations has produced the transformation of the peri-urban waterscape. The hydrosocial cycle works to produce a new and more fragmented socionatural landscape in the peri-urban area.

VIII. References

AGUAHH. (2007). *Programa Municipal de Agua Potable, Alcantarillado Sanitario, Saneamiento, y Disposición de Aguas Residuales, 2007-2009*. Hermosillo, Sonora, México: Municipio de Hermosillo.

Ahlers, R. (2002). "Moving in or staying out: Gender dimensions of water markets," in Scott Whiteford and Roberto Melville, eds., *Protecting a Sacred Gift: Water and Social Change in Mexico* (La Jolla: Center for U.S.-Mexican Studies) pp.65-85.

Allen, A. (2003). Environmental planning and management of the peri-urban interface: perspectives on an emerging field. *Environment and Urbanization*, 15(1), 135-147.

Allen, A., Dávila, J. D., & Hoffman, P. (2006). *Governance of Water and Sanitation Services for the Peri-urban Poor. A Framework for Understanding and Action in Metropolitan Regions*. Development Planning Unit, UCL, London. Retrieved April 14, 2009, from http://www.ucl.ac.uk/dpu/pui/publications/index.html

Bakker, K. J. (2003). *An Uncooperative Commodity: Privatizing Water in England and Wales.* New York: Oxford University Press.

Bauer, C. J. (2004). *Siren Song: Chilean Water Law as a Model for International Reform.* Washington, DC: Resource for the Future Press.

Blaikie, P., & Brookfield, H. (1987*). Land Degradation and Society*. London: Routledge Kegan & Paul.

Briscoe, J. (1996). *Water as an Economic Good: The Idea and What It Means in Practice.* A paper presented at the World Congress of the International Commission on Irrigation and Drainage, Cairo, Egypt.

Brook, R., & Davila, J. (2000). *The Peri-Urban Interface: A Tale of Two Cities*. UK: Natural Resources Systems Programme.

Brook, R., Purushothaman, S., & Hunshal, C. (Eds.). (2003). *changing frontiers – The Peri Urban Interface Hubli-Dharwad, India.* Bangalore, India: Books for Change.

Bryant, R.L. (1998). Power, knowledge and political ecology in the third world: a review. *Progress in Physical Geography* 22 (1), 79-94.

Budds, J. (2008). Whose Scarcity? The Hydrosocial Cycle and the Changing Waterscape of La Ligua River Basin, Chile. In M. K. Goodman, M. Boykoff, & K. Evered (Eds.), *Contentious Geographies* (pp. 59-78). Ashgate Publishing, Ltd.

Carabias, J., & Landa, R. (2005). *Agua, medio ambiente y sociedad: hacia la gestión integral de los recursos hídricos en México*. México: UNAM, El Colegio de México, Fundación Gonzalo Río Arronte.

del Castillo, J. M. (1994). Protección y restauración ecológica-ambiental de la Presa Abelardo Rodríguez Luján, en Hermosillo, Sonora. *Estudios Sociales*, V(9), 65-102.

CEA. (2008). *Estadísticas del Agua en el Estado de Sonora*. Retrieved October 20, 2009, from http://www.ceasonora.gob.mx/archivos/admin/file/Estadisticas_Agua_Sonora_ed2008.pdf

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., et al. (2007). Regional Climate Projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, et al. (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Comrie, A., & Glenn, E. (1998). Principal components-based regionalization of precipitation regimes across the southwest United States and northern Mexico, with an application to monsoon precipitation variability. *Climate Research*, 10(3), 201-215.

CONAGUA. (2007). *Estadísticas del Agua en México*. Comisión Nacional del Agua. Retrieved April 1, 2009, from http://www.agua.org.mx/content/view/3649/28/

CONAGUA (1991). *Oficio No. BOO.782.2/000531*. Gerencia Estatal en Sonora. Hermosillo. Unpublished document.

Conca, K. (2006). *Governing Water: Contentious Transnational Politics and Global Institution Building* (illustrated edition.). The MIT Press.

De Janvry, A., Gordillo, G., & Sadoulet, E. (1997). *Mexico's Second Agrarian Reform: Household and Community Responses, 1990-1994.* La Jolla, CA: Center for U.S.-Mexican Studies University of California.

Del Río Sánchez, M. D. (2005). *Segundo Informe de Gobierno.* Hermosillo, Sonora, México: Municipio de Hermosillo.

Díaz-Caravantes, R. (n.d.). *Balancing Urban and Peri-Urban Exchange: Rural Livelihoods in Mexico*. Unpublished manuscript.

Díaz, R. E., & Camou, E. (2005). El agua en Sonora: tan cerca y tan Lejos. Estudio de caso del ejido Molino de Camou. *Región y Sociedad*, XVII(034), pp. 127-165.

Douglas, I. (2006). Peri-Urban Ecosystems and Societies: Transitional Zones and Contrasting Values. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 18-29). UK: Earthscan Publications Ltd.

Figueroa, V. E. (2008). *Conflicto, el agua entre la agricultura y la ciudad:"El caso del Acueducto Las Malvinas en Hermosillo, Sonora, 2004-2005".* Tesis de Maestría, El Colegio de Sonora.

Garduño, H. (2005). “Lessons from implementing water rights in Mexico,” in Bryan Bruns et al, *Water Rights Reform*, pp.85-112.

Gleick, P. H. (1996). Basic water requirements for human activities: meeting basic needs. *Water International*, 21(2), 83. doi: Article

Global Water Partnership Technical Advisory Committee (TAC). (2000). *Integrated Water Resources Management. Global Water Partnership*. Retrieved May 20, 2009, from http://www.gwpforum.org/gwp/library/TACNO4.PDF

González, F. (2010, February 4). Garantiza Agua para Todos. *Expreso*, Portada.

Hallack-Alegria, M., & Watkins, D. (2007). Annual and warm season drought intensity-duration-frequency analysis for Sonora, Mexico. *Journal of Climate*, 20(9), 1897-1909. doi: 10.1175/JCL14101.1

INEGI. (2005). *Conteo de población y vivienda 2005.*

Lagarda, C. (1998). Alternativas de solución de agua para Hermosillo. In N. Pineda (Ed.) *Hermosillo y el agua. Infraestructura hidráulica, servicios urbanos y desarrollo sostenible* (pp. 11-37). Hermosillo, Sonora, México: El Colegio de Sonora, Centro de Investigación en Alimentación y Desarrollo, Universidad de Sonora.

Lara, A. A. C., Whiteford, S., & Marquez, M. C. (2005). *Seguridad, agua y desarrollo. El futuro de la frontera Mexico-Estados Unidos*. Colegio de la Frontera.

Lavadenz, I., & Deininger, K. (2001). *Mexico Land Policy - A decade after the Ejido Reform.* Washington, DC: World Bank.

Liverman, D., & Merideth, R. (2002). Climate and society in the US Southwest: the context for a regional assessment. *Climate Research*, 21(3), 199-218.

Lynch, K., & Poole, N. (2006). Horticulture and Market Information at the Peri-Urban Interface: Agricultural Marketing in Tanzania. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 74-93). UK: Earthscan Publications Ltd.

Magaña, & Conde. (2000). Climate and freshwater resources in northern Mexico: Sonora, a case study. *Environmental Monitoring and Assessment*, 61(1), 167-185.

Martínez, J. M. (2002). Acuíferos y Libre Comercio: El Caso de la Costa de Hermosillo. *Texas Center for Policy Studies*. Retrieved March 9, 2009, from www.texascenter.org/publications/sonora.pdf

McGregor, D., Simon, D., & Thompson, D. (2006). *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (illustrated edition.). UK: Earthscan Publications Ltd.

Moreno, J. L. (2006). *Por abajo del agua: sobreexplotación y agotamiento del acuífero de la Costa de Hermosillo, 1945-2005*. Hermosillo, Sonora, México: El Colegio de Sonora.

Narain, V., & Nischal, S. (2007). The peri-urban interface in Shahpur Khurd and Karnera, India. *Environment and Urbanization*, 19(1), 261-273. doi: 10.1177/0956247807076905

NWL (National Water Law). (1992). Mexican Congress

NWL (National Water Law). (2004). Mexican Congress

Pablos, G. (1998). Situación del agua en el Valle del Yaqui y Cd. Obregón, Sonora. In N. Pineda (Ed.) *Hermosillo y el agua. Infraestructura hidráulica, servicios urbanos y*

desarrollo sostenible (pp. 99-107). Hermosillo, Sonora, México: El Colegio de Sonora, Centro de Investigación en Alimentación y Desarrollo, Universidad de Sonora.

Peet, R. and M. Watts (eds.) 1996. *Liberation ecologies: environment, development and social movements*, Routledge, London.

Pineda, N. (1999a). Actores sociales y distribución de costos y beneficios en la privatización del agua potable en Aguascalientes. *Ciudades*, 43, 57–64.

Pallánez, M. (2002). *Valoración económica de los servicios ambientales sustentados por la presa Abelardo Luján Rodríguez los casos del agua y la fauna, 1990-2000.* Tesis de Maestría. El Colegio de Sonora. Unpublished manuscript.

Pineda Pablos, N. (2006). Dar de beber a Hermosillo. In D. Barkin (Ed.), *La Gestión del Agua Urbana en México* (pp. 235-248). México: Universidad de Guadalajara; Universidad Autónoma Metropolitana, Unidad Xochimilco.

Ramírez, J. C., Conde, Ó., & León, R. (1997). La Nueva Economía Urbana. In Historia Contemporánea 1929-1984, *Historia General de Sonora* (Third., pp. 187-222). Hermosillo, Sonora, México: Gobierno del Estado de Sonora.

Ray, A., Garfin, G., Wilder, M., Vasquez-Leon, M., Lenart, M., & Comrie, A. (2007). Applications of monsoon research: Opportunities to inform decision making and reduce regional vulnerability. *Journal of Climate*, 20(9), 1608-1627. doi: 10.1175/JCL14098.1

Robbins, P. (2004). *Political Ecology: A Critical Introduction*. Wiley-Blackwell.

SAGARHPA. (2005). *Programa Estatal de Mediano Plazo de Aprovechamiento Sustentable del Agua 2004-2009*. Gobierno del Estado de Sonora. Retrieved April 2, 2009, from http://www.sonora.gob.mx/biblioteca/documentos/pmp/agua.pdf

Salazar, M. D. C. (2005a). Comprarán derechos de agua. El Imparcial, 2/A. April 12.

Salazar, M. D. C. (2005b). *Contrato Las Malvinas, ¿A Prueba de Fugas?* El Imparcial, 2/A. July 28.

Scott, C., & Banister, J. (2008). The dilemma of water management "regionalization" in Mexico under centralized resource allocation. *International Journal of Water Resources Development*, 24(1), 61–74.

Scott, C., Faruqui, N., & Raschid-Sally, L. (Eds.). (2004). *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities*. Wallingford, U.K.: CABI Publishing. Retrieved October 5, 2009, from http://www.idrc.ca/openebooks/112-4/

Seager, R., Ting, M., Held, I., Kushnir, Y., Lu, J., Vecchi, G., et al. (2007). Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, 316(5828), 1181-1184. doi: 10.1126/science.1139601

Smith, N. (1984). *Uneven Development*. New York: Blackwell.

Swyingedouw, E. (1997). Power, nature, and the city. The conquest of water and the political ecology of urbanization in Guayaquil, Ecuador: 1880-1990. *Environment and Planning A*, 29(2), 311-332.

Swyngedouw, E. (1999). Modernity and hybridity: Nature, Regeneracionismo, and the production of the Spanish waterscape, 1890-1930. *Annals of the Association of American Geographers*, 89(3), 443-465.

Swyngedouw, E. (2004). *Social Power and the Urbanization of Water: Flows of Power*. Oxford: Oxford University Press, USA.

Tacoli, C. (2006). *The Earthscan Reader in Rural-Urban Linkages*. UK: Earthscan Publications Ltd.

Thobani, M. (1995). *Tradable property rights to water: How to improve water use and resolve water conflicts.* World Bank, Finance and Private Sector Development Note No.34.

Treminio, R. (2004). *Experiencias en Agricultura Urbana y Peri-Urbana en America Latina y el Caribe, Necesidades de Políticas e Involucramiento Institucional*. Food and Agriculture Organization of the United Nations. Retrieved April 14, 2009, from http://www.rlc.fao.org/es/agricultura/aup/pdf/expe.pdf

Walker, P. A. (2005). Political ecology: where is the ecology? *Progress in Human Geography*, 29(1), 73-82. doi: 10.1191/0309132505ph530pr

Whiteford, S., & Melville, R. (2002). *Protecting a Sacred Gift: Water and Social Change in Mexico* (illustrated edition.). La Jolla, CA: Center for U.S.-Mexican Studies University of California.

Wilder, M. (2002). *In name only: Water policy, the state and ejidatario producers in Northern Mexico*. Ph.D. dissertation, University of Arizona.

Wilder, M. & Romero, P. (2006). Paradoxes of Decentralization: Water Reform and Social Implications in Mexico. *World Development*, 34(11), 1977-1995.

Wilder, M. & Whiteford, S. (2006). Flowing Uphill Toward Money: Groundwater Management and Ejidal Producers in Mexico's Free Trade Environment. In L. Randall (Ed.), *Changing structure of Mexico: political, social, and economic prospects* (pp. 341-358). Armonk, N.Y.: M.E. Sharpe.

Zimmerer, K. (1996). Ecology as Cornerstone and Chimera in Human Geography. In C. Earle, K. Mathewson, & M. S. Kenzer (Eds.), *Concepts in Human Geography* (pp. 161-187). Lanham, Maryland: Rowman & Littlefield Publishers.

IX. Tables and Figures

Table 1. Key turning points in the recent history of Hermosillo's water scarcity

Year(s)	Action	Location	Cause	Impact
1981	***ALR Dam converted to urban use***	***Outskirts of Hermosillo***	***Need to increase city water supply***	***On downstream agricultural producers***
1984	Ford Motor builds new plant	Hermosillo	Stimulate economic development	Creation of 1,200 direct jobs
1996	***Hermosillo water crisis***	***Hermosillo***	***Drought***	***Increased pressure to locate new sources of water for city supply***
1998-2005	Onset of severe drought; reservoirs at record low levels	Statewide (including Hermosillo)	Periodic droughts; climate change	Severe economic impacts, esp. in ranching; agriculture; water rationing in cities
2002	Transfer of water services management from state to municipalities	Statewide (including Hermosillo)	Conflict over desalination proposal; National Water Law allows the transfer	Agua de Hermosillo municipal agency created to manage urban water provision
2006-Present	Alleviation of drought	Hermosillo	More normal precipitation years	Water is not rationed in Hermosillo

Source: Compiled by authors, based on research.

Table 2. Water uses in the Sonora River Basin

Area	Uses	Surface Water		Groundwater		Total		
		#	Volume (m3)	#	Volume (m3)	#	Volume (m3)	% by Area
Sonora River Basin	**Urban**	0	0	637	65,949,518	637	65,949,518	18
	Livestock	141	292,421	953	3,311,832	1,094	3,604,252	1
	Agriculture	56	40,640,355	936	209,311,976	992	249,952,331	68
	Industrial	2	41,000	23	10,062,634	25	10,103,634	3
	Multiple uses	1	51,211	575	35,838,031	576	35,889,242	10
	Domestic	0	0	160	70,769	160	70,769	0
	Services	1	41,472	14	1,034,751	15	1,076,223	0
	Total	***201***	***41,066,459***	***3,298***	***325,579,511***	***3,499***	***366,645,969***	***100***
Peri-Urban Area	**Urban**	0	0	44	60,134,582	44	60,134,582	38
	Livestock	8	9,125	73	1,030,578	81	1,039,703	1
	Agriculture	5	3,981,000	372	73,116,636	377	77,097,636	49
	Industrial	0	0	17	2,705,176	17	2,705,176	2
	Multiple uses	0	0	196	16,197,986	196	16,197,986	10
	Domestic	0	0	48	32,163	48	32,163	0
	Services	0	0	14	1,034,751	14	1,034,751	1
	Total	***13***	***3,990,125***	***764***	***154,251,872***	***777***	***158,241,997***	***100***

Source: Compiled by authors, based on REPDA.

Table 3. Ejido Basic Information

Reference	Ejido	Creation date	Certification of land rights			# of ejido's commu-nities	2005's population in ejido's land
			Date	Number of ejidatarios	Total surface		
A	La Victoria	1934	2000	151	1,414	2	3,917
B	Mesa del Seri	1932	1995	63	5,582	1	939
C	San Pedro	1937	1994	106	2,449	1	3,141
D	El Alamito	1937	1994	123	1181	1	726
E	Zamora	1933	1994	84	1374	1	1,204
F	San Juan	1937	1996	40	2,283	2	504
G	Codorachi	1937	1994	32	1083	1	319
H	Torreon	1938	1995	48	2038	1	68
I	La Labor	1937	1993	30	1466	1	58
J	El Zacaton	1936	1993	24	1198	1	296
K	El Carmen	1936	1997	21	713	1	68
L	Molino de Camou	1936	1994	61	1,427	1	1,222
M	Villa de Seris	1937	1996	192	4,627	1	210
N	La Manga	1941	1997	79	2,868	1	84
O	La Yesca	1937	1994	48	1,517	1	99
P	San Miguel	1987	2002	30	1194	1	27
			Total	***1132***	***32,414***	***18***	***12,882***

Source: Compiled by authors, based on Registro Agrario Nacional

Table 4. Contemporary water supply strategies in Hermosillo

Project	Affected water supply region	Implemented date	Compensation to previous water users
ALR dam used for urban water supply and urban untreated wastewater used for agricultural purposes	peri-urban area	1981	Transfer to urban untreated wastewater
Wells in La Victoria	peri-urban area	1986	None
Wells in La Sauceda	inside the city	1987	No previous users affected
Molinito dam constructed	peri-urban area	1991	Partial (just some agricultural users)
Infiltration Gallery constructed	peri-urban area	1996	None
All the water from the ALR dam used for urban purpose	peri-urban area	1996	Transfer to urban untreated wastewater
Molino dam used for urban water supply and ALR dam stopped storing water	peri-urban area	1998	Partial (just some agricultural users)
Wells in the Mesa del Seri	peri-urban area	1998	None
Desalting Plant	Costa de Hermosillo	Not implemented	Not implemented
Aqueduct El Novillo	Valle del Yaqui	Not implemented	Not implemented
Aqueduct Pesqueira	Pesquiera	Not implemented	Not implemented
Wells in the Willard	peri-urban area	2002	No previous users affected
Aqueduct from El Realito, Sur y Pueblitos	Inside the city	2002	No previous users affected
Buying water rigths from an irrrigation district	Costa de Hermosillo	2006	Buying rigths
Buying water rights from Las Malvinas	peri-urban area	2006	Partial (not to third parties)
Aqueduct El Molinito	peri-urban area	2008	Partial (just some agricultural users)

Source: Compiled by authors, based on research

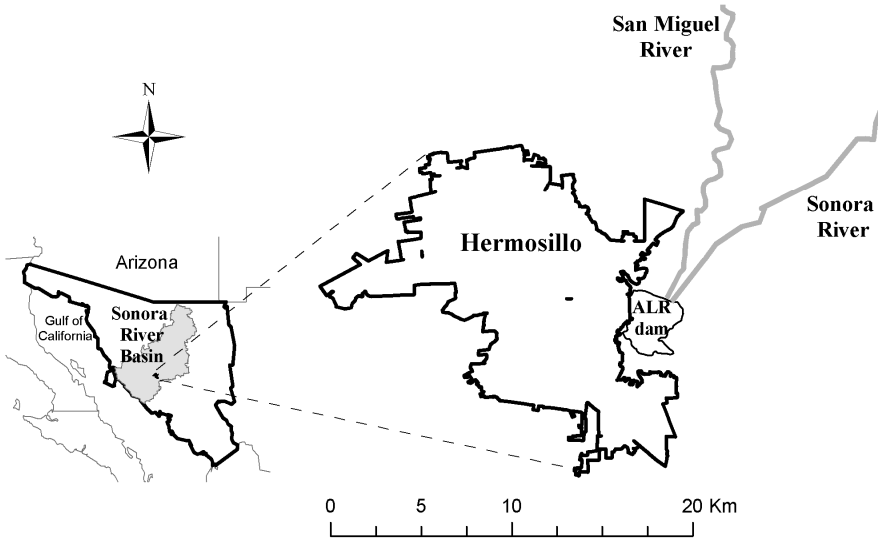


Figure 1. Study area

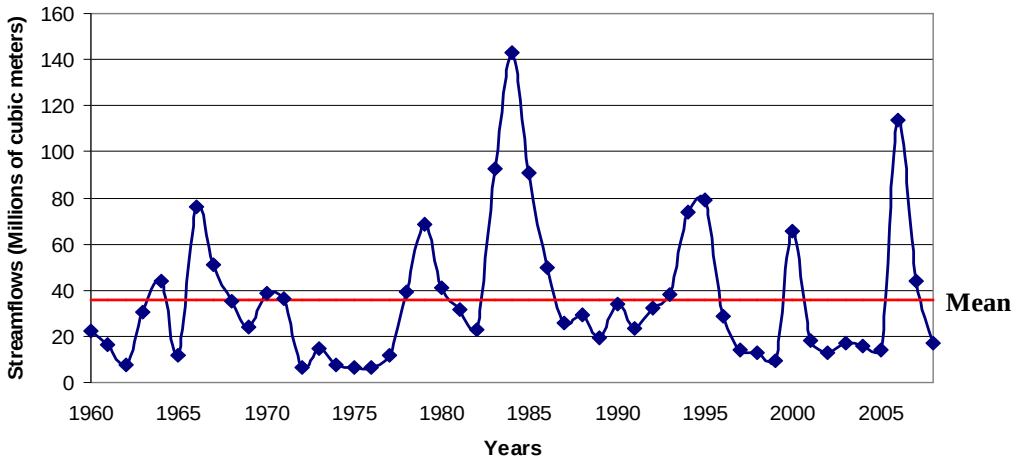
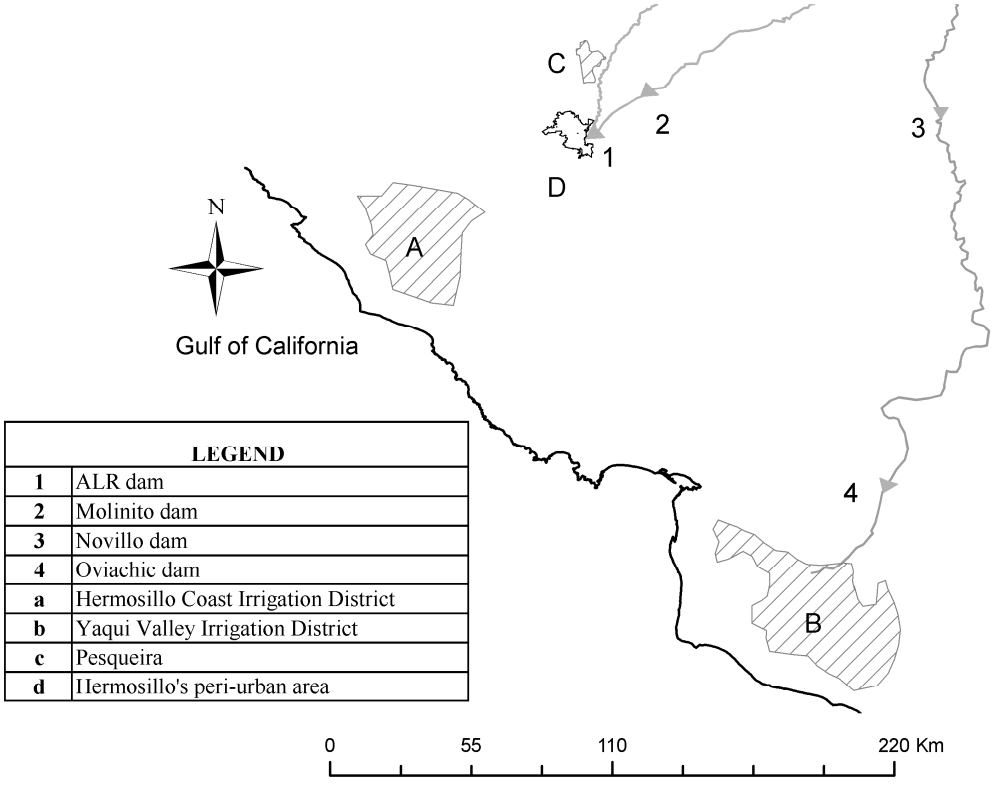


Figure 2. Sonora river hydrograph

Source: Compiled by authors, based on CONAGUA data



LEGEND	
1	ALR dam
2	Molinito dam
3	Novillo dam
4	Oviachic dam
a	Hermosillo Coast Irrigation District
b	Yaqui Valley Irrigation District
c	Pesqueira
d	IIermosillo's peri-urban area

Figure 3. Regions involved in Hermosillo water supply strategies

Source: Compiled by authors, based on research

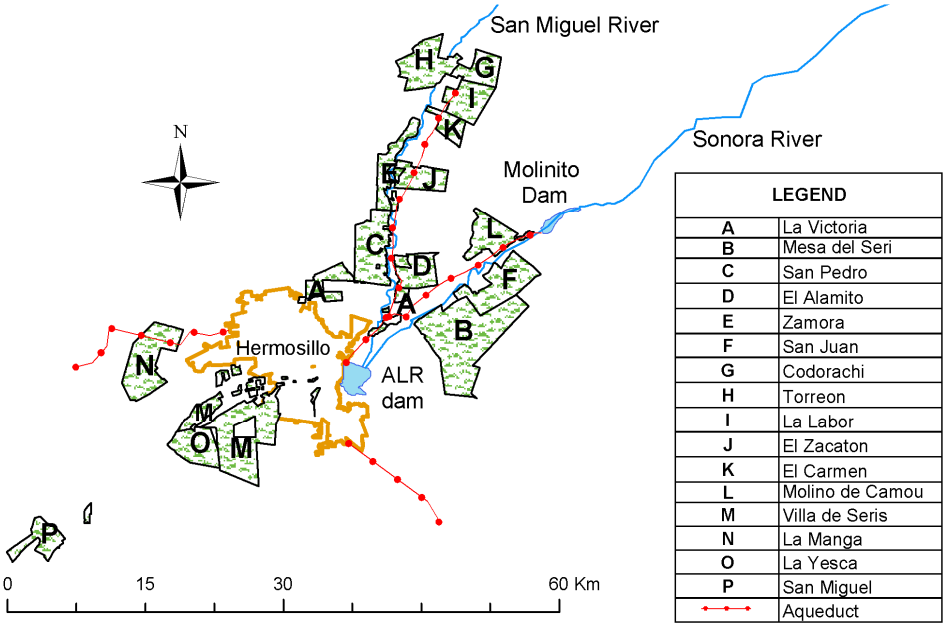


Figure 4. Peri-urban Ejidos of Hermosillo.

Source: Compiled by authors, based on Registro Agrario Nacional

APPENDIX B

BALANCING URBAN AND PERI-URBAN EXCHANGE: RURAL LIVELIHOODS IN MEXICO

Rolando E. Díaz-Caravantes

(For submission to Geographical Journal)

Abstract

The peri-urban area is the region where the urban-rural interface is most dynamic and evident. On one hand, the peri-urban area supplies natural resources, such as land for urban expansion and agricultural products to feed the urban population. In arid and semi-arid lands, such as northern Mexico, these areas may also be the source of water for the city's domestic demand. On the other hand, scholars argue that peri-urban residents may have a more advantageous geographical position for selling their labor and agriculture products in cities and, by doing so, sustaining their livelihoods. Although a considerable number of studies examine how livelihoods are affecting natural resources, particularly in rural Latin America forest-dependent communities, few studies have examined how the transfer of natural resources from the peri-urban to urban affects *peri-urban* livelihoods. This evaluation is critical because the livelihoods of Mexican peri-urban *ejidos* are being drastically reconfigured by urban expansion. In Mexico, it is calculated that that two-thirds of the required land for urban expansion will come from peri-urban ejidos. In the case of Hermosillo, a tremendous pressure on water resources of peri-urban ejidos due to urban demand has been demonstrated. Based on semi-structured interviews and structured surveys with ejidatario producers and water managers, this paper examines how peri-urban livelihoods have been reshaped by cities' natural resources reallocation

causing ejidatarios in many cases to lose their livelihoods, but without creating new urban jobs as an alternative means of subsistence, resulting in a net negative outcome for ejido members.

I. Introduction

The livelihoods of peri-urban areas are being critically reshaped by urban expansion. In Mexico, it is calculated that that two-thirds of the required land for urban expansion will come from peri-urban ejidos (Lavadenz & Deininger, 2001). In the case of Hermosillo, urban expansion has also produced a huge pressure on the water resources of peri-urban ejidos. On the other hand, according to scholars, the livelihoods of those located in the peri-urban areas could be benefited by activities related to city such as access to urban markets for peri-urban agriculture or jobs produced in industries and services in the city. The questions that emerge from these insights are: How has the urban water demand of the city of Hermosillo impacted livelihoods of peri-urban ejidos? To what degree have peri-urban livelihoods been benefited by the urban jobs? Is there a trade-off to such that these ejidos have obtained a benefit from urban jobs as a way of balancing the loss of traditional livelihoods in agriculture and ranching?

The significance of this study lies in its relevance to contemporary human-nature relationships in Latin American countries. First, in the Latin American context, there is a very well developed scholarship on how population dynamics affect the availability of natural resources, but there is a very limited examination of how peri-urban livelihoods are affected by the transfer of natural resources. Second, although peri-urban scholars have stated that water resources for economic livelihoods in peri-urban areas are critical because of the many income activities depending on these resources, the social impact of water transfers from the peri-urban area to the city is underexplored in the scholarly literature and demands systematic evaluation.

Water resources play a critical role in arid regions in feeding the reservoirs and groundwater wells that are the primary source of municipal water supply in most cities in

northwestern Mexico. This is the case in Hermosillo, where the Sonora River has been used to provide water that serves both municipal and agricultural needs in Hermosillo and its peri-urban areas. However, urban water demand has increased affecting peri-urban ejidos and producing in many cases that ejidatarios abandoning or selling their land, and therefore loosing their livelihoods. On the other hand, based on data from this NOAA-funded research,[16] this paper demonstrates that there is limited evidence that suggests that the geographical position of peri-urban ejidos, close to the city, represents an advantage for their livelihoods.

This paper draws on research conducted on peri-urban ejidos of the city of Hermosillo, the state capital of Sonora. The research was conducted in a 10-month period from June 2008 to March 2009; the study of the ejido Molino de Camou was initiated in 2000-2001 and updated in the recent fieldwork period. Findings reported are based on mixed methods: approximately 60 open-ended and semi-structured interviews and 82 intensive written surveys with ejido members, and approximately 20 semi-structured interviews with federal, state, and local water officials, as well as academics from the region.

II. Literature review

Latin Americanist scholars have been notably focused on livelihood analysis (Wilder & Romero, 2006; Eakin, 2006; Chowdhury & Turner II, 2006; Perreault, 2005; Zimmerer, 2004; McSweeney, 2004; Whiteford & Melville, 2002; Perz & Walker, 2002; Bebbington, 2000). A common approach on these studies is the focus on how external drivers, such as market, state, and social/environmental changes, influence the livelihood prospects of vulnerable populations. These authors emphasize the importance of micro-

[16] This study was part of two larger projects, both funded by the National Oceanic and Atmospheric Administration (NOAA) on water, urban growth, and adaptation to climate change in southern Arizona and northwest Mexico, including Climate Assessment of the Southwest (CLIMAS) Program; and a NOAA Sectoral Applications Research Program (SARP), Moving Forward: Adaptation and Resilience to Climate Change, Drought, and Water Demand in the Urbanizing Southwest and Northern Mexico.

level analysis in order to find the complex ways in which livelihoods are affecting. Zimmerer (2004) for example calls for a reinforcement of household-level analysis as a distinctive feature of much cultural and political ecology, and overlapping "human dimensions" research that emphasizes human-environment interaction in specific resource systems (2004: 796).

In Latin American studies, household-level analysis has received significant interest due to its capabilities to enhance and improve environmental studies (Chowdhury & Turner II, 2006; Fox, et al., 2003; Perz & Walker, 2002; Liverman et al., 1998). In these studies, there is a particular interest in how biophysical variables such as forest cover and soil quality are related to population variables (e.g., household size, on-farm population density, and migration). Perz and Walker (2002), for example, have examined the interaction of household life cycles and land use allocation in the Amazon. Based on a quantitative-household survey analysis they conclude that land and capital availability as well as the numbers of dependent children, labor availability, and generational transitions influence the likelihood of adopting productive conservation programs, in this Amazon case, agroforestry systems.

Perz and Walker (2002) follow the environmental perspective that population dynamics can affect local environment and resources with significant impacts, such as deforestation, for the sustainability of natural resources and biodiversity conservation (McShane & Wells, 2004; Sayer & Campbell, 2003; Hardin, 1968). These studies are focused on how population dynamics affect natural resources, which is extremely important, especially if we aim to examine the causes of environmental change. However, on the contrary, changes in the quality and quantity of natural resources (i.e. drought and natural disaster) can also have important impacts on household and demographic dynamics such as harming sources of income (de Sherbinin et al., 2008). This is the case of livelihoods of people located in the peri-urban area of the city of Hermosillo, which according to Díaz-Caravantes & Wilder (n.d.) were negatively affected due to increased urban water demand exacerbated under conditions of drought.

Before describing this case study, it is important to clarify how the concept of the "peri-urban" is understood and used in this article. There is no a single satisfactory definition of the peri-urban; rather, the peri-urban is a context-specific social construction (McGregor et al., 2006a; Tacoli, 2006; Brook & Davila, 2000). The word "peri-urban" can be used to denote a place or process. As a place, it can be defined as the zone surrounding a city's existing boundaries. As a process, the peri-urban can be understood as a flow or interface of goods and services between rural and urban areas (Narain & Nischal, 2007; Allen, 2003; Brook et al., 2003). The latter definition emphasizes that peri-urban interface as a process of social exchange between urban and rural communities. However, as Allen (2003) emphasizes, from an environmental perspective, the peri-urban interface can also be characterized as a natural ecosystem affected by the material and energy flows demanded by both, the urban and rural. In this regard, the peri-urban interface is not only a social process, but also a process of environmental exchange.

Allen (2003) identifies three processes of environmental change in the peri-urban interface. One is the change in land use, such as from agricultural to residential or industrial uses. Another is the transfer in the use of natural resources such as forest, water and pollution. Finally, there is the change in the generation of waste and use of environmental services, such as increased solid and liquid waste in the peri-urban zone. Following these insights, the case of Hermosillo illustrated a transfer of natural resources, specifically water, from the peri-urban area to the city.

On the other hand, according to this body of work, peri-urban livelihoods might potentially also be benefited by their geographical location near the city (McGregor et al., 2006b; Douglas, 2006; Lynch & Poole, 2006; Brook & Davila, 2000). These benefits may include access to urban markets for peri-urban agriculture[17]. Lynch and Poole (2006), for example, study the mechanism by which smallholder producers overcome the

[17] Many times are associated peri-urban agriculture and urban agriculture, however, this paper is focused around the city and not within it, as the term urban agriculture suggests. This geographical distinction is emphasized in the term peri-urban agriculture. In addition, in the case of Hermosillo there is no evidence that agriculture within the city is a considerable phenomenon. For more information about urban agriculture there is a considerable literature on the International Development Research Centre (IDRC, 2009) and Resources Centres on Urban Agriculture and Food Security (RUAF Foundation, 2009).

informational constraints in fruit and vegetable market systems. They conclude that although peri-urban smallholders have access to urban markets, the smallholders have significant limitations in access to market information and are also limited in their ability to respond to risks of entering new markets (Lynch & Poole, 2006, p. 91). In addition, the peri-urban residents may benefit by employment for the jobless, access to health and education, and opportunities provided by urban infrastructure. Finally, peri-urban farmers benefit from the availability of urban food waste they employ as livestock feed or fertilizers (Douglas, 2006). Following these insights, this paper analyzes not only the costs for livelihoods in the transference of natural resources to the city but also social and economic benefits from urban areas to peri-urban ejidos, specifically urban jobs obtained by peri-urban ejidatarios and their families.

Although over the last decades peri-urban livelihoods have rarely featured in published work (Simon et al., 2004), in recent years more accounts of livelihoods impacted in the peri-urban fringe have come out in different papers and volumes, with a few exceptions focused on Latin American countries (Díaz-Chavez, 2006; Allen, 2006; Stoian, 2005; Buechler & Scott, 2000), the majority has centered on Asian and African countries (Mattingly, 2009; Hirsch, 2009; Thornton, 2008; Narain & Nischal, 2007; Oberhauser & Hanson, 2007; Simon et al., 2004; Jaiyebo, 2003). Except for Stoian's work on Bolivia (2005), most of the Latin American work is sited in Mexico. Díaz-Chavez (2006) introduces an indicator framework to assess sustainability of peri-urban areas of Mexico City. In this framework, she introduces a set of indicators for rural livelihoods such as agriculture, livestock and forestry production. She also introduces a set of environmental indicators such as land use, pollution and water resources; however, she does not indicate how livelihoods and environment interact.

With a focus on peri-urban water resources, Allen et al. (2006) analyze the link between peri-urban livelihoods and water resources, but just in relation to water and sanitation services in the peri-urban areas. However, as the authors also argue, water use for economic livelihoods in peri-urban areas is quite important because many income activities, such as agriculture and horticulture, depend on the availability of water. For

those involved in these activities, lack of water due to growing urban demand, poses a serious threat to livelihoods (Allen et al., 2006; Treminio, 2004).

Buechler and Scott (2000) examine the Mexican basin Lerma-Chapala, very close to the city of Irapuato. In their case, they analyze the dispute between an ejido located close to the city and private landowners about urban wastewater[18]. According to the authors, the ejido's considerable distance away from Irapuato and the fact that it is downstream explain why this ejido have lost access to water. The long distance from the city helps to understand why almost does not depend on city's jobs. An important conclusion is that water, even if it is residual water, is an important resource for sustaining agriculture and therefore, livelihoods of farmers.

In this regard, transferring water uses from supporting livelihoods in peri-urban areas to the city is critical because Mexican peri-urban ejidos are being drastically reconfigured by urban expansion. According to estimates by the World Bank and Mexican government, two-thirds of the land required for urban expansion will come from the ejido sector, especially targeting peri-urban ejidos (Lavadenz & Deininger, 2001). Peri-urban livelihoods are also affected by global transformations. Global economic transformation coupled with climate change leads to a situation of regional water and land use intensification known as *double exposure* (Leichenko & O'Brien, 2008). For this study case, the North American Free Trade Agreement (NAFTA), signed in 1994 by Mexico, the U.S. and Canada, is of particular importance. An iconic illustration of these transformations is the case of wheat. While in 1990, Mexico imported US$46. 3 millions in wheat, in 2002, the value of imported wheat increased to US$236.8 millions, an increment of 411% (Mella & Mercado, 2006). Integration of the NAFTA region involves national-level reforms in agricultural policies, such as elimination of subsidies and price supports that expose the agricultural sector, especially smallholders, to market volatility and fluctuating prices. Rural scholarship has amply shown how, free trade and liberalization strategies lead to considerable challenges for Mexico's agricultural producers (Wilder & Whiteford, 2006; Schwentesius & Gómez, 2001). In addition, due to

[18] In fact, the use of wastewater in irrigated agriculture is and will be a world-wide practice (Scott et al., 2004; FAO 2001; WHO/UNICEF (2000); Gleick, 2000). This practice is part of the peri-urban water uses.

neoliberal policies, the "Article 27" constitutional reforms of 1992 changed the land tenure of ejidos from inalienable property (e.g., land that could not be sold) to individual titles in which the *ejidatarios*[19] are able to sell their land.

In keeping with neoliberal reforms, dramatic revisions to the nation's water policy in a new National Water Law were introduced in 1992. The law established new aspects such as decentralization of urban water management and irrigation districts. This law also established the National Commission of Water (CONAGUA) as the authority responsible for the administration of all national water issues and all the hydraulic work (NWL, 1992, p. 2). The new law also addresses some aspects of water markets, such as now users are free to transfer their rights when only the user changes or within the areas (Garduño, 2005, p. 104). Because water markets require legal security, the new law also codified water rights through the Public Registry of Water Rights (Registro Público de Derechos de Agua). Before REPDA, ejidos in the study area had water rights but lacked any specific volumetric assignment. Now ejidos can potentially have a secure volumetric assignment.

In order to examine the research questions, I draw upon a framework for livelihoods analysis developed by Ellis (2000) and Scoones (1998). Their livelihoods analysis framework has been articulated into a set of particular methodologies to try to synthesize rural livelihoods components (Ellis, 2000; Scoones, 1998). According to Ellis (2000), development policies and programs have failed to acknowledge the full complexity and diversity of livelihoods, and consequently have ignored local capacities for engaging with transformations. Thus, this framework helps to understand local livelihoods and accounts for capacities for transformation. The Institute for Development Studies defines livelihoods as “the capabilities, assets, (including both material and social resources) and activities required for a means of living” (Scoones, 1998, p. 5). However, geographer Anthony Bebbington established that assets are not only simple resources that people use as means of living, they give them also the capability to be and to act, to

[19] Individual with formal membership in the ejido.

change the world (1999, p. 2022). In this regard, livelihood strategies are not only concerned with how local people can survive, but also how people can re-negotiate their livelihoods (Bebbington, 1999). Ellis's livelihoods analysis framework is an adequate conceptualization because it takes into account rural livelihood diversification, which is "the process by which rural households constructs a diverse portfolio of activities and assets in order to survive and to improve their standard of living" (Ellis, 2000). Rural livelihood diversification, considered in the Ellis' livelihoods analysis framework, allows examining how people can re-negotiate their means of sustenance.

According to Ellis (2000), the key indicators for assessing rural livelihood diversification are:

Seasonality (e.g., production cycles of crops); risk strategies (e.g., diversification of production activities); Labor Markets (e.g., farm and non-farm labor markets); Migration patterns; and Credit market failures (e.g., the lack of availability of funds to finance agricultural production).

By adapting Ellis' livelihood analysis, I examine livelihood strategies of peri-urban ejidos to deal with four external transformations that affect livelihoods of peri-urban ejidos: urban expansion, climate conditions, agricultural free-trade and ejido land and water reform. Following this and based on approximately 60 open-ended and semi-structured interviews with ejidatarios, factors affecting their livelihoods were determined, as shown in Figure 1.

Figure 1

Although livelihoods are connected to more than labor and farm changes, as stated above, this study examines in detail these two factors as the two primary sources of income for the peri-urban ejidos, as shown in Figure 1. According to Ellis (2000), one of the indicators of rural livelihood diversification is labor markets because "farm and non-farm labor markets reduce the seasonality and risks of crop production to construct viable rural livelihoods" (2000, p. 66). For that reason in Figure 1, *labor strategies* are stated as

a fundamental element of livelihoods. This is divided into farm and off-farm labor markets. Additionally, Ellis (2000) considers migration a type of diversification that links up with labor market factors in household and individual decision-making for survival. For that reason, migration is included as a key indicator in Figure 1 as well. "Local" refers to the people who work in the city of Hermosillo and "migration" refers to the people who seek work outside of the ejido and outside of Hermosillo, at a national or international level. Farm changes in Figure 1 is associated with seasonality issues, which in the livelihoods analysis framework emphasizes the fact that "production cycles of crops are determined by the onset of rains, their duration, the length of the growing season…." (Ellis, 2000, p. 58). In this case study, climate conditions, specifically drought, create challenges for livestock production by affecting the number of cattle that can be maintained in the grazing land. Drought also exacerbates urban water demand from the peri-urban area. This has diminished or eliminated the availability of water in the peri-urban ejidos, negatively affecting agricultural land.

Ellis (2000) establishes that economic problems in agricultural production, such as credit market failures, are considerable factors weighing against rural diversification. In this case study, the North American Free Trade Agreement (NAFTA) has had considerable negative impacts on the price of wheat and therefore provided an impulse for a change of crop pattern. In addition, urban expansion has not only produced the increase of water demand, but also the augmentation of urban land speculation, particularly in ejido grazing lands, where ejidatarios have decided to divide and sometimes sell the grazing land to be used as recreational ranchettes (known as *lotes campestres*) by Hermosillo residents. The sale of agricultural and grazing land has been allowed, and sometimes encouraged, by the Artícle 27 land reform.

In addition, as mentioned before, the National Water Law of 1992 requires legal security of water rights and for that reason it codifies the rights through REPDA.

The conceptualization displayed in Figure 1 guided the development of a set of indicators and questions for a written survey applied to 82 ejidatarios in 5 ejidos of the peri-urban area. The sampling methodology employed is discussed in detail in section IV

on this paper. Basically, the survey was divided in 6 sections: agricultural diversification, livestock production, land tenure and water rights, climate risk strategies, household information, and labor and migration of household's members. The study site and findings are discussed in the next section of the paper.

III. Study area

In 2000, the city of Hermosillo, the capital of Sonora, was the 8th biggest city of the northern border states of Mexico (INEGI, 2000). By 2005, Hermosillo had 641,971 inhabitants (INEGI, 2005), and it is projected to grow to nearly one million inhabitants by 2030 (CONAPO, 2009). This city is not only significant in absolute numbers of total population, but also for its growth rate. In 1990, Hermosillo recorded 406,417 inhabitants (INEGI, 1990), which in comparison with the 2005 population represents an increment of 58% in fifteen years; whereas, the national population only increased 27% over the same period. According to the United Nations, total urban population in Central and South America was 370,312,000 inhabitants by 2000, with estimated growth in 53% by 2030 (United Nations, 2009). In this regard, Hermosillo's case exemplifies a broader occurrence in Latin American countries where rapid urban population growth is becoming standard.

Increasing population in developing cities has caused urban sprawl affecting the urban periphery (Angel, Sheppard, & Civco, 2005). As demonstrated by Díaz-Caravantes & Wilder (n.d.), in the case of the city of Hermosillo, growing urban water demand has primarily affected ejidos located on the peri-urban area. The ejido is the most representative group of Mexican rural society, as the most noticeable and specific outcome of agrarian reform arising from the Mexican Revolution of 1910. By 1980, half of Mexico’s cultivated land was in ejidos.

The 16 peri-urban ejidos included in this case study have around 32,000 hectares with about 1,000 total ejido members. Their principal productive activities are small-scale irrigated agriculture and small-scale cattle ranching. The principal destination of

the calves is the U.S. beef market. The ranching ejidos have an average of 11 head of cattle per producer. The farming ejidos have an average of 5 irrigable hectares per ejidatario. To supplement their incomes, some ejido families have off-farm sources of income from men working as day laborers on private farms in the vicinity or as skilled laborers (brick layers) around the ejidos or in the city of Hermosillo.

Figure 2

The 16 ejidos can be categorized by the location and type of urban water supply impact.[20].La Victoria, Mesa del Seri, San Pedro and El Alamito are all located in the aquifer Mesa del Seri-La Victoria and are adversely affected due to recent urban wells serving Hermosillo that were established very close to the ejido land, but at the same aquifer. These urban wells caused the drying up of the ejido wells and now most of the ejido land is abandoned. In a second classification on its own, San Juan is the most negatively affected ejido due to the El Molinito aqueduct. In the third group are the ejidos affected by the Las Malvinas project, which consists of urban wells established on the aquifers San Miguel and Río Zanjón. According to CONAGUA's agents, Codorachi and El Torreón were the most negatively affected ejidos by losing access to their water, but La Labor and El Carmen, and finally, to a lesser extent, El Zacatón and Zamora. The Ejido Molino de Camou was affected by reduced water quantity from 1998 to 2006, although less than the rest of the ejidos because at least they could farm in one growing season (Díaz-Caravantes & Camou, 2005). In 2007, Molino de Camou was able to negotiate with *Agua de Hermosillo*[21] (AGUAHH) and *Comisión Nacional del Agua*[22] (CONAGUA) to improve its irrigation system and augment the volume of extraction. Finally, in the fifth group are the downstream users, which although these improved in water quantity, in water quality they were highly affected because since 1996, according to a state government agent and several ejidatarios, they received only urban untreated

[20] See Díaz-Caravantes and Wilder (n.d.) for full discussion of this categorization and findings.
[21] The agency responsible for urban water management at municipal level
[22] The federal agency responsible for water policy and management at national level

wastewater which limited its usefulness for crop irrigation as described above. Table 1 shows a classification of the impacts on these ejidos. The recent history of water transfers between the peri-urban ejidos and the City of Hermosillo clearly demonstrates that loss of access to water in the ejidos is due to 1) water transfers to Hermosillo to serve the urban population; and 2) successful resistance by other water users, including powerful irrigation districts southwest and southeast of Hermosillo (Díaz-Caravantes and Wilder, n.d.). This article examines the specific impacts on ejido livelihoods associated with the urban water transfers.

IV. Methodology

For the purposes of the livelihood analysis, in order to determine what ejidos would be surveyed, first, five groups were classified corresponding to the type of impact on ejidos by urban water supply facilities (Table 1). In order to examine all of the types of impact on ejidos by urban water supply, one ejido of each group was selected. Ejido La Victoria was selected for group 1 because it was the first groundwater-based ejido affected by urban infrastructure facilities (e.g., wells) and in this sense is the most emblematic ejido that represents water problems of group 1. In group 2, San Juan was selected because this is the only ejido impacted by El Molinito aqueduct. According to the open-ended interviews, Codorachi was the most affected ejido by the Malvinas project, and for that reason this ejido was selected for group 3. Molino de Camou is the only ejido in group 4 and therefore it was selected. Many ejidatarios from La Yesca were interviewed in the first phase of this research. This previous work would facilitate the surveying process and for that reason La Yesca was the selected ejido for the group 5.

Because urban water scarcity drove intense urban water extraction from the peri-urban area beginning in the mid-1990s, it is fundamental to analyze how peri-urban ejido livelihoods were transformed from that time forward. In almost 15 years many changes in the ejidos' demography have occurred, some people have died and others have migrated out of the ejidos. Because interviewing migrated ejidatarios was deemed not feasible,

migrant individuals were dropped from the target population. According to these criteria, the target population for this survey was the ejidatarios who resided in their ejido continually from the mid-1990s to the present.

In order to identify the ejidatarios who resided there in the mid-1990s, I use the lists established in the land reform program (PROCEDE) [23]. Based on these lists and in interviews with key informants I determined the target population in each ejido, which resulted in the following table.

Table 2

According to table 2, of the 238 ejidatarios registered in the PROCEDE lists, 118 ejidatarios were the target population, however 8 did not want or were not able to answer the survey and 28 were not located after three visits to their houses. One hundred twenty (120) ejidatarios were not considered in the target population because they had died, migrated or currently lived off the ejidos. Of the outsiders, 61 individuals migrated or simply lived in Hermosillo, just one was reported in the U.S., and 2 migrated out of the town but key informants did not know where they are. In total, the target population resulted in 82 respondents distributed as shown in table 2[24]. The survey was conducted from December 2008 to February 2009. The surveys were analyzed using the program Statistical Package for the Social Sciences (SPSS).

The range of the respondents varies between 30 and 83 years old. Twenty-two percent of respondents were between 30 and 50 years old, 35% were between 51- 60

[23] PROCEDE means Programa de Certificación de Derechos Ejidales y Titulación de Solares. In Molino de Camou, Codorachi, and La Yesca the program was implemented on 1994, in San Juan on 1996 and La Victoria in 2000. Because in the case of La Victoria was not in the mid 1990s, I complement this information with a list of PROCAMPO (a subside program granted by the Mexican agriculture agency) from 1994.

[24] The number of respondents by ejido varies from a minimum of 13 in Codorachi to a maximum of 19 in Molino de Camou. Obviously, these are small number of cases. For that reason it was decided to survey all of the ejidatarios on the target population and not a sample, as used in statistics analysis. What is to say, the respondents by ejido are not a sample of the ejido, it is the total target population by ejido. Although, due to the small number of cases I am not to be able to statistically generalizing the findings, I consider the survey a useful tool to strength and enhance the information obtained through qualitative interviews. This is the importance of using mixed methods on this research.

years old, and 43% were older than 60 years of age. These data illustrate the aging of the ejidatario demographic. Ninety-four percent of the interviewees were men, which corresponds to the traditional gender composition in ejidos.

V. Farm Changes

Water shortage in Hermosillo started in the mid-1990s[25]. This water condition combined with the drastic urban population growth (around 130% from 1970 to 1990) has motivated Hermosillo authorities to implement several water projects in the peri-urban fringe, as discussed briefly above. The prolonged drought and urban water policy choices have affected agricultural land of peri-urban ejidatarios by pushing them to change their traditional crop or selling their land or simply stop cultivating their land. In this regard, the survey asked to what degree the ejidatarios consider their agricultural activity had been damaged by infrastructure of urban water supply such as dams, wells, and aqueducts. Seventy-one percent of respondents said highly damaged, 16% somewhat damaged, 11% not damaged, and 2% responded they do not know. The 11% that said that they did not have any damage are from ejido La Yesca.

Since a total of 87 percent of the ejidatarios state that they were negatively affected by the hydraulic infrastructure built to serve the city, I developed two indicators--water impact level and wealth level of households—to be used to understand whether there is a link between level of household wealth and water impacts.

Poverty has a considerable relationship with the availability of water resources (Liverman & Merideth, 2002; De Janvry et al., 1997). Liverman and Meredith (2002) establish that the poor are often more vulnerable to extreme events such as drought because they have less access to key socioeconomic resources. Moreover, as stated above, DeJanvry et al. (1997) have found that ejido access to agricultural water is a

[25] According to CONAGUA records (2009), from 1936 to 2008 the Sonora River registered an average annual streamflow of 36 million cubic meters (Mm3), while from 1981 to 1995 the average annual was 52 Mm3. From 1996 to 2005, the Sonora River basin registered an average annual of 20.9 Mm3. In 2006 and 2007 were recorded streamflows of about 113Mm3 and 44 Mm3, respectively. However, in 2008 only 17 Mm3 was recorded.

critical indicator for moving out of poverty. Due to the water shortage, some ejidos opt to reduce the irrigated surface (i.e. Codorachi, San Juan) or to reduce the number of irrigations by growing cycle (i.e. Molino de Camou). Following this, water impact level is calculated based on the proportion of number of years, between 1994 and 2008, negatively affected in the irrigation activity either by reducing the irrigated surface or reducing the number of irrigations[26].

Wealth level of households in this study is calculated using a composite index combining four household characteristics[27]: model of farm tractor, the model of truck or cars, number of head of cattle, and housing quality (telephone, restroom, roof, wall and flooring material, and domestic water service). Based on these household characteristics, I developed the classification presented in Table 3.

Table 3

The column "Total" in Table 3 shows the percentage ranked at different wealth levels in each ejido (low, medium and high in each ejido is 100%). La Yesca has a large percentage of households in the high wealth category, followed by Codorachi. At the same time, Molino de Camou, San Juan and La Victoria the level in the high wealth category varies between 5 and 7 percent. In the low wealth category, the biggest percentages are Molino de Camou, Codorachi and La Victoria, meanwhile in La Yesca has only 11 percent. Although the number in each case may be small, this information lets us know some important trends. Particularly relevant is the fact that La Yesca has a considerable percentage of ejidatarios in the high wealth level.

Table 3 also shows the percentage of wealth level in each ejido compared with water impact level. If there is a relationship between low wealth level and water impact,

[26] Water impact level was calculated based on water quantity and not on water quality because according to the interview findings, only La Yesca was negatively affected in water quality terms, and in the survey I needed a variable that was consistent for measurement across the 5 selected cases, such as water quantity.
[27] The method used was principal component analysis obtained using the SPSS. For this method we used a factor or index that orders a combination of the four characteristics of the total sample, in this case, the 82 cases. For more information about the method see Consejo Nacional de Población (CONAPO, 2001).

what we would expect to find is that high and medium household wealth would have more intersection with no- to low-water-impact level. Furthermore, we would expect to find that low levels of household wealth are associated with medium to very high water impact level. This is completely evident in the case of La Yesca, where virtually all households in the high wealth category (67%) reported no- or very low-water-impact and all medium households in the medium wealth category (22%) reported no water impact. The opposite case is ejido La Victoria, where all the households in the low wealth categories (40%) reported a very high water impact. In San Juan almost all of the high and medium wealth households reported low or very low water impact levels. In Molino de Camou and Codorachi there is not a clear interrelation.

As shown, one of the most drastic cases impacting ejidatarios' livelihood occurred in the ejido La Victoria where, according to interviews with key informants, around 70% of the total farmers has stopped cultivating. The fact illuminates a key reality: they abandoned their land because they cannot compete against urban water wells, which are well-financed to extract very deep groundwater.

In one of the surveyed ejidos, water scarcity, land transaction, and urban development have an important connection. In La Victoria of the 56 land rights, the 25% have been sold. I interviewed two ejidatarios that have sold their land. They reported that the buyer was a very influential person of the city of Hermosillo, with a very good relationship with the last governor (2003-2009). These ejidatarios said that because the ejido La Victoria is located very close to the city this person was interested in buying the land for urbanizing in future years. They said that they sold their land because without water the agricultural land is not anymore useful and they needed the money to survive. They reported that if they had had water for agricultural purposes they would never sell their land because it was their means of living.

Maybe less critical than selling the land, but very important in terms of livelihood strategies, are the changes in crop pattern. Figure 3 shows the crop pattern in the last 15 years on the Fall-Winter Growing Cycle[28].

Figure 3

Figure 3a is very relevant to the changes in crop pattern in all ejidos. Clearly, the principal shift has been from wheat to livestock pasture. The surface in wheat from 1993 to 1998 was between 500 and 600 hectares; from 1998 to 2008 wheat declined to between 300 and 400 hectares, a decrease of around 30%. On the other hand, the surface in pasture from 1993 to 1998 was not more than 300 hectares and increased by the 1998-2008 period to about 500 hectares, an increase of approximately 60 percent. In all the ejidos it is possible to observe this pattern, but more drastically in Molino de Camou, where wheat production almost disappears.

Of the total 82 surveys, 39 ejidatarios had farmed wheat since before 1994. However, 26 stopped cultivating wheat between 1994 and 2008. When asked about the reasons, half of the survey respondents said that it was because the production cost is higher than the market value. Wheat production problems are associated with integration into global agricultural markets, specifically NAFTA, which phased out subsidies for this crop. The other half of the wheat producers halted cultivation of wheat due to problems with water, either quantity or quality. An ejidatario from Molino de Camou explained to me that wheat need to be irrigated six times per growing cycle and even one lost “riego”--especially the last one in March/April—will result in total crop loss. Due to the water shortage, sometimes the wheat producers irrigated only three or four times, and lost the crop. According to the responses on the survey, no one has received compensation for crop losses.

[28] Not all the ejidatarios were registered on PROCAMPO. Therefore, although the numbers of hectares is not the total of production by ejido, there is a good approximation to examine how crop pattern have changed.

For the spring-summer growing cycle we can observe a similar trend as in the fall-winter cycle.

Figure 4

Figure 4a shows the crop pattern for all ejidos. In 1994, sorghum and corn covered about 400 hectares and pasture about 200 hectares. However, since 2000, livestock pasture covers almost of the total surface in spring-summer. The same trend is apparent in all ejidos, with the exception of La Yesca, which in spring-summer has always sown pasture. As stated above, la Yesca is one the ejidos that after 1996 only received untreated wastewater. This change limited the type of crops that can be farmed because the State of Sonora Health Department prohibited vegetable farming for human consumption. Another restriction is that alfalfa cannot be farmed because the water can "burn" the crop. The ejidatarios farm basically pasture, such as rye-grass, and wheat. Wheat is sold as a pasture for local pig farms and the rye grass is used to feed their own cattle. Their cattle produce milk that is sold in Hermosillo markets. According to the interviews in La Yesca, there are no epidemiological problems because the agricultural products are not consumed directly by humans. However, they are consumed indirectly as cheese or pork. An ejidatario told me that sometimes some cows died without any evident reason, suggesting that it is due to the wastewater, but other ejidatarios present contradicted this idea.

Of the total surveys, 9 respondents sowed corn prior to or in 1994, and all of them for household subsistence. However, currently, none of them continues with corn. Four respondents reported abandoning corn production due to economic problems, and four others due to lack of sufficient water.

During both growing cycles, then, this study has documented the diminution or disappearance of *traditional* crops such as wheat and corn in the peri-urban ejidos and the increase of pasture such as rye grass, sorghum-grass, and alfalfa. This change is not only due to water shortage and economic problems in traditional crops, but also a consolidation of ranching activities in peri-urban ejidos.

Since the 1960s, an extensive cattle breeding has been practiced in the ejidos of the Sonora River region (Camou, 1998). According to Camou, in the Sonora River region, the ejidatarios are considered *poquiteros* (small-scale ranchers) that breed calves during approximately one year and then sell the calves to U.S. feeder farms that fatten the calves for the beef market. Under current conditions, a small-scale rancher obtains more economic benefit than a wheat producer (Díaz-Caravantes, 2001, pp. 89-96). However, another important reason is related to water. Of the total survey respondents, 15 started cultivating some type of pasture after 1996 when Hermosillo's urban water shortages intensified and the city water supply was focused on the peri-urban area. Ejidatarios from San Juan and Molino de Camou explained to me that they shifted to ranching because it has less uncertainty than wheat. Wheat, as aforementioned, needs to be irrigated six times in regular periods to obtain a good production, while pasture, for example rye grass, produces good pasture after only two irrigation sessions, given that pasture is less water-dependent than wheat or corn. The wastewater users of La Yesca, on the other hand, said that rye grass and sorghum-grass are resistant to the effect of untreated wastewater and it can be used to feed the cattle. However, they complain that they cannot sow alfalfa because the wastewater burns it.

According to the survey, all of the 15 ejidatarios that started to cultivate pasture after 1996 use it for feeding their own livestock. By contrast, the four alfalfa producers report that they sell bales of alfalfa to other ejidatarios. At first glance, the shift from human food crops to pasture might mean an increment of the number of cattle; however, this is not completely the case. The annual livestock census (SAGARHPA, 2009) recorded the following information.

Figure 5

As displayed in Figure 5[29], in Molino de Camou, Codorachi and San Juan there is not a constant increase in the number of heads of cattle. In San Juan and Molino de Camou there is an increment, but this drastically declined in 2003. The only ejido that

[29] There is not database for Ejido La Victoria. The year 2006 does not have records for all ejidos. Codorachi and Molino de Camou do not have some records.

shows a sustained increase is La Yesca, from about 300 heads of cattle in 1997 to 550 in 2007.

The number of cattle an ejidatario in these conditions can raise depends on many factors, including the quantity and quality of pasture. These two factors are linked to water availability because, as shown in Figure 1, water scarcity reduces the irrigable area of agricultural land and affects vegetation in grazing land. From the survey, 49 respondents were small-scale ranchers. When asked what they would do if in the next year there was a drought, 18 said that they would sell cattle because drought would reduce the quantity of irrigable water and therefore the quantity of pasture. This strategy explains the 2003 decline in heads of cattle in San Juan and Molino de Camou because the Molino Dam was almost empty in that year. As shown in Figure 2, San Juan and Molino de Camou are the nearest ejidos to Molino Dam. An additional factor that complicates the ejido San Juan in 2003 was than in that year CONAGUA installed groundwater measuring in the ejido wells to be sure that they did not pass the water rights granted by CONAGUA in 2000, which, according to the ejidatarios, is not enough even for one growing cycle. Under these conditions, these ejidatarios made a rational choice to sell the cattle because the number of cattle is very flexible. One year, the ejidatarios can sell a considerable portion of their livestock and in the next year they can start to recover their herd by breeding new cattle.

Quantity and quality of pasture in these ejidos is totally associated with the conditions of grazing land as well[30]. Grazing land has suffered two substantial impacts. First, as stated above, from 1996 to 2005 the Sonora River basin registered about 42% below-average streamflows due to drought; the same occurred in 2008. In survey responses, when asked about the degree of the impact of the drought in the region, 77% of the respondents said highly affected, 20% said somewhat affected and 3% said not affected. Although on the survey responses there is not clear consensus about when the drought started, 83% of the survey's respondents said that the drought has not finished. When asked about the principal indicator of drought from their perspective, 32% of the

[30] Ejido La Victoria does not have grazing land

surveyed ejidatarios mentioned the lack of water in the ejido wells and 16% commented on the lack of pasture in the grazing land. This data lets us know that ejidatarios perceived a negative impact on pasture from drought.

Grazing land is also affected by a process of fragmentation due to multiple causes. On one hand, according to the interviews, when PROCEDE was implemented in the 1990s the governmental agents parcellized the agricultural land, but also they encouraged the ejidatarios to parcelize the grazing land, which before the 1990s had always been shared as a common pool resource. This proposal found an ally in the internal division of ejidos. Not all the ejidatarios were ranchers before the Article 27 land reform. Prior to the reforms, only the members of the ejido who were *poquiteros* used the ejido´s common pool grazing land. One ejidatario said that the non-ranching producers were jealous of the poquiteros and for that reason the first group encouraged the division of the grazing land. Another factor, which was recorded in the case of Molino de Camou and La Yesca, was the possibility of selling their part of grazing land for multiple purposes, such as urban land use. The combination of these factors has resulted in the fragmentation of grazing land. After the parcellization, in Molino de Camou each ejidatario (both crop producers and ranchers alike) has 20 hectares, in Codorachi approximately 30, in San Juan around 50, and in La Yesca, each ejidatario has 20 hectares. The repercussions of this fragmentation become clear when we realize that, in Sonora, extensive livestock need 25 hectares for each cow-and-calf pair (Camou, 1998). Thus, after parcellization, many ejidatarios were left with insufficient pasture for their cow-calf operation and, for that reason, they changed their crop pattern on their agricultural land from traditional crops to pasture. On the survey, 60% of the respondents had at least 3 cows and, of this percentage, 35% did not need to buy pasture in 1994 and now they need to purchase (i.e. bales of alfalfa).

Another important factor with implications for the number of cattle is the economic needs of the household. According to the interviews, some people like livestock because they feel that their cattle are like a savings in the bank, when they have an emergency due to illness of a family member, for example, they can sell cows and

obtain money immediately. Cattle represent a liquid asset while in wheat production profits can only be yielded at the end of the growing season. Ranchers also rely on selling milk to cover the daily expenses, and the sale of the calves is like a Christmas bonus.

VI. Income Strategies

Ellis (2000) established that farm and non-farm labor markets provide an alternative income source that offsets the seasonality of crop production and reduces the associated risks , allowing producers to construct viable rural livelihoods. Following this, the survey asked about the labor strategies of the ejidatarios in the study region. On the survey, we asked about the conditions in 1994 and now.[31] In 1994, 34% of the ejidatarios were part of labor markets, while in 2008, just 23% were salaried workers, distributed by activities as displayed in Figure 6. This change in the percentage salaried workers from 1994 to 2008 has a relationship with age in people. According to the survey, of the 28 ejidatarios that were working in 1994, 10 were older than 60 years in 2008, which is to say, many of them now are senior citizens (or *tercera edad*).

Figure 6

Figure 6 shows the distribution of salaried worker's ejidatarios by activity and by place of work. As observed, the number of ejidatarios who are salaried worker decreased in virtually all the places of work, except for the number of workers on their own ejido. The exception for individuals working on their own ejido is due to two ejidatarios who worked as security guards in the recreational ranchettes. The ironic part of this case is that these two ejidatarios sold their grassland to be used as recreational ranchettes and later were able to get a job on their old land. As we can observe in Figure 6, the

[31] 1994 was selected as a year of reference to evaluate the conditions of ejidatarios before urban water shortage existed. An additional reason for selecting this date is that in this year land's reform started in most of the study ejidos. Moreover, in that year was signed NAFTA, which has had important implications for the socioeconomic context of ejidos.

proportion of ejidatarios who work in Hermosillo is small. In fact, this proportion decreased from 1994 to 2008.

As stated, the decrease in the numbers of ejidatarios that work in Hermosillo can be explained by the fact that they are aging and no longer considered employable in their salaried off-farm jobs. In any case, the final outcome is that fewer ejidatarios are receiving income from Hermosillo comparing with other places of work. In general terms, if we consider that in 2008 just 3 of the 82 ejidatarios had a job in Hermosillo, the income benefits from Hermosillo look smaller. Nonetheless, the benefits of Hermosillo could be through a household member as well. For that reason, the survey also examines the income impacts of ejidatario household members.

Table 4

Table 4 shows the degree of dependency on jobs in Hermosillo jobs in 2008 and 1994. The column "Workers" shows the number of households with at least one salaried worker. The column "HMO workers" shows the number of households with at least one member working in Hermosillo. The column "%HMO workers" shows the percentage of "HMO workers" divided by the total number of households by ejido. As observed in the column "%HMO workers," 20% of households in 2008 and 18% in 1994 had at least one household member employed in Hermosillo. Although these percentages are important, these are not enough to consider that there is a high degree of dependency on employment in Hermosillo both in 1994 and 2008. The occupation of ejidatario household members is as follows.

Table 5

Comparative jobs in Table 5 mean the occupations of the ejidatario household members (including the ejidatarios) that are repeated in 2008 and 1994. The *non-comparative jobs* mean the jobs that are not repeated between these dates. Most of the

"new" jobs are business employees, while in the comparative jobs industrial workers were increased and bricklayers decreased in 50% from 1994 to 2008. A possibility is that the change from bricklayers to industrial workers and business employees may mean the transformation from non-educated jobs to more educated and therefore, it may be reasonable to assume, to better-paid jobs. However, the evidence does not support this suggestion because, according to the survey results, those employed in Hermosillo in 1994 had, on average 6.6 years of school, compared with 5.93 in 2008. Thus, the household members employed in Hermosillo in 1994 had higher educational attainment than do their more recent counterparts.

In order to measure the effects of rural diversification, Ellis proposes wealth ranking based on income level (2000, pp. 206-207). Wealth ranking is a useful exercise to examine the relationship between this variable with the benefits obtained from the salaried workers in Hermosillo. However, determining income level on the survey was a difficult exercise because the ejidatarios do not know the exact income of their household members. For that reason, income level is estimated using the indicator *wealth level of household* of Table 3.

Table 6

Table 6 also displays the percentage of households that received income from Hermosillo, which could be because at least one member of the household has a job in Hermosillo (Table 5) or because at least one relative, living outside of the household, sends remittances from Hermosillo. If ejidatario households would be benefiting from jobs in Hermosillo, what we would expect is that households in the high and medium wealth levels would have a higher percentage with revenues from the city. However, the data do not support this suggestion. In all households in the high and medium wealth levels (with the exception of high wealth level in Molino de Camou) the percentage of households with income from Hermosillo is lower than those in which no household member has a job in Hermosillo. Based on this, we can conclude that there is not a substantial relationship between these two variables, that is, level of wealth is not related with income from employment in Hermosillo.

VII. Discussion

Just as population dynamics can significantly affect local environmental resources, changes in the quality and quantity of natural resources also can have important impacts on livelihoods of local people. This is the case of peri-urban ejidos, which are being reconfigured by urban expansion. In the case of Hermosillo, a tremendous pressure on the water resources of peri-urban ejidos due to urban demand has been demonstrated.

This pressure has affected the agricultural land of peri-urban ejidos by driving them to shift their crop patterns or simply to stop cultivating their land. In La Victoria, more than two-thirds of ejidatarios have stopped cultivating their agricultural land. In all the ejidos included in the study, about one-third of the ejidatarios have sold their agricultural land, grassland, or both. In all of these situations water problems are a major determinant. Seventy-one percent of survey respondents reported that their agricultural activity had been highly damaged by the encroachment or expansion of urban water infrastructure, and 16% reported it was somewhat damaged. In the same way, when the wealth level in each ejido was examined compared with its water impact level, we found that low wealth level corresponds to high water impact and high household wealth level corresponds to no- to low-water-impact level.

Shifting their crop pattern is the main strategy that most of the ejidatarios have implemented to deal with agricultural water scarcity. Ejidos that used to sow wheat in the fall-winter growing season and corn in the spring-summer season have now turned primarily to growing grass to feed their own livestock because, among other reasons, pasture is less dependent on water availability than wheat and corn. In most cases, this change in crop pattern has not resulted in an increase in the number of head of cattle as might be expected, but rather as a way to compensate the scarcity of grassland due to land fragmentation and drought.

Corn production was for self-consumption of the ejido families, whereas wheat crops are sold to Hermosillo mills. Pasture, on the other hand, is used to feed cattle and produce calves, which are sent to the U.S. beef market. This micro-decision produced by

multiple factors intensifies the so-called "end of food self- sufficiency" in Mexico, as noted by scholars years ago (Barkin, et al., 1991; Barkin & Suárez San Román, 1985). This crop pattern reduces rural and urban food security in Mexico because it directly feeds cattle rather than people. Moreover, these cattle are destined for exportation to a foreign country, whereas wheat and corn were consumed in local and regional markets.

The peri-urban literature suggests there are beneficial trade-offs for peri-urban areas due to the potential for employment in nearby cities. However, according to this study there is limited evidence to support that that hypothesis. Currently, the proportion of ejidatarios working in Hermosillo is smaller than 15 years ago and fewer ejidatarios are receiving income benefits from Hermosillo. Additionally, the number of ejido families with at least one member as a salaried worker in the city is only 20 percent, which is not enough to state that ejido households have a high degree of dependency on urban jobs. As displayed in Table 5, the principal changes in Hermosillo occupation between 1994 and 2008 was from bricklayers to industrial and business employees, but there is no data supporting that this may mean a more-educated workforce or better-paid jobs.

An alternative "strategy" to deal with a lack of jobs in Hermosillo and the agricultural production problems caused by water scarcity has been the sale of grassland parcels to be used as recreational ranchettes by urban residents seeking a bit of land to use as a weekend retreat and/or for a potential future second home or cabin. In the survey, of the 82 respondents, 33% had sold their grassland parcels, and around 20% of the 82 respondents sold their parcels to be used as recreational ranchettes. Of course, this is not a sustainable option because according to the interviews the money obtained by this transaction runs out very quickly. The only sustainable case was an ejidatario from Molino de Camou that sold his grassland lot for buying a parcel of agricultural land in the same ejido.

Since household wealth is a major topic in livelihood analysis, I compare this variable with a variable that represents Hermosillo benefits (income) and Hermosillo detrimental outcomes (water impact level). I found that in most of the high and medium

household wealth cases, the percentage of households with income from Hermosillo is lower than those without income from Hermosillo. On the other hand, as demonstrated there is a relationship when relative household wealth levels are compared with water impact level in agriculture. This exercise indicates that, at least in the current structure of the household, the negative impacts of new infrastructure to address Hermosillo's urban expansion are more severe for ejidos than the benefits available to peri-urban residents from living near Hermosillo. Thus, the net trade-off between these two processes is negative for the ejidos.

All of the ejidos suffered losses of access to their water resources due to the installation of deep urban wells, the construction of new dams or aqueducts to store and transport water, or simple cutting off of access to traditional sources. Downstream users, the Presa ALR irrigation district, were able to negotiate their water rights and now they use untreated wastewater. Thanks to this negotiation, according to the ejidatarios from La Yesca, they have improved their irrigation system because they have more stability in water quantity. For that reason, the majority of La Yesca (downstream) survey respondents report having no irrigation problems. This fact may explain why La Yesca ejidatarios are selling their land rights less often or less actively than other ejidos. In addition, it may explain why La Yesca is the only ejido where the number of head of cattle is consistently increasing, and why in La Yesca there are more households in the high and medium wealth level than in other ejidos. Wastewater, many times perceived as filthy and a hazard, in the case of peri-urban ejidos, is like possessing black liquid gold (Scott et al., 2004). However, there are health and epidemiological issues concerning the use of untreated wastewater, even limitations in crop diversification, which restrict the agricultural livestock activity of this ejido. Nonetheless, the evidence from La Yesca demonstrates that water quantity stability is linked with economic welfare, but drastic water problems, such as those exhibited by La Victoria, is associated with economic vulnerability.

VIII. Conclusions

Ejidos in Mexico have been challenged by neoliberal transformations to land tenure, agricultural supports, and trade arrangements. Over the last decade, small-scale farming communities located in arid and semi-arid lands, such as northern Mexico, have also dealt with a prolonged drought that caused huge economic losses in the ranching and agriculture sectors. Nonetheless, an additional challenge exists for ejidos located close to cities at the urban fringe or in peri-urban regions. Although ejidos in this region have traditionally had access to water since ejido communities were formed as part of Mexico's massive land reform program in the post-revolutionary period, in the last decade, these communities have had to compete with the city of Hermosillo's growing demand for water, which has proven a powerful and unbeatable rival. Consistent with findings regarding the increased vulnerability of ejidatarios who lost access to irrigation water elsewhere in Sonora (Wilder & Romero, 2006), the loss of access to water has significantly affected peri-urban ejidos causing ejidatarios to abandon or sell their land, and therefore lose their main livelihoods, or has forced ejidatarios to change crop patterns with serious disadvantages for regional food security and local and regional grain markets.

Some strategies have been developed by ejidatarios to deal with water scarcity. One of the most considerable is the change toward livestock. The move into cattle production has had both positive and adverse outcomes for different producers. Cow-calf operations have proven to be a reliable commodity with a price that has provided sufficient livelihood for many producers. On the other hand, the crop shift from grain to pasture may contribute to a reduction of rural and urban food security in Mexico, directing food crops to cattle rather than humans. Moreover, the cattle are destined for exportation to the U.S., whereas the previous crops—corn and wheat—were consumed in local and regional markets. An additional livelihood diversification strategy to deal with a lack of jobs in Hermosillo and the agricultural production problems caused by water

scarcity has been the sale of grassland parcels to be used as recreational ranchettes by urban residents; however, this is not a sustainable option.

Some scholars argue that peri-urban residents may have a more advantageous geographical position for selling their labor and agriculture products in cities and, by doing so, sustaining their livelihoods—and, indeed this may be true in particular contexts, since the way peri-urban regions function is highly specific to context, as discussed in the introduction. However, in the case of the peri-urban ejidos of Hermosillo, there is little evidence to sustain this hypothesis. On the contrary, livelihoods are being more negatively affected by Hermosillo's water policies relating to urban expansion.

Rural livelihoods of peri-urban ejidos show the underdeveloped outcomes of the urban development of Hermosillo. If Hermosillo continues the same trend of expansion, probably most of the peri-urban ejidos in future years will be neighbors inside the city boundaries. If the same policy of taking the means of production of ejidatarios continues, a new periphery of misery would appear.

IX. References

Allen, A. (2003). Environmental planning and management of the peri-urban interface: perspectives on an emerging field. *Environment and Urbanization,* 15(1), 135-147.

Allen, A., Dávila, J. D., & Hoffman, P. (2006). *Governance of Water and Sanitation Services for the Peri-urban Poor. A Framework for Understanding and Action in Metropolitan Regions.* Development Planning Unit, UCL, London. Retrieved April 14, 2009, from http://www.ucl.ac.uk/dpu/pui/publications/index.html

Angel, S., Sheppard, S. C., & Civco, D. L. (2005). *The Dynamics of Global Urban Expansion*. Transport and Urban Development Department of the World Bank. Retrieved May 11, 2009, from http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/0,,contentMDK:20970341~pagePK:148956~piPK:216618~theSitePK:337178,00.html

Barkin, D., Batt, R. L., & DeWalt, B. R. (1991). *Alimentos Vs. Forrajes: La Sustitución Entre Granos a Escala Mundial* (1º ed.). México, D.F: Xochimilco.

Barkin, D., & Suárez San Román, B. (1985). *El Fin De La Autosuficiencia Alimentaria* (1º ed.). México, D.F: Océano.

Bebbington, A. (2000). Reencountering Development: Livelihood Transitions and Place Transformations in the Andes. *Annals of the Association of American Geographers,* 90(3), 495-520.

Bebbington, A. (1999). Capitals and Capabilities: A Framework for Analyzing Peasant Viability, Rural Livelihoods and Poverty. *World Development,* 27(12), 2021-2044.

Brook, R., & Davila, J. (2000*). The Peri-Urban Interface: A Tale of Two Cities*. UK: Natural Resources Systems Programme.

Brook, R., Purushothaman, S., & Hunshal, C. (Eds.). (2003). *changing frontiers – The Peri Urban Interface Hubli-Dharwad, India.* Bangalore, India: Books for Change.

Buechler, S. J., & Scott, C. A. (2000). "Para Nosotros, Esta Agua es Vida." El Riego en Condiciones Adversas: Los Usuarios de Aguas Residuales en Irapuato México. In C. A. Scott, P. Wester, & B. Marañon-Pimentel (Eds.), *Asignación, productividad y manejo de recursos hídricos en cuencas. (Allocation, productivity and management of basin water resources),* Serie Latinoamericana (pp. 135-171). México D.F., México: International Water Management Institute.

Camou, E. (1998). *De rancheros, poquiteros, orejanos y criollos: Los productores ganaderos de Sonora y el mercado internacional*. México: El Colegio de Michoacán y CIAD A.C.

Chowdhury, R. R., & Turner II, B. (2006). Reconciling Agency and Structure in Empirical Analysis: Smallholder Land Use in the Southern Yucatán, Mexico. *Annals of the Association of American Geographers*, 96(2), 302-322.

CONAGUA. (2009). *Escurrimientos El Cajón y El Orégano 08*. Unpublished data.

CONAPO. (2009). *De la población de México 2005-2050*. Retrieved October 9, 2009, from http://www.conapo.gob.mx/index.php?option=com_content&view=article&id=36&Itemid=234

CONAPO. (2001). *Índices de Marginación, 2000*. Retrieved October 30, 2008, from www.conapo.gob.mx

De Janvry, A., Gordillo, G., & Sadoulet, E. (1997). *Mexico's Second Agrarian Reform: Household and Community Responses, 1990-1994*. La Jolla, CA: Center for U.S.-Mexican Studies University of California.

Díaz-Caravantes, R. E. (2001). *Cambios socioeconómicos en el ejido Molino de Camou a partir de la construcción de la presa El Molinito.* Tesis de Maestria. El Colegio de Sonora. Unpublished manuscript.

Díaz-Caravantes, R. E., & Camou, E. (2005). El agua en Sonora: tan cerca y tan Lejos. Estudio de caso del ejido Molino de Camou. *Región y Sociedad*, XVII(034), pp. 127-165.

Díaz-Caravantes, R. E., & Sánchez-Flores, E. (n.d.). *Peri-urban Land Use/Cover Change and Water Transfers: New Geographies of Land Studies.* Unpublished manuscript.

Díaz-Caravantes, R. E., & Wilder, M. (n.d.). *Water, Cities and Peri-Urban Vulnerabilities in Northwest Mexico.* Unpublished manuscript.

Díaz-Chávez, R. A. (2006). Measuring Sustainability in Peri-Urban Areas: Case Study of Mexico City. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 246-265). UK: Earthscan Publications Ltd.

Douglas, I. (2006). Peri-Urban Ecosystems and Societies: Transitional Zones and Constrasting Values. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 18-29). UK: Earthscan Publications Ltd.

Eakin, H. (2006). *Weathering Risk in Rural Mexico: Climatic, Institutional, and Economic Change.* University of Arizona Press.

Ellis, F. (2000). *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press, USA.

FAO (Food and Agriculture Organization of the United Nations). (2001) *Crops and Drops: Making the Best Use of Water for Agriculture*. FAO, Rome, Italy, pp. 1–22.

Fox, J., Rindfuss, R. R., Walsh, S. J., & Mishra, V. (Eds.). (2003). *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS* (1º ed.). Kluwer Academic Publishers.

Garduño, H. (2005). "Lessons from implementing water rights in Mexico," in Bryan Bruns et al, *Water Rights Reform*, pp.85-112.

Gleick, P. H. (2000). *The World's Water 2000-2001: The Biennial Report on Freshwater Resources*. Island Press.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, 162(3859), 1243-1248.

Hirsch, P. (2009). Revisiting frontiers as transitional spaces in Thailand. *The Geographical Journal*, 175(2), 124-132.

IDRC. (2009). *Homepage*. Retrieved October 8, 2009, from http://www.idrc.ca/index_en.html

INEGI. (2000). *Censo general de población y vivienda 2000.* Retrieved October 9, 2009, from http://www.inegi.org.mx/inegi/default.aspx?s=est&c=10239&e=&i=

INEGI. (2005). *Conteo de población y vivienda 2005*. Retrieved October 9, 2009, from http://www.inegi.org.mx/inegi/default.aspx?s=est&c=10382&e=&i=

INEGI. (1990). *Censo general de población y vivienda 1990*. Retrieved October 9, 2009, from http://www.inegi.org.mx/inegi/default.aspx?s=est&c=10202

Jaiyebo, O. (2003). Women and household sustenance: changing livelihoods and survival strategies in the peri-urban of Ibadan. *Environment and Urbanization*, 15(1), 111-120.

Lavadenz, I., & Deininger, K. (2001). *Mexico Land Policy - A decade after the Ejido Reform.* Washington, DC: World Bank.

Leichenko, R., & O'Brien, K. (2008). *Environmental Change and Globalization: Double Exposures.* Oxford University Press, USA.

Liverman, D., Moran, E. F., Rindfuss, R. R., & Stern, P. C. (Eds.). (1998). *People and Pixels: Linking Remote Sensing and Social Science.* Washington, D.C: National Academy Press.

Liverman, D., & Merideth, R. (2002). Climate and society in the US Southwest: the context for a regional assessment. *Climate Research,* 21(3), 199-218.

Lynch, K., & Poole, N. (2006). Horticulture and Market Information at the Peri-Urban Interface: Agricultural Marketing in Tanzania. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 74-93). UK: Earthscan Publications Ltd.

Mattingly, M. (2009). Making land work for the losers: Policy responses to the urbanization of rural livelihoods. *International Development Planning Review*, 31(1), 37-53.

McGregor, D., Simon, D., & Thompson, D. (2006). The Peri-Urban Interface in Developing Areas: The Research Agenda. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 313-325). UK: Earthscan Publications Ltd.

McShane, T. O., & Wells, M. P. (Eds.). (2004). *Getting Biodiversity Projects to Work: Towards More Effective Conservation and Development*. Columbia University Press.

McSweeney, K. (2004). The Dugout Canoe Trade in Central America's Mosquitia: Approaching Rural Livelihoods Through Systems of Exchange. *Annals of the Association of American Geographers*, 94(3), 638-661.

Mella, J. M., & Mercado, A. (2006). La economía agropecuaria mexicana y el TLCAN. *Comercio Exterior*, 56(3), 181-193.

Narain, V., & Nischal, S. (2007). The peri-urban interface in Shahpur Khurd and Karnera, India. *Environment and Urbanization*, 19(1), 261-273.

NWL (National Water Law). (1992). Mexican Congress

Oberhauser, A. M., & Hanson, K. T. (2007). Negotiating Livelihoods and Scale in the Context of Neoliberal Globalization: Perspectives from Accra, Ghana. *African Geographical Review*, 26, 11-36.

Perreault, T. (2005). State restructuring and the scale politics of rural water governance in Bolivia. *Environment and Planning A*, 37, 263-284.

Perz, S. G., & Walker, R. T. (2002). Household life cycles and secondary forest cover among small farm colonists in the Amazon. *World Development*, 30(6), 1009-1027.

RUAF Foundation. (2009*). Homepage*. Retrieved October 8, 2009, from http://www.ruaf.org/

SAGARHPA. (2009). *Annual Livestock Census*. Unpublished data.

Sayer, J., & Campbell, B. (Eds.). (2003). *The Science of Sustainable Development: Local Livelihoods and the Global Environment.* Cambridge University Press.

Schwentesius, R., & Gómez, M. Á. (2001). El TLCAN y el sector agroalimentario de México. *Comercio Exterior*, 51(6), 545-554.

Scoones, I. (1998). Sustainable Rural Livelihoods: A Framework for Analysis. *IDS Working Paper*, 72.

Scott, C., Faruqui, N., & Raschid-Sally, L. (Eds.). (2004). *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities*. Wallingford, U.K.: CABI Publishing. Retrieved October 5, 2009, from http://www.idrc.ca/openebooks/112-4/

de Sherbinin, A., VanWey, L. K., McSweeney, K., Aggarwal, R., Barbieri, A., Hunter, L. M., et al. (2008). Rural household demographics, livelihoods and the environment. *Global Environmental Change*, 18(1), 38-53.

Simon, D., McGregor, D., & Nsiah-Gyabaah, K. (2004). The changing urban-rural interface of African cities: definitional issues and an application to Kumasi, Ghana. *Environment and Urbanization*, 16(2), 235-248.

Stoian, D. (2005). Making the best of two worlds: Rural and peri-urban livelihood options sustained by nontimber forest products from the Bolivian Amazon. *World Development*, 33(9), 1473-1490.

Tacoli, C. (2006). *The Earthscan Reader in Rural-Urban Linkages*. UK: Earthscan Publications Ltd.

Thornton, A. (2008). Beyond the Metropolis: Small Town Case Studies of Urban and Peri-urban Agriculture in South Africa. *Urban Forum*, 19, 243-262.

Treminio, R. (2004). *Experiencias en Agricultura Urbana y Peri-Urbana en America Latina y el Caribe, Necesidades de Políticas e Involucramiento Institucional*. Food and Agriculture Organization of the United Nations. Retrieved April 14, 2009, from http://www.rlc.fao.org/es/agricultura/aup/pdf/expe.pdf

United Nations. (2009). *World Urbanization Prospects: The 2007 Revision Population Database.* Retrieved October 9, 2009, from http://esa.un.org/unup/

Whiteford, S., & Melville, R. (2002). *Protecting a Sacred Gift: Water and Social Change in Mexico* (illustrated edition.). La Jolla, CA: Center for U.S.-Mexican Studies University of California.

WHO (World Health Organization)/UNICEF (United Nations International Children's Education Fund). (2000) *Global Water Supply and Sanitation Assessment 2000 Report*. WHO/UNICEF, Geneva, Switzerland, 80 pp.

Wilder, M. & Romero, P. (2006). Paradoxes of Decentralization: Water Reform and Social Implications in Mexico. *World Development*, 34(11), 1977-1995.

Wilder, M. & Whiteford, S. (2006). Flowing Uphill Toward Money: Groundwater Management and Ejidal Producers in Mexico's Free Trade Environment. In L. Randall (Ed.), *Changing structure of Mexico: political, social, and economic prospects* (pp. 341-358). Armonk, N.Y.: M.E. Sharpe.

Zimmerer, K. S. (2004). Cultural ecology: placing households in human-environment studies – the cases of tropical forest transitions and agrobiodiversity change. *Progress in Human Geography*, 28(6), 795-806.

X. Tables and Figures

Table 1. Type of Impacts in Peri-Urban Ejidos

Group	Ejido	Type of irrigation	Urban Water Supply Facilities Impact on Ejidos					Degree of Impact on Agricultural Water Use	
			Surface Water		Groundwater				
			Residual water	Dam System	Wells in Mesa del Seri-La Victoria	Wells in San Miguel or Zanjón	Aqueduct El Molinito	Quantity	Quality
1	La Victoria	Groundwater		✓	✓			High	Medium
	Mesa del Seri	Groundwater		✓	✓			High	None
	San Pedro	Groundwater		✓	✓			High	None
	El Alamito	Groundwater		✓	✓			High	None
2	San Juan	Groundwater		✓			✓	High	None
3	Codorachi	Both				✓		High	None
	Torreon	Both				✓		High	None
	La Labor	Groundwater				✓		Medium	None
	Zacaton	Groundwater				✓		Low	None
	El Carmen	Groundwater				✓		Medium	None
	Zamora	Groundwater				✓		Low	None
4	Molino de Camou	Surface		✓				Low	None
5	Villa de Seris	Surface	✓	✓				None	High
	La Manga	Surface	✓	✓				None	High
	La Yesca	Surface	✓	✓				None	High
	San Miguel	Surface	✓	✓				None	High

Source: Own research

Table 2. Respondents' selection

Ejido	Target population			Not target population				*Total*
	Respondents	Not founded	Not want/able response	Dead	Hermosillo	U.S.	Migration	
Molino de Camou	19	13	5	13	9	1	1	*61*
Codorachi	13	3	2	7	7	0	0	*32*
San Juan	17	2	1	14	5	0	1	*40*
La Yesca	18	0	0	13	18	0	0	*49*
La Victoria	15	10	0	9	22	0	0	*56*
Total	***82***	***28***	***8***	***56***	***61***	***1***	***2***	***238***

Table 3. Wealth ranking and Water Impact Level

Ejido	Wealth Level	Water Impact Level						Total
		None	Very Low	Low	Medium	High	Very High	
Molino de Camou	Low	16%	5%	5%	16%	16%	0%	*58%*
	Medium	11%	5%	5%	16%	0%	0%	*37%*
	High	0%	0%	5%	0%	0%	0%	*5%*
Codorachi	Low	8%	23%	0%	23%	0%	0%	*54%*
	Medium	8%	0%	8%	0%	0%	0%	*15%*
	High	8%	15%	8%	0%	0%	0%	*31%*
San Juan	Low	6%	12%	0%	12%	0%	0%	*29%*
	Medium	0%	47%	12%	0%	6%	0%	*65%*
	High	0%	0%	6%	0%	0%	0%	*6%*
La Yesca	Low	11%	0%	0%	0%	0%	0%	*11%*
	Medium	22%	0%	0%	0%	0%	0%	*22%*
	High	61%	6%	0%	0%	0%	0%	*67%*
La Victoria	Low	0%	0%	0%	0%	0%	40%	*40%*
	Medium	0%	0%	0%	13%	20%	20%	*53%*
	High	0%	0%	0%	0%	7%	0%	*7%*

Table 4. Household dependency on Employment in Hermosillo

Ejido	Total	2008			1994			%2008-%1994
		Workers	HMO workers	%HMO workers	Workers	HMO workers	%HMO workers	
Molino de Camou	19	10	3	16	12	6	32	-16
Codorachi	13	5	3	23	4	1	8	15
San Juan	17	6	4	24	3	3	18	6
La Yesca	18	2	2	11	1	1	6	6
La Victoria	15	10	4	27	10	3	20	7
Total	***82***	***33***	***16***	***20***	***30***	***14***	***18***	***2***

Table 5. Occupations of household's members in Hermosillo

Ejido	Comparative jobs						Non-comparative jobs				
	Bricklayer		Industrial Worker		Housecleaner		AGUAHH	Business's Employee	Peddler	Education	Government
	2008	1994	2008	1994	2008	1994	2008				1994
Molino de Camou	3	10	0	1	1	0	0	0	0	0	0
Codorachi	0	0	0	0	1	1	0	2	1	0	0
San Juan	3	2	1	0	1	1	0	1	0	0	1
La Yesca	0	0	2	0	1	1	0	0	0	1	0
La Victoria	0	0	6	1	0	0	1	1	0	0	1
Total	***6***	***12***	***9***	***2***	***4***	***3***	***1***	***4***	***1***	***1***	***2***

Table 6 Wealth Ranking and Hermosillo Income

Ejido	Wealth Level	HMO_Income		Total
		None	Yes	
Molino de Camou	**Low**	53%	5%	*58%*
	Medium	26%	11%	*37%*
	High	0%	5%	*5%*
Codorachi	**Low**	31%	23%	*54%*
	Medium	15%	0%	*15%*
	High	23%	8%	*31%*
San Juan	**Low**	24%	6%	*29%*
	Medium	41%	24%	*65%*
	High	6%	0%	*6%*
La Yesca	**Low**	11%	0%	*11%*
	Medium	22%	0%	*22%*
	High	50%	17%	*67%*
La Victoria	**Low**	27%	13%	*40%*
	Medium	40%	13%	*53%*
	High	7%	0%	*7%*

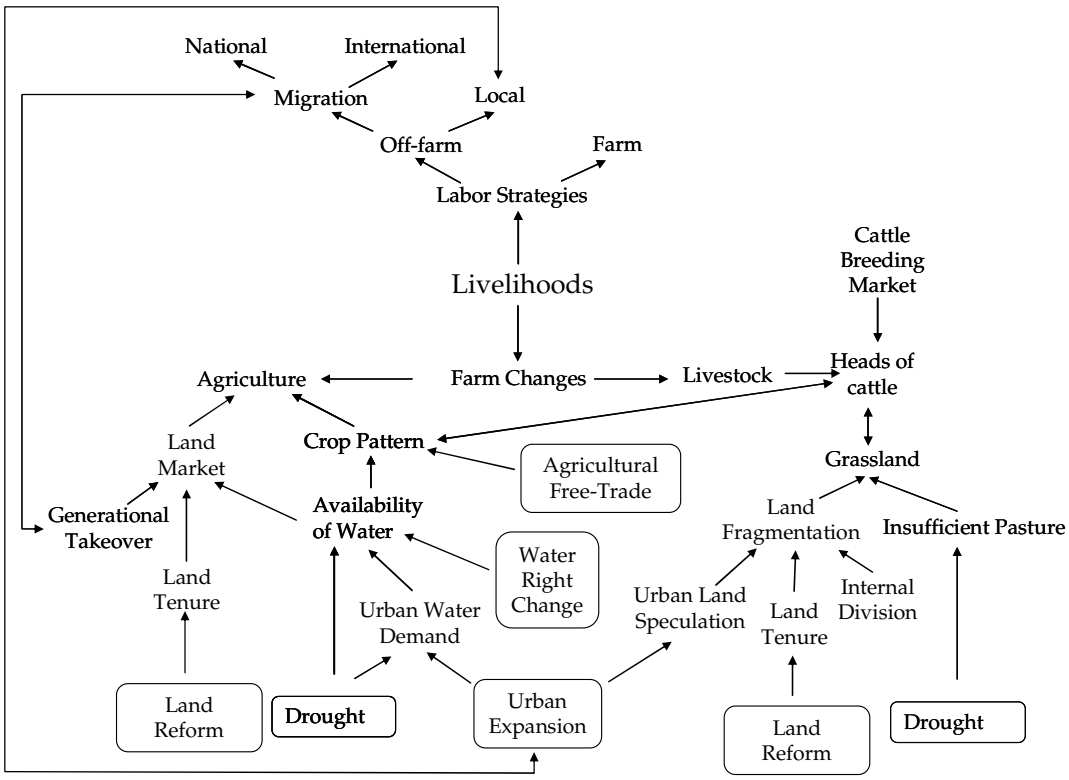


Figure 1. Factors affecting livelihoods

Source: Based on own research.

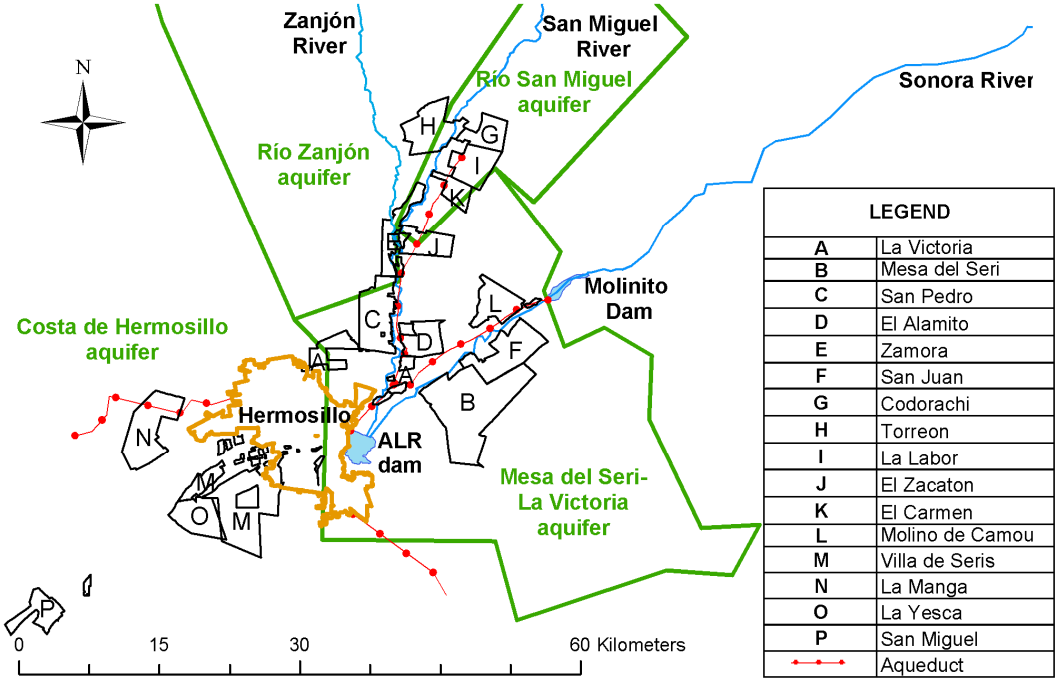


Figure 2. Study area

Source: Based on Registro Agrario Nacional and CONAGUA

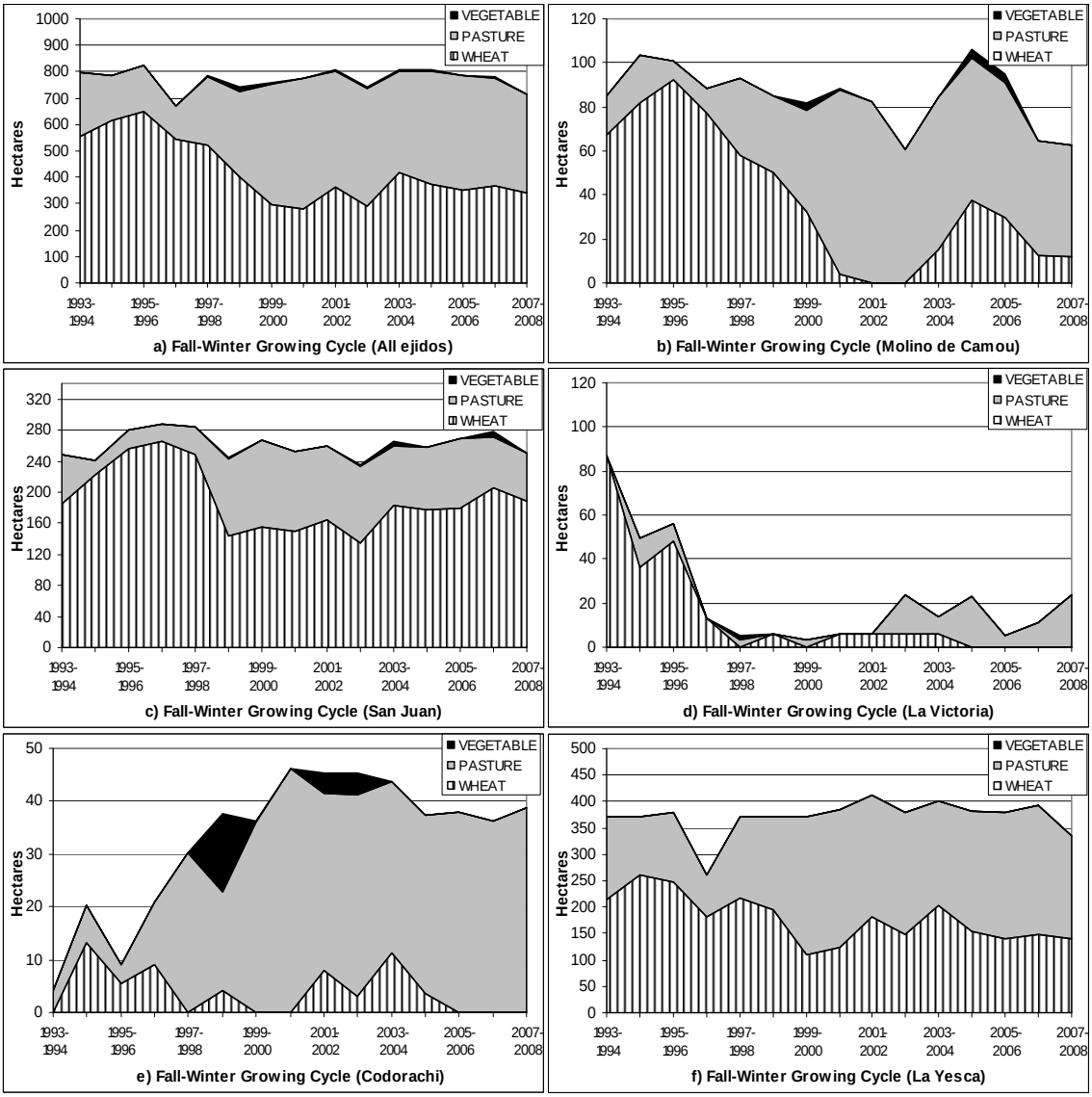


Figure 3. Fall-Winter Growing Cycle

Source: Own research based on PROCAMPO and irrigation district Presa ALR data

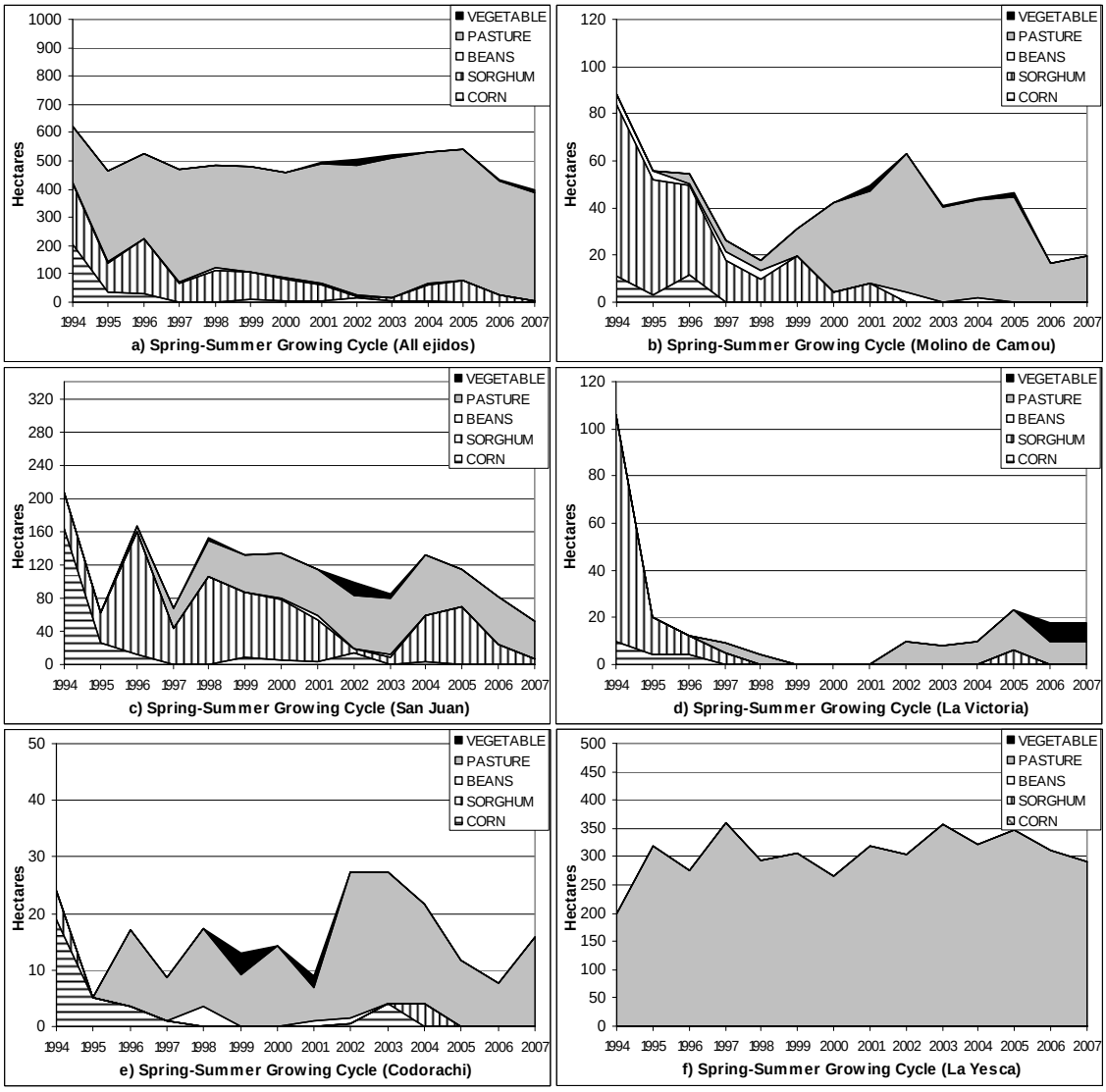


Figure 4. Spring-summer Growing Cycle

Source: Own research based on PROCAMPO and Irrigation district Presa ALR data

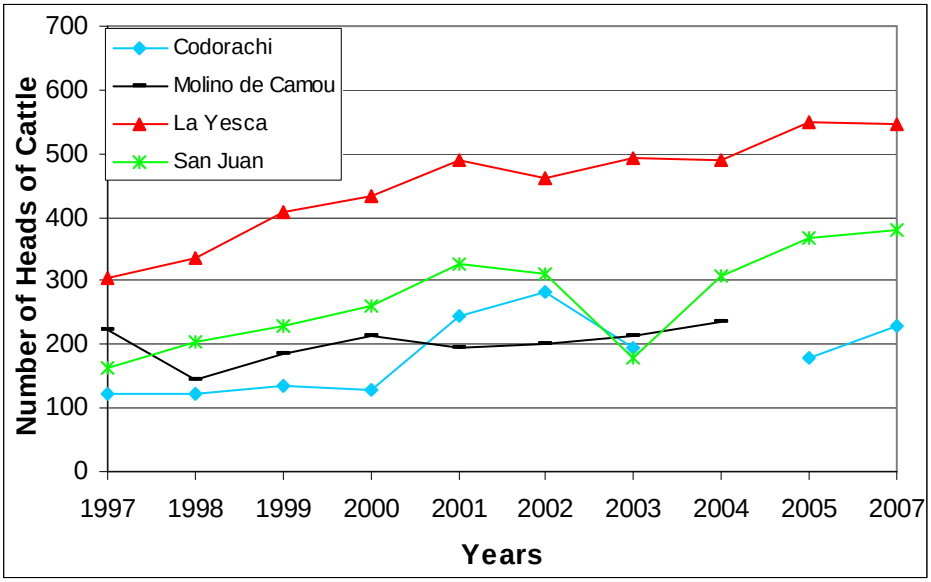


Figure 5. Number of Heads of Cattle by Ejido

Source: Based on annual livestock census of Secretaría de Agricultura, Ganadería, Recursos Hidráulicos, Pesca y Acuacultura (SAGARHPA).

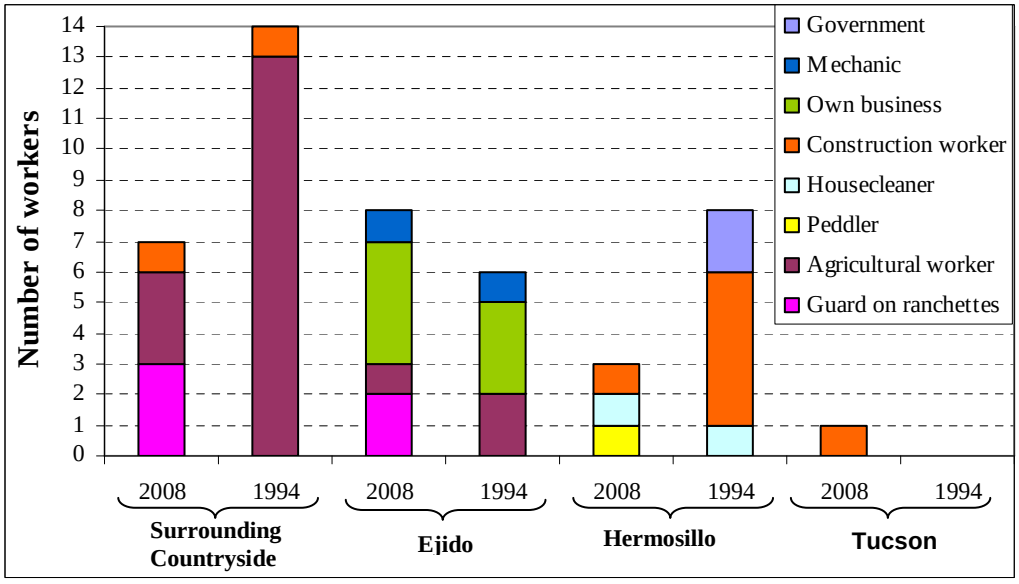


Figure 6. Ejidatarios with salaried income

Source: Own survey

APPENDIX C

PERI-URBAN LAND USE/COVER CHANGES AND WATER TRANSFERS: NEW GEOGRAPHIES OF LAND STUDIES

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(For submission to Journal of Latin American Geography)

Abstract

There is an extensive literature that links land use/cover changes with population dynamics. Traditionally, these studies examine how land use/cover change as an effect of demographic transformations. In this study, a new variable, water transfer, is included to this land-livelihood relationship. By including this variable we expand the scope of land studies exploring a broader and more complex explanation of land use/cover changes. Water transfers from the peri-urban to urban areas dramatically affect livelihoods of peri-urban residents and, as a consequence, land use/cover in the peri-urban area is transformed. This research evaluates the land use/cover change dynamics and their effects in the peri-urban area of the city of Hermosillo, Sonora (Mexico) by linking household surveys, semi-structured interviews and remote sensing analysis based on Landsat imagery. This study demonstrates that urban expansion causes at least two other types of land use/cover changes beyond the urban fringe that are not usually detected and explained in common land use/cover change studies. The first one is the loss of agricultural land due to water transfers from peri-urban communities to the city. The second one is the transformation of grazing lands to recreational ranchettes (known as *lotes campestres*) acquired by urban families, where a decrease of vegetation cover takes place. By doing this, we demonstrate that in the peri-urban area, water is a critical factor

that produces land use/cover changes and we identified a new land use type, recreational ranchettes.

I. Introduction

Academic efforts to link household surveys with the examination of land use/cover changes is by no means new (Turner et al., 2007; Fox et al., 2003; Liverman et al., 1998). However, there is limited research about the triple effect of the water-livelihoods-land interrelationship on peri-urban areas. This evaluation is critical because, as shown by Díaz-Caravantes and Wilder (n.d.) in the case of Hermosillo, the peri-urban area is the most negatively affected region due to the strategies that the city has pursued to supply water. These water transfer strategies resulted in a water transfer from peri-urban agricultural uses to urban domestic uses. This transfer has affected considerably the livelihoods of peri-urban livelihoods, but also has affected in the land use/cover of these small farm communities. For this paper, the peri-urban regions can be understood as an area of transition along an 'urban-rural gradient' (McGregor et al., 2006, p. 10).

Based on a methodology that includes a post-classification approach to compare the main land use/cover types extracted from a multispectral Landsat imagery dataset, 52 household surveys, and about 30 semi-structured interviews in small farm communities, we examine how urban expansion has affected, in the context of drought, water and land resources of small farming communities (ejidos) in peri-urban areas. More specifically, this paper seeks to answer the following questions: What is the link between water transfers and land use/cover changes in peri-urban areas? How can transformations in livelihoods due to water transfer affect peri-urban land? How is the peri-urban landscape modified by urban water policy?

We have found that urban water infrastructure has produced significant land use/cover change in the peri-urban area. One is the transformation of ejido grazing lands to recreational ranchettes (known as *lotes campestres*) by urban families. Another is the

loss or abandonment of agricultural land due to the water transfers from peri-urban communities to the city.

II. Literature review

Among the scientific community and the society in general there has been a growing concern about the complex environmental problems caused by human alteration of ecosystems. Land cover changes, in particular, have major effects on the environmental and socio-economic sustainability of communities (Watson et al., 2000). Land cover change itself represents one of the most substantial ways of ecosystem alteration and is linked commonly to other forms of environmental degradation such as erosion, habitat and biodiversity loss, and groundwater depletion (Lambin & Strahler, 1994).

Human-driven changes in the terrestrial surface are fundamental factors that cause global environmental change with significant impacts on the structure and function of ecosystems and on human well-being (Turner et al., 2007). Frequently, the scholars that examine human-land interactions investigate the relationships between demographic variables (household size, age and sex composition, fertility, migration, and mortality) and natural resources, such as forest cover, timber, and soil quality in areas such the Amazon region, Central America, Asia, and Africa (Chowdhury & Turner II, 2006; Fox et al., 2003; Lambin, 2003; Perz & Walker, 2002; Liverman et al., 1998; Sever, 1998). Sever (1998), for example, examines land use/cover change in Guatemala where deforestation is increasing due to social driving forces such as human, migration, road construction and land development. Focused on the Amazonia and based on a quantitative household survey analysis, Perz and Walker (2002) studied how household life cycles affect land use change in the region. These authors conclude that land and capital availability as well as child dependency, labor availability and generational transitions influence the likelihood of adopting productive conservation programs, in this case, agroforestry systems.

As well as forests depletion, land cover change linked to urbanization processes is one of the most insidious manifestations of ecosystem's deterioration (Dewan & Yamaguchi, 2009; Batisani & Yarnal, 2009; Yuan, 2008; Hasse & Lathrop, 2003). In fact, urbanized landscapes are the most critical expression of land cover alteration (Forman, 1995).

If we consider the global trends, we can see the magnitude of this problem. According to a report published by the Transport and Urban Development Department of the World Bank, urban built-up areas in the world consumed some 400,000 square kilometers in 2000 and cities are now expected to grow 2.5 times in area by 2030, consuming some 1 million square kilometers (Angel et al., 2005). Although, according to Angel et al. (2005) this area is just 1.1% of the total land areas of countries, urban areas have marked effects on environmental conditions at both local and global scales (Herold et al., 2003).

Urbanization is currently proceeding more quickly in developing countries than in the developed world. By 2030 developing cities with populations exceeding 100,000 inhabitants are expected to triple their land area, while developed cities are expected to increase their land area by 2.5 times (Angel et al., 2005). Increasing population in developing cities has caused rapid changes in urban areas, such as an increment in transportation services and housing services demand (Angel et al., 2005). The effect of population is very critical given that according to the United Nations (2009), world urban population was 2,853,909,000 inhabitants by 2000 and it is estimated to increase around 74% by 2030.

Land use/cover changes on urban areas have been extensively studied by remote sensing tools through key indicators such as impervious surface and built-up area. Specifically, the amount of urban impervious surface has become a key indicator of urban expansion in remote sensing studies because it produces evident environmental impacts (Weng, 2007; Carlson & Arthur, 2000; Arnold & Gibbons, 1996). As an example, impervious surface directly impact the amount of runoff to water bodies (Ridd, 1995). As

is well-known, the augmentation of runoff causes significant problems of flooding and pollution (Conway, 2007; Booth et al., 2002).

Despite the importance of these studies, they have do not too much to say about the human-environment interaction that produces land use/cover changes on the urban areas. This topic needs to be studied in Mexico because according to a World Bank study on the implications of urbanization for peri-urban areas, urban expansion of Mexico's 110 major cities represents a considerable challenge for rural livelihoods because two-thirds of the land required for this expansion will come from the ejido sector—specifically, from peri-urban ejidos located at the edges of cities (Lavadenz & Deininger, 2001, pp. 18-19). Undoubtedly, land use change from agricultural to urban use is one of the most important effects of urban sprawl on rural livelihoods.

The word "peri-urban" can be used to denote a place or process. As a place, it can be defined as the area surrounding to a city's existing boundaries. As a process, the peri-urban can be understood as an interface of goods and services between the rural and urban areas (Narain & Nischal, 2007; Allen, 2003; Brook et al., 2003). Accordingly, for this paper peri-urban regions can be understood as an area of transition along an 'urban-rural gradient' (McGregor et al., 2006, p. 10). Allen (2003) emphasizes that one of the processes of environmental change occurring in the peri-urban region is the change in land use, such as from agricultural to residential or industrial uses in which the problem is the loss of agricultural land and, therefore, the loss of livelihoods for poor farmers and shortages in food production.

A considerable number of studies have examined the land-livelihoods relationship on the peri-urban area (Jaiyebo, 2003; Narain, 2009; Smith, 2007; Brook et al., 2006; Kelly, 2006; van den Berg et al., 2003). Brook et al. (2006), for example, based in the case of the city of Hubli-Dharwad, study how the size of the landholding is related to the dairy markets from the peri-urban area to the city. In this study, they showed that the dairy production is bigger in villages near to the city where access to markets is better regardless of the size of landholding. However, small landowners and the landless need to buy more pasture for the livestock, reducing its economic benefits from the market.

Focused on the process of land conversion from agricultural to urban uses, van den Berg et al. (2003) examine the agricultural transformation of the peri-urban area of Hanoi, Vietnam. In this study, they show that farmers who lose their land due to urban development get a fixed compensation without a real-estate market. Nonetheless, some farmers have the strategy of using this compensation to develop farms farther from the city.

As argued by scholars, the consequences of urban expansion on life quality and sustainability have been usually considered as an essential input of urban policy making and planning; however, the effects of urban expansion from the perspective of peri-urban areas have been largely neglected (Banzhaf et al., 2009; McGregor et al., 2006). This situation is more evident in the case of water transfers from the peri-urban to the urban area. This disregard has been particularly evident in our case study, where small-scale farming communities or ejidos located in the peri-urban area have undergone considerable land use/cover changes caused mainly by urban water augmentation policy. As shown by Díaz-Caravantes and Wilder (n.d.), in the case of Hermosillo, the peri-urban area is the most negatively affected region by the strategies of the city of Hermosillo to supply water to the city in a context of growing water scarcity due to drought and use patterns. Dams, wells and water policy and management have been the means of transference from peri-urban agricultural uses to urban domestic uses.

In Mexico, a limited number of studies have examined the relation of water resources with peri-urban livelihoods (Allen et al. 2006; Díaz-Caravantes & Camou, 2005; Buechler and Scott, 2000). Allen et al. (2006) analyze the link between peri-urban livelihoods and water supply and sanitation services in the peri-urban areas around Mexico City. In addition, they argue that water use for economic livelihoods in peri-urban areas is quite important because many income activities depend on the availability of water. Buechler and Scott (2000) analyze the dispute between a peri-urban ejido and

private landowners by urban wastewater[32] in a Mexican case. In this paper, they conclude that water, even residual water is a critical resource for sustaining livelihoods of farmers.

If we found a few number of studies focused on water-livelihoods interface in the peri-urban areas, there is a more limited research regarding the water-livelihoods-land interrelationship. Urban water supply strategies have negatively impacted livelihoods of ejidatarios[33] by harming, and many times even causing to disappearance of their traditional means of subsistence based on agriculture and livestock (Díaz-Caravantes, n.d.). Nonetheless, urban water infrastructure has also produced significant land use/cover change in the peri-urban area. One is the transformation of ejido grazing lands to recreational ranchettes (known as *lotes campestres*) by urban families. Another is the loss or abandonment of agricultural land due to the water transfers from peri-urban communities to the city.

This water-livelihoods-land interrelationship is schematized in the following figure.

Figure 1

In the context of this analysis, we suggest that the notion of the peri-urban 'waterscape' is a distinct concept from the peri-urban landscape that embraces the water-land-livelihoods interrelation. From the landscape ecology perspective, landscapes are viewed as spatially complex, heterogeneous assemblages of patch types. Landscape disturbances affect critical ecological services including surface water supply and regulation, erosion control and sediment retention, waste assimilation, soil formation processes, genetic resources banking, and provision of recreation and leisure opportunities (Costanza et al., 1997). Urbanized landscapes are the most critical expression of land cover alteration (Forman, 1995).

[32] In fact, the use of wastewater in irrigated agriculture is and will be a world-wide practice (Scott et al., 2004; FAO 2001; WHO/UNICEF (2000); Gleick, 2000). This practice is part of the peri-urban water uses.
[33] Individual with formal membership in the ejido

The peri-urban landscape is commonly conceptualized as the land surrounding the city which is a fixed and bounded area of territory on the outskirts of a city (Crossman et al., 2007; Stehlik et al., 2007; Ode & Fry, 2006; Henne, 2005). However, as stated by Bakker (2003) water is a flow resource not easily bounded. As demonstrated by Díaz-Caravantes and Wilder (n.d.), although some ejidos are located nearly 30 kilometers from Hermosillo, its water can be accessed by the city, therefore incorporating this rural farming area as if it were part of the peri-urban region. A peri-urban waterscape can encompass a much broader geographical area because of the specific properties of water that allow flows to be transported from distant peri-urban regions to a major city. The ability to capture water flows to cities from long distances creates an ample and more flexible 'peri-urban' phenomenon that is not as finitely bounded as in the case of land. For that reason, we argue that when both the hydrological and geographic boundaries of a city are examined, it should be treated as a peri-urban water landscape or, in other words, peri-urban "waterscape" (Díaz-Caravantes & Wilder, n.d.; Swyngedouw, 1999). In addition to this change in geographical scope, when we conceptualize the peri-urban waterscape, we also start to consider not only the phenomena such as land annexation, but also land use/cover changes due to urban water demand, as schematized in Figure 1.

III. Data and Methods

Study area

This paper focused on peri-urban ejidos of the city of Hermosillo, where urban water demand has particularly targeted the water resources of peri-urban farming communities (Díaz-Caravantes & Wilder, n.d.). There are 16 ejidos that in some degree were negatively affected by city’s water supply strategies. These ejidos comprise around 32,000 hectares with about 1,000 total ejido members. The principal productive activities in these ejidos are small-scale irrigated agriculture and small-scale cattle ranching.

Water shortage in Hermosillo started in the mid 1990s. According to records of *Comisión Nacional del Agua* (CONAGUA, 2009), in the last seven decades, the Sonora River registered average annual streamflows of 36 million cubic meters (Mm3). From 1996 to 2005, this basin registered below the average, which was 20.9 Mm3. In 2006 and 2007 were recorded streamflows above the average. However, in 2008 only 17 Mm3 were recorded. Drought conditions combined with drastic urban population growth of around 130% from 1970 to 1990 has motivated Hermosillo's authorities to implement multiple water infrastructure in the peri-urban fringe (Díaz-Caravantes & Wilder, n.d).

Figure 2

Linking methodologies

Scholars argue that linking social science methodologies such as household surveys and image analysis methodologies like remote sensing could strengthen the capabilities of detection in land use/cover studies (Fox et al., 2003). Specifically in this study, household surveys and semi-structured interviews are used to illustrate the link between water transfers, peri-urban livelihoods and transformations in farm activities, while remote sensing methods are used to demonstrate how land cover has changed in the peri-urban ejidos.

Household surveys and interviews

First, we conducted around 60 open-ended and semi-structured interviews with ejidatarios to determine how urban water infrastructure has affected their livelihoods. The 16 selected ejidos for this purpose can be divided by the location and type of urban water supply impact as follows[34].

[34] For an extensive description of how these ejidos were affected see Díaz-Caravantes & Wilder (n.d.)

Table 1

La Victoria, Mesa del Seri, San Pedro and El Alamito are all located in the aquifer Mesa del Seri-La Victoria and were adversely affected due to the drilling of recent urban wells serving Hermosillo that limited their access to irrigation water. Of the surviving ejidatarios that remain able to irrigate, only La Victoria reported water quality problems. In a second categorization by itself, San Juan is the most damaged ejido due to El Molinito aqueduct negatively affected its wells. In the third group are the ejidos affected by the Las Malvinas project, which consists of urban wells established on aquifers that had provided historically irrigation water to the ejidos. Of these Codorachi and El Torreón were the most negatively affected ejidos, following by La Labor and El Carmen, and finally, to a lesser extent, El Zacatón and Zamora. The Ejido Molino de Camou was negatively affected when its growing seasons were limited to one instead of two after 1998 due to a water policy in favor of the city as explained in the following sections. However, in 2007, Molino de Camou was able to negotiate with the municipal water agency *Agua de Hermosillo*[35] (AGUAHH) and CONAGUA to improve its irrigation system and increase the volume of extraction. Finally, in the fifth group are the downstream users, who despite experienced improvements in water quantity, in were highly negatively affected in terms of water quality because, since 1996, they received only urban untreated wastewater which limited their cultivation options.

Based on this system of categorization, we determined the ejidos to be included in a socioeconomic survey to analyze how land use/cover and livelihoods were affected by urban expansion. In order to have a sample of each of the 5 groups, one ejido of each group was selected. The selected ejidos were La Victoria, San Juan, Codorachi, Molino de Camou and La Yesca[36]. A total of 82 surveys were conducted, distributed as follows: 19 in Molino de Camou, 13 in Codorachi, 17 in San Juan, 18 in La Yesca and 15 in La Victoria.

[35] The agency responsible for urban water management at municipal level
[36] For a broader description of the methodology following on the survey see Díaz-Caravantes (n.d.)

Land use/cover categorization and analysis

Based on the interviews and survey information we identified four land use/cover changes in the peri-urban ejidos, which we categorize as follows.

Table 2

This categorization was made in order to establish which ejidos requires a more detailed analysis of land use/cover changes. Group 1 brings together the cases where remote sensing indicators, such as impervious surface and built-up area, are more evident because the city boundary is adjacent or contiguous to ejido land. Of the two ejidos in this group, Villa de Seris has faced very visible land use/cover changes; for that reason, we selected this ejido to be included in the remote sensing analysis. In all of the ejidos a change in the grazing land was recorded. As a result of a land reform promoted by the Mexican government in the early 1990s, ejido grazing lands have been divided into parcels, formally or informally. In fact, in group 2 this single change has occurred. The fragmentation of the grazing land has had more notorious consequences in group 3. In all of the ejidos in this group, some ejidatarios have started to sell their parcel of grazing land to be used as recreational ranchettes. Based on this, we decided to take the ejido Molino de Camou as a representative of group 2 and 3 because this ejido was included on the socioeconomic survey and we have useful survey/interview data. The most relevant common characteristic of group 4 is that in these ejidos a considerable part of the agricultural land has been abandoned. Because ejido La Victoria was the first groundwater-based ejido affected by urban water infrastructure and was selected for inclusion in the socioeconomic survey, we chose this ejido as a representative of group 4.

In the last decades, remote sensing technology has provided the means for a timely and accurate monitoring of land cover change because it makes possible the study of spatio-temporal trends, which permits the assessment of regional and global ecological

processes (Sánchez-Flores & Yool, 2007). Due to its advantages in covering large areas with high spatial detail and high temporal frequency, remotely sensed products are increasingly used for land cover change monitoring (Lu et al., 2004).

In remote sensing, land cover change detection consists of identifying the state of an object or phenomenon by observing it at different times (Singh, 1989). The phenomena of interest are the changes in the initial land cover conditions along a time series captured in an image set. Land cover changes, therefore, can be defined as the difference in the reflectance values of two image pixels or objects recorded at two different dates (Lambin & Strahler, 1994). Once land cover changes are detected, the changes of spatial units can be used to assess spatial reconfiguration of the landscape.

In this study, the remote sensing analysis of land use/cover change was performed at two different scales. First, we classified the main categories around the city of Hermosillo to detect the advance of the impervious and built-up area over the shrubland and agriculture in the peri urban fringe. Second, we extracted the main classes at the ejido level to detect the main land transformations produced by urban expansion. This approach allowed having a comparative framework to relate the remotely sensed changes with the results of the ejido surveys. The remote sensing analysis was based on a post classification approach to compare the main land use/cover types extracted from a multispectral Landsat imagery dataset. The dates and other characteristics of these images are listed in Table 3. Pre-processing included resampling all datasets to 30 m of spatial resolution and projecting to UTM zone 12N with a WGS84 datum for spatial consistency.

Table 3

The selected images were classified using a supervised classification process based on a support vector machine (SVM). This is a classification algorithm derived from statistical learning theory that allows separating the classes with a decision hyperplane that maximizes the margin between the classes (Vapnik, 1995). The location of this optimal hyperplane in the multispectral image space is supported on vectors or data

points, defined from the training that increases the classification performance (Wu et al., 2004). We used a SVM based on a radial kernel function, with a γ parameter of 0.167, a 100 penalty parameter, and 0 classification probability threshold to ensure all pixel values were included in the process. Training of the SVM algorithm was based on field knowledge and visual interpretation of Landsat 4-5 TM images of the area. The main classes identified for the study were urban, agriculture, shrubland, riparian vegetation and dense shrubland, barren[37], water and mountain scrub.

Accuracy assessment of all classifications was performed using independent randomly distributed ground samples for each ejido area. For the 1987 classifications, ground assessment was made based on field knowledge, historic maps and records. The 1995 classified were assessed using aerial photograph and historic records. Classifications of 2007 were verified based on high resolution imagery and field records. From these samples we built error matrices to calculate overall accuracy and kappa coefficients for each date. To assure a homogenous coverage of the field points in each ejido we distributed the points proportionally to area as follows:

- Vila de Seris: 2pts/km2 = 93 pts.
- Molino de Camou: 3pts/km2 = 48 pts.
- La Victoria: 3pts/km2 = 25 pts
- Hermosillo 0.5 pt/km2 = 224 pts.

The results of the accuracy assessment are as follows.

Table 4

As displayed in Table 4, the overall accuracies are greater than 80% in all cases, while the Kappa statistics are greater than 0.75 in all cases. These accurate assessment results indicate that reliable land cover features were extracted in this classification. As

[37] Barren soil is considered as the non urban area where remote sensing analysis does not detects non actively growing vegetation. In this regard, barren soil comprises different land use/cover types with this characteristic such as cleared land and fallow land.

could be noted, overall accuracies are bigger in the three ejidos than in Hermosillo. This ensures a better classification of the ejidos, which are the primary area of study in this paper.

IV. Results

Applying a remote sensing-based examination of urban expansion to the city of Hermosillo we obtained the following results.

Figure 3

Table 5

As displayed in Table 5 the main land use/cover changes are urban and agricultural types. Urban land increased from 12.7% in 1987 to 24.6% in 2007 (from 5,698 to 11,025 hectares), which is an increment of 93.4%. Agricultural land decreased from 19.1% in 1987 to 6.8% in 2007. We can observe that the most important change in agricultural land occurred between 1995 and 2007, when this type diminished from 16.5% in 1995. In the twenty years covered by this study agricultural land lost about 5,471 hectares. An additional important change also occurred in the area covered by water. This change corresponds to the decrease on the Abelardo L. Rodriguez (ALR) dam area, which in 2007 was practically empty.

Although the land use/cover changes inside the city are interesting to examine in order to ascertain the urban growth patterns, this is not the objective of this paper. As stated, our aim is to examine land use/cover changes produced by urban water transfers inside the peri-urban ejidos. For that reason, we need to move on to the peri-urban ejidos to study them in detail.

. If we were to consider only urban land expansion, or, as stated in this paper, the peri-urban landscape, we would conclude that Villa de Seris would be the most altered ejido, as we can see in Table 6.

Table 6

According to this table, a considerable change has occurred in the area covered by agricultural land. Of its total surface of about 4,673 hectares, shrubland has undergone the most drastic change, a reduction from about 64% to 45% in twenty years.

Urban land has increased from practically 0% in 1987 to 10% in 2007. The urbanization process has been consolidated in the northeast of the ejido land, which is adjacent to the city of Hermosillo boundary. As displayed in Figure 4, the urban land has mainly replaced the space occupied in 1987 by agricultural land and shrubland.

Figure 4

If we were to follow only this approach to analyze the impacts of urban expansion in the peri-urban area we would conclude that of the three ejidos, Villa de Seris is the only one affected by urban expansion. However, when we consider the peri-urban waterscape by taking into account the effect of urban water transfer in the peri-urban area, we are able to observe new findings regarding the environmental, political and economic drivers of the observed land use/land cover changes. The agricultural land in ejido La Victoria is a good example of this.

In 1986 eleven urban wells were established in the outskirts of ejido La Victoria, located in the northeast of the city (del Castillo, 1994). In interviews, ejidatarios from La Victoria said that during the period from 1986 to the mid 1990s they did not have any significant problem of water quantity for agricultural purposes. However, in 1996, the local government established an infiltration gallery for collecting sub-surface flows from

the river by around 500 liters per second[38]. Ejidatarios from La Victoria said that since that moment the ejido wells dried up. According to the ejidatarios, the infiltration gallery in conjunction with the installation of urban wells (in 1986) and the reductions of streamflows affected them adversely. The city's wells go to hundreds of feet below the surface. The ejidatarios reported in interviews that they cannot compete with the city's wells because they do not have enough financial support for drilling deeper wells. In order to confirm water shortage on the peri-urban ejidos, in the socioeconomic survey a *water impact level* was estimated. This indicator was calculated based of the number of years (from 1994 2008) negatively affected in the irrigation activity by reducing the irrigated surface in some cases or reducing the number of irrigations in other cases. According to this estimation, 60% of the total 15 respondents in La Victoria reported a very high impact level, 27% a high impact level, and the rest a medium impact level. This data indicate that water was considerably reduced in this ejido.

Because of the lack of water, the ejidatarios of La Victoria have abandoned their agricultural land. Of the 56 members of this ejido that in the mid 1990s had a parcel, 70% have stopped cultivating their agricultural land. In the socioeconomic survey, of the 9 respondents that have stopped cultivating, all reported making this decision because of the lack of water due, in turn, to the establishment of the urban wells.

Linking the survey and interview data clearly illuminates how changing access to water is a driver of land use change. The socioeconomic survey shows a land use/cover change due to urban expansion, linked in turn to urban water supply. In order to verify survey information, we analyzed land use/cover change based on remote sensing analysis as seen in the following figure.

Figure 5

[38] According to a CONAGUA agent, the gallery only works two years because of the reduced streamflows on the river system. The infiltration gallery now is used as a part of the pumping system, but no longer for its original purpose (AGUAHH, 2007, p. 22).

Figure 5 shows the evolution of the 422 hectares of agricultural land from 1987 to 2007. As evident in Figure 5, agricultural land has drastically diminished. Table 7 displays the numbers of this change.

Table 7

As displayed in Table 7, the percentage of barren land has increased from 9.5% in 1987 to almost 75.6% in 2007. On the other hand, agricultural land has diminished from around 67.3% in 1987 to 24.4%, which is a loss of 181 hectares, almost 43% of the total agricultural are. Water shortage in the agricultural land has also pushed peri-urban ejidatarios to sell their land. According to the interviews, since the mid 1990s, in La Victoria 25% of the total ejidatarios sold their land rights. On the survey, of the 3 respondents that have sold their land, all of them indicated the lack of water as the main reason for doing so. If we multiply the water shortage effect from this ejido to others, and moreover, if we consider that this has also happened on private land (small-scale private producers known as *pequeños propietarios*) located in the peri-urban area, the consequences of urban expansion probably would be considerably increased. Although it may require more analysis, the evidence suggests that this water transfer-land cover change interrelationship explains why in the peri-urban area of Hermosillo, agricultural land diminished from 19.1% in 1987 to 6.8% in 2007 (Table 5).

By itself, this link between water and land is sufficient to demonstrate the importance of considering the urban expansion effect as a peri-urban waterscape phenomenon. Nonetheless, another land use/cover change can be demonstrated illustrated by the case of the ejido Molino de Camou.

Molino de Camou was among the most negatively affected ejidos by the extension of urban water infrastructure. Before the Molinito dam was constructed in 1991, Molino de Camou used surface water through a weir constructed of branches, sticks and sand to divert water to earthen canals (Díaz-Caravantes & Camou, 2005). The site of this canal was located in the dam impoundment and therefore the traditional

system disappeared. However, the ejidatarios were able to reach an accord with the government that they will receive water by the dam outlet. CONAGUA also granted them a water concession for around 1.4 millions of cubic meters (Díaz-Caravantes & Camou, 2005).This agreement changed in 1998 when Molinito dam started to be used to store water and release it through the Sonora River to recharge the aquifer Mesa del Seri-La Victoria, which is used to provide water to the city via the urban wells located in that area (Díaz-Caravantes & Wilder, n.d.). After that date, CONAGUA started to restrict the surface water for the ejido with a volume that was not enough even for one growing season[39] (Díaz-Caravantes & Camou, 2005). According to the socioeconomic survey, 48% of the ejidatarios of Molino de Camou experienced either a high or medium *water impact level* (Díaz-Caravantes, n.d.). Due to water shortage for agricultural land, the ejidatarios of Molino de Camou have opted for changing their crop pattern from wheat and corn to growing grass to feed their own livestock because, among other reasons, pasture is less dependent on water availability than wheat and corn, and therefore, grass is less vulnerable to water shortage linked both to natural causes and to urban water policy. Of the 19 ejidatarios surveyed in the ejido Molino de Camou, 5 ejidatarios changed to pasture grass when water scarcity started. Now, all of them use their agricultural land as grassland to feed their livestock. Although this practice is not new in the ejido, there is an increment due to water scarcity. This land use increases soil compaction by livestock producing significant environmental problems such as a reduction of nutrient and oxygen availability in agricultural land (Skinner et al., 2009; Drewry et al., 2008).

The change from agricultural to grassland is important; however in terms of extension, there is another change related with grazing land used for urban purposes. In the last decade, grazing land of peri-urban ejidos has experienced a process of fragmentation encouraged in part by a change in land tenure. According to the interviews, when the newest Mexican land reform was implemented in the 1990s, governmental officials encouraged the ejidatarios to parcellize the grazing land at no cost. This, in

[39] Although this water policy in favor of the city would apparently change with the increment of the volume of water right from 1.4 to 2.1 Mm3, at the moment of finishing this research, the water's restriction continued.

combination with an organizational division inside ejidos resulted in the fragmentation of grazing land. In the ejido Molino de Camou, the grazing land was divided in 1997 resulting in around 20 hectares per ejidatario.

Due to the lack of jobs in Hermosillo and the agricultural production problems caused by water scarcity the ejidatarios of the peri-urban area have sold part of the grazing land to be used as recreational ranchettes by urban residents (Díaz-Caravantes, n.d.). The buyers are primarily urban residents who purchase the lots to use them as a weekend retreat for celebrating or, as a buyer said, "for escaping from the city for a while". In the socioeconomic survey, of the 19 respondents of the ejido Molino de Camou, 13 had sold their parcel of grazing land; 11 of these parcels are used as recreational ranchettes. Of the 11 sellers, all of them stated that their agricultural activity had been damaged by new urban water infrastructure, especially by the Molinito Dam. Of these, 8 resulted in a high or medium *water impact level.*

Table 8 shows the overall land use/cover changes detected in the ejido Molino de Camou.

Table 8

As observed in Table 8, riparian/dense shrubland cover has considerably diminished from 26.1% in 1987 to 15.6 % in 2007. At the end of the 1990s, due to lack of access to credit, the ejido stopped producing on around 150 hectares of collective agricultural land located in the southwest of the ejido (see Figure 6). This explains why agricultural land faced a significant reduction from 22% in 1987 to 16.5% in 2007. As stated, in the ejido Molino de Camou we are interested in the land use/cover changes that occurred in the grazing land (blue polygon in Figure 6).

Figure 6

As displayed in this figure, considerable land use/cover changes have occurred in the grazing land of the ejido. According to our geographical observations in situ, of the approximately 1,000 hectares of grazing land, about 230 hectares are now recreational ranchettes (red polygons in Figure 6). Table 9 shows the land use/cover changes in the recreational ranchettes's polygons.

Table 9

Table 9 shows that inside these recreational ranchettes barren land has substantially increased from 0% in 1987 to around 24% in 2007, which are around 54 hectares. Shrubland and riparian/dense shrubland diminished more than 10%, respectively, in these twenty years. This suggests that barren land has replaced both types in similar degrees.

Although in Figure 6 the recreational ranchette's polygons are shown in 1987 and 1995, actually this land use started to appear in 1998. If we consider the 54 hectares of barren land in these 9 years (1998-2007), we have a rate of 6 hectares cleared per year. On the other hand, we know that each lot has a size of 25 per 50 meters, sufficient for 8 ranchettes per hectare. With these numbers we can see the magnitude of the land disturbance problem. Inside the grazing land of this ejido, the equivalent of 48 lots per year has been cleared.

Figure 7

The increase in barren soil in recreational ranchettes is attributed to choices of some urban residents to remove part of the vegetation when they buy a lot. The degree of deforestation can vary from parcel to parcel. For example, Figure 7a shows a recreational ranchettes where the residents apparently planted new trees, while Figure 7b illustrates a case where almost all of the trees have been removed.

V. Discussion

A considerable number of studies have examined the land-livelihoods relationship in the peri-urban area. However, there are few studies regarding the three-way interrelationship among water, livelihoods, and land in the peri-urban area. This case illustrates how "new" land use/cover changes are detected when we conceptualize the peri-urban landscape as a peri-urban waterscape-- that is to say, when we link urban expansion not only to phenomena such as land annexation, but also to land use/cover changes due to urban water demand.

As stated, if we were considered only the peri-urban landscape, we may conclude that Villa de Seris is the most-- and perhaps the only--ejido altered by urban expansion. As documented, in Villa de Seris, urban land has increased in the northeast of the ejido land, which is adjacent to the city of Hermosillo. However, by linking household surveys and remote sensing tools from the perspective of “waterscape”, we illustrate two major land use/cover changes occurring in the peri-urban ejidos.

La Victoria is one of the most impacted ejidos in the peri-urban area. Due to water shortage, about 70% of the ejidatarios have stopped cultivating their agricultural land. The remote sensing information confirmed that agricultural land has drastically decreased by more than half in almost 20 years. This case illustrated the loss of arable land by urban expansion requirements, although this land, for the time being at least, is not occupied as urban land. This is unproductive barren land use because is not used anymore as agricultural land, and is neither urban nor shurbland, as shown in the remote sensing data, it is not shrubland either. On the other hand, it is very probable that the loss of this agricultural land may cause more land to be opened up somewhere to agriculture to compensate the ejido's gap in the agricultural products market. The case of ejido La Victoria takes on new dimensions when we realize that this is only one case among many similar ejidos and that very probably agricultural private land located in the peri-urban area was affected in the same way, though excluded from our current study parameters.

This regional impact explains why agricultural land diminished from 19.1% in 1987 to 6.8% in 2007 around the city of Hermosillo.

A second substantial land use/cover change is happening in the grazing land of peri-urban ejidos. Since 1998, urban water infrastructure has affected the ejido Molino de Camou. Due to the lack of off-farm jobs and the agricultural production problems caused by water scarcity the ejidatarios of the peri-urban area have started to sell grazing land for urban purposes as a recreational ranchettes. According to the remote sensing analysis, this new land use in the grazing land has produced a common, but severe, land cover change inside these lots, barren land. If we consider that this is only the case of one ejido of many that follow this trend, we realize the extent of the current and potential threat to native plants in the peri-urban area because riparian and shrubland areas are disappearing.

Nonetheless, the emergence of recreational ranchettes as a notable land use is not only significant in terms of vegetation removal; as observed in the images, this land use type is dispersed and fragmented throughout the grazing lands and is also affecting wildlife. Landscape fragmentation caused by clearing areas in these lots represents one of the most adverse effects on natural ecosystems in this area. More insidious, however, are the ecological consequences caused by fences and other linear disturbances to wildlife, introduced as part of the new land ownership scheme. These elements inhibit the ability of small mammals and reptiles to breed and exchange with neighbor populations, which affects genetic biodiversity and may threaten species survival. In general, reduction of functioning healthy ecosystems is frequently the cause of multiple disturbances in ecological communities,

Although less significant in terms of affected area, than these two major land use/cover changes, the ejido Molino de Camou also evidences a third important alteration in the use of agricultural land. Because of water shortage ejidatarios have opted for growing pasture grass on agricultural land rather than grains for human consumption. This change was also accompanied by an increase in the existing practice of introducing livestock to agricultural land, causing soil compaction. Multiple studies have documented severe consequences of compaction on soil quality.

VI. Conclusions

Land use/cover changes produce several drivers of environmental degradation such as erosion, habitat and biodiversity loss, and groundwater depletion. Urbanization is one of the most drastic changes in the ecosystem, but as we have shown this could be underestimated if we were only to consider the effect of urbanization as a peri-urban landscape. In this paper, when we include water transfers from the peri-urban as another driver of explanation we were able to identify new significant land use/cover changes occurring in the peri-urban area, specifically in the agricultural land and grazing land of several ejidos.

Undoubtedly, these land use/cover changes need more research to evaluate the exact consequences of land alteration. Nonetheless, this first approach is enough to demonstrate the importance of including the waterscape in analyses of transformation of peri-urban areas. In both cases we found a three-way water-livelihoods-land interrelationship. Water transfers negatively affect peri-urban livelihoods producing changes in the ejido land. In the case of La Victoria we found why agricultural land around the city has been drastically reduced. In ejido Molino de Camou we found how uncertainty in water availability has damaged livelihoods and has promoted the development of a largely undocumented (and unproductive) land use, recreational ranchettes.

If we had examined these cases using only the traditional land-livelihood approach we likely would have concluded that, as anticipated, local populations disturbed the environment. However, we have found that by adding water and examining the water-livelihood-land linkages, the loss of access to water is a critical variable driving a change in local livelihoods and, as consequence, in the environment.

VII. References

AGUAHH. (2007). *Programa Municipal de Agua Potable, Alcantarillado Sanitario, Saneamiento, y Disposición de Aguas Residuales, 2007-2009*. Hermosillo, Sonora, México: Municpio de Hermosillo.

Allen, A. (2003). Environmental planning and management of the peri-urban interface: perspectives on an emerging field. *Environment and Urbanization*, 15(1), 135-147.

Allen, A., Dávila, J. D., & Hoffman, P. (2006). *Governance of Water and Sanitation Services for the Peri-urban Poor. A Framework for Understanding and Action in Metropolitan Regions.* Development Planning Unit, UCL, London. Retrieved April 14, 2009, from http://www.ucl.ac.uk/dpu/pui/publications/index.html

Angel, S., Sheppard, S. C., & Civco, D. L. (2005). *The Dynamics of Global Urban Expansion. Transport and Urban Development Department of the World Bank*. Retrieved May 11, 2009, from http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/0,,contentMDK:20970341~pagePK:148956~piPK:216618~theSitePK:337178,00.html

Arnold, C., & Gibbons, C. (1996). Impervious surface coverage - The emergence of a key environmental indicator. *Journal of the American Planning Association*, 62(2), 243-258.

Bakker, K. J. (2003). *An Uncooperative Commodity: Privatizing Water in England and Wales.* New York: Oxford University Press.

Banzhaf, E., Grescho, V., & Kindler, A. (2009). Monitoring urban to peri-urban development with integrated remote sensing and GIS information: a Leipzig, Germany case study. *International Journal of Remote Sensing*, 30(7), 1675-1696.

Batisani, N., & Yarnal, B. (2009). Urban expansion in Centre County, Pennsylvania: Spatial dynamics and landscape transformations. *Applied Geography*, 29(2), 235-249.

van den Berg, L., van Wijk, M., & Van Hoi, P. (2003). The transformation of agriculture and rural life downstream of Hanoi. *Environment and Urbanization*, 15(1), 35-52.

Booth, D., Hartley, D., & Jackson, R. (2002). Forest cover, impervious-surface area, and the mitigation of stormwater impacts. *Journal of the American Water Resources Association,* 38(3), 835-845.

Brook, R. M., Bhat, P., & Nitturkar, A. (2006). Livelihoods from Dairying Enterprises for the Landless in the Peri-Urban Interface around Hubli-Dharwad, India. In D. McGregor, D. Simon, & Thompson (Eds.), *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (pp. 94-103). UK: Earthscan Publications Ltd.

Brook, R., Purushothaman, S., & Hunshal, C. (Eds.). (2003). *changing frontiers – The Peri Urban Interface Hubli-Dharwad, India*. Bangalore, India: Books for Change.

Buechler, S. J., & Scott, C. A. (2000). "Para Nosotros, Esta Agua es Vida." El Riego en Condiciones Adversas: Los Usuarios de Aguas Residuales en Irapuato México. In C. A. Scott, P. Wester, & B. Marañon-Pimentel (Eds.), *Asignación, productividad y manejo de recursos hídricos en cuencas. (Allocation, productivity and management of basin water resources),* Serie Latinoamericana (pp. 135-171). México D.F., México: International Water Management Institute.

Carlson, T. N., & Arthur, S. T. (2000). The impact of land use -- land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective. *Global and Planetary Change*, 25(1-2), 49-65.

del Castillo, J. M. (1994). Protección y restauración ecológica-ambiental de la Presa Abelardo Rodríguez Luján, en Hermosillo, Sonora. *Estudios Sociales*, V(9), 65-102.

Chowdhury, R. R., & Turner II, B. (2006). Reconciling Agency and Structure in Empirical Analysis: Smallholder Land Use in the Southern Yucatán, Mexico. *Annals of the Association of American Geographers*, 96(2), 302-322.

CONAGUA. (2009). *Escurrimientos El Cajón y El Orégano 08*. Unpublished data.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso M., Hannon, B. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253.

Conway, T. (2007). Impervious surface as an indicator of PH and specific conductance in the urbanizing coastal zone of New Jersey, USA. *Journal of Environmental Management*, 85(2), 308-316.

Crossman, N., Bryan, B., Ostendorf, B., & Collins, S. (2007). Systematic landscape restoration in the rural-urban fringe: meeting conservation planning and policy goals. *Biodiversity and Conservation*, 16(13), 3781-3802. doi:10.1007/s10531-007-9180-8

Dewan, A. M., & Yamaguchi, Y. (2009). Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Applied Geography*, 29(3), 390-401.

Díaz-Caravantes, R. E., & Camou, E. (2005). El agua en Sonora: tan cerca y tan Lejos. Estudio de caso del ejido Molino de Camou. *Región y Sociedad*, XVII (034), pp. 127-165.

Díaz-Caravantes, R. E. (n.d.). *Balancing Urban and Peri-Urban Exchange: Rural Livelihoods in Mexico.* Unpublished manuscript.

Díaz-Caravantes, R. E., & Wilder, M. (n.d.). *Water, Cities and Peri-Urban Vulnerabilities in Northwest Mexico.* Unpublished manuscript.

Drewry, J., Cameron, K., & Buchan, G. (2008). Pasture yield and soil physical property responses to soil compaction from treading and grazing — a review. *Aust. J. Soil Res.*, 46(3), 237-256.

Forman, R. T. T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions.* Cambridge University Press.

Fox, J., Rindfuss, R. R., Walsh, S. J., & Mishra, V. (Eds.). (2003). *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS* (1º ed.). Kluwer Academic Publishers.

Hasse, J. E., & Lathrop, R. G. (2003). Land resource impact indicators of urban sprawl. *Applied Geography*, 23(2/3), 159.

Henne, S. K. (2005). "New Wilderness" as an Element of the Peri-Urban Landscape. In I. Kowarik & S. Körner (Eds.), *Wild Urban Woodlands: New Perspectives for Urban Forestry* (1º ed., pp. 247-262). Springer-Verlag Berlin Heidelberg.

Herold, M., Goldstein, N. C., & Clarke, K. C. (2003). The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sensing of Environment*, 86(3), 286.

Jaiyebo, O. (2003). Women and household sustenance: changing livelihoods and survival strategies in the peri-urban areas of Ibadan. *Environment and Urbanization*, 15(1), 111-120.

Kelly, P. F. (2006). The Politics of Urban-Rural Relations: Land Use Conversion in the Philippines. In C. Tacoli (Ed.), *The Earthscan Reader in Rural-Urban Linkages* (pp. 265-284). UK: Earthscan Publications Ltd.

Lambin, E., & Strahler, A. (1994). Indicators of land-cover change for change vector analysis in multitemporal space at coarse spatial scales. *International Journal of Remote Sensing*, 15, 2099-2119.

Lambin, E. F. (2003). Linking Socioeconomic and Remote Sensing Data at the Community or at the Household Level: Two Case Studies from Africa. In J. Fox, R. R. Rindfuss, S. J. Walsh, & V. Mishra (Eds.), *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS* (1º ed., pp. 223-240). Kluwer Academic Publishers.

Liverman, D., Moran, E. F., Rindfuss, R. R., & Stern, P. C. (Eds.). (1998). *People and Pixels: Linking Remote Sensing and Social Science*. Washington, D.C: National Academy Press.

Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing*, 25(12), 2365-2401.

McGregor, D., Simon, D., & Thompson, D. (2006). *The Peri-Urban Interface: Approaches to Sustainable Natural and Human Resource Use* (illustrated edition.). UK: Earthscan Publications Ltd.

Narain, V., & Nischal, S. (2007). The peri-urban interface in Shahpur Khurd and Karnera, India. *Environment and Urbanization*, 19(1), 261-273.

Narain, V. (2009). Growing city, shrinking hinterland: land acquisition, transition and conflict in peri-urban Gurgaon, India. *Environment and Urbanization*, 21(2), 501-512.

Ode, A., & Fry, G. (2006). A model for quantifying and predicting urban pressure on woodland. *LANDSCAPE AND URBAN PLANNING*, 77(1-2), 17-27.

Perz, S. G., & Walker, R. T. (2002). Household life cycles and secondary forest cover among small farm colonists in the Amazon. *World Development*, 30(6), 1009-1027.

Ridd, M. (1995). Exploring a V-I-S (Vegetation-Impervious Surface-Soil) Model for Urban Ecosystem Analysis through Remote-Sensing - Comparative Anatomy for Cities. *International Journal of Remote Sensing*, 16(12), 2165-2185.

Sánchez-Flores, E., & Yool, S. R. (2007). Sensitivity of change vector analysis to land cover change in an arid ecosystem. *International Journal of Remote Sensing*, 28(5), 1069-1088.

Sever, T. L. (1998). Validating Prehistoric and Current Social Phenomena upon the Landscape of the Peten, Guatemala. In D. Liverman, E. F. Moran, R. R. Rindfuss, & P. C. Stern (Eds.), *People and Pixels: Linking Remote Sensing and Social Science* (pp. 145-163). Washington, D.C: National Academy Press.

Singh, A. (1989). Digital Change detection techniques using remotely-sensed data. *International Journal of Remote Sensing*, 10(6), 989-1003.

Skinner, A., Lunt, I. D., Spooner, P., & McIntyre, S. U. E. (2009). The effect of soil compaction on germination and early growth of Eucalyptus albens and an exotic annual grass. *Austral Ecology*, 34(6), 698-704.

Smith, M. (2007). Urban Expansion in Oaxaca, Mexico: Research on the Fringe. *Yearbook of the Association of Pacific Coast Geographers*, 69, 88-100.

Stehlik, I., Caspersen, J., Wirth, L., & Holderegger, R. (2007). Floral free fall in the Swiss lowlands: environmental determinants of local plant extinction in a peri-urban landscape. *JOURNAL OF ECOLOGY*, 95(4), 734-744.

Swyngedouw, E. (1999). Modernity and hybridity: Nature, Regeneracionismo, and the production of the Spanish waterscape, 1890-1930. *Annals of the Association of American Geographers*, 89(3), 443-465.

Turner, B. L., Lambin, E., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences*, 104(52), 20666-20671.

United Nations. (2009). *World Urbanization Prospects: The 2007 Revision Population Database.* Retrieved October 9, 2009, from http://esa.un.org/unup/

Vapnik, V. (1995). *The Nature of Statistical Learning Theory*. New York: Springer-Verlag.

Watson, R., Noble, I., Ravindranath, N., Verardo, D., & Dokken, D. (2000). Special report on land use, land-use change in forestry. *Intergovernmental Panel on Climate Change.*

Weng, Q. (2007). *Remote Sensing of Impervious Surfaces* (1º ed.). CRC.

Wu, T., Lin, C., & Weng, R. (2004). Probability estimates for multi-class classification by pairwise coupling. *Journal of Machine Learning Research*, 5, 975-1005.

Yuan, F. (2008). Land-cover change and environmental impact analysis in the Greater Mankato area of Minnesota using remote sensing and GIS modelling. *International Journal of Remote Sensing*, 29(4), 1169-1184.

VIII. Tables and Figures

Table 1. Type of Impacts in Peri-Urban Ejidos

Group	Ejido	Type of irrigation	Urban Water Supply Facilities Impact on Ejidos					Degree of Impact on Agricultural Water Use	
			Surface Water		Groundwater				
			Residual water	Dam System	Wells in Mesa del Seri-La Victoria	Wells in San Miguel or Zanjón	Aqueduct El Molinito	Quantity	Quality
1	La Victoria	Groundwater		✓	✓			High	Medium
	Mesa del Seri	Groundwater		✓	✓			High	None
	San Pedro	Groundwater		✓	✓			High	None
	El Alamito	Groundwater		✓	✓			High	None
2	San Juan	Groundwater		✓			✓	High	None
3	Codorachi	Both				✓		High	None
	Torreon	Both				✓		High	None
	La Labor	Groundwater				✓		Medium	None
	Zacaton	Groundwater				✓		Low	None
	El Carmen	Groundwater				✓		Medium	None
	Zamora	Groundwater				✓		Low	None
4	Molino de Camou	Surface		✓				Low	None
5	Villa de Seris	Surface	✓	✓				None	High
	La Manga	Surface	✓	✓				None	High
	La Yesca	Surface	✓	✓				None	High
	San Miguel	Surface	✓	✓				None	High

Source: Own research

Table 2. Categorization of land use/cover changes occurring in each ejido

Group	Ejido	Type of land use/cover changes by ejido			
		Adjacent	Ranchettes	Grazing land	Abandoned
1	Villa de Seris	✓		✓	
	La Manga	✓		✓	
2	San Juan			✓	
	Codorachi			✓	
	La Labor			✓	
	San Miguel			✓	
	Torreon			✓	
3	Molino de Camou		✓	✓	
	Zacaton		✓	✓	
	El Carmen		✓	✓	
	El Alamito		✓	✓	
	La Yesca		✓	✓	
4	La Victoria			✓	✓
	Mesa del Seri			✓	✓
	San Pedro			✓	✓
	Zamora			✓	✓

Table 3. Characteristics of selected Landsat images for land use/cover classification

Date	Sensor	Spatial Resolution (m)
June 13, 1987	TM	30
March 31, 1995	TM	30
April 17, 2007	ETM+	28.5

Table 4. Accuracies of land-cover classifications

Year	Hermosillo		Villa de Seris		Molino de Camou		La Victoria	
	Overall accuracy	Kappa coefficient	Overall accuracy	Kappa coefficient	Overall accuracy	Kappa coefficient	Overall accuracy	Kappa coefficient
1987	83.5%	0.779	86.0%	0.710	87.5%	0.785	88.0%	0.753
1995	80.4%	0.750	87.1%	0.803	85.4%	0.777	88.0%	0.763
2007	84.8%	0.786	84.9%	0.796	83.3%	0.767	92.0%	0.752

Table 5. Land use/cover changes Hermosillo

Land use/cover changes	Percentage of land cover type by year		
	1987	**1995**	**2007**
Shrubland	44.0	38.3	46.8
Riparian/Dense shrubland	2.0	3.1	4.5
Agriculture	19.1	16.5	6.8
Water	4.5	9.0	1.3
Barren	1.4	2.8	3.5
Urban	12.7	17.7	24.6
Mountain scrub	16.4	12.6	12.4
Total	100.0	100.0	100.0

Table 6. Land use/cover changes in Villa de Seris

Land use/cover changes	Percentage of land cover type by year		
	1987	**1995**	**2007**
Shrubland	63.8	48.7	45.2
Riparian/Dense shrubland	4.5	2.7	5.9
Agriculture	18.7	27.6	20.9
Water	0.0	0.3	0.0
Barren	0.0	5.4	5.5
Urban	0.2	3.7	9.9
Mountain scrub	12.7	11.6	12.5
Total	100.0	100.0	100.0

Table 7. Land use/cover changes in La Victoria

Land use/cover changes	Percentage of land cover type by year		
	1987	**1995**	**2007**
Shrubland	23.2	0.0	0.0
Agriculture	67.3	54.7	24.4
Water	0.0	1.6	0.0
Barren	9.5	43.7	75.6
Total	100.0	100.0	100.0

Table 8. Land use/cover changes in Molino de Camou

Land use/cover changes	Percentage of land cover type by year		
	1987	**1995**	**2007**
Shrubland	51.7	50.0	53.8
Riparian/Dense shrubland	26.1	23.2	15.6
Agriculture	22.0	25.3	16.5
Water	0.2	0.4	0.0
Barren	0.0	1.2	14.1
Total	100.0	100.0	100.0

Table 9. Land use/cover changes in the recreational ranchettes

Land use/cover changes	Percentage of land cover type by year		
	1987	**1995**	**2007**
Shrubland	83.7	83.8	73.3
Riparian/Dense shrubland	16.3	15.6	3.2
Barren	0.0	0.7	23.5
Total	100.0	100.0	100.0

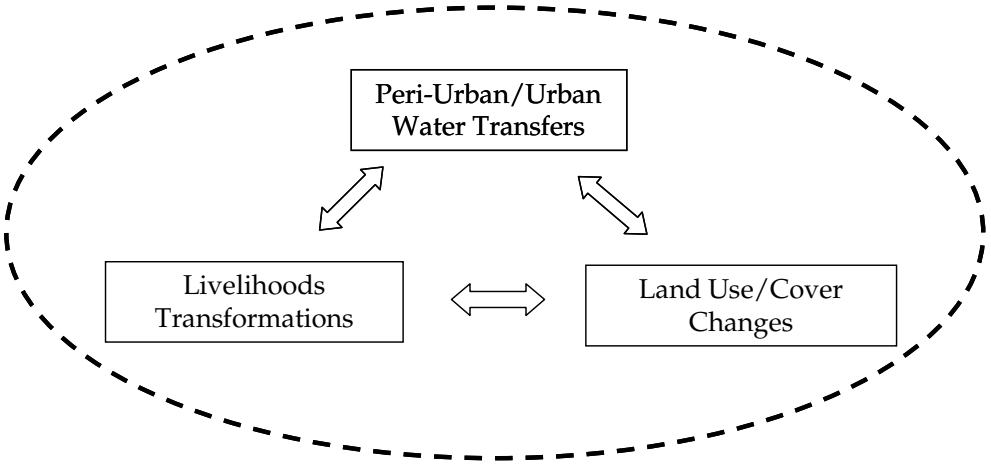

Figure 1. Peri-Urban Waterscape

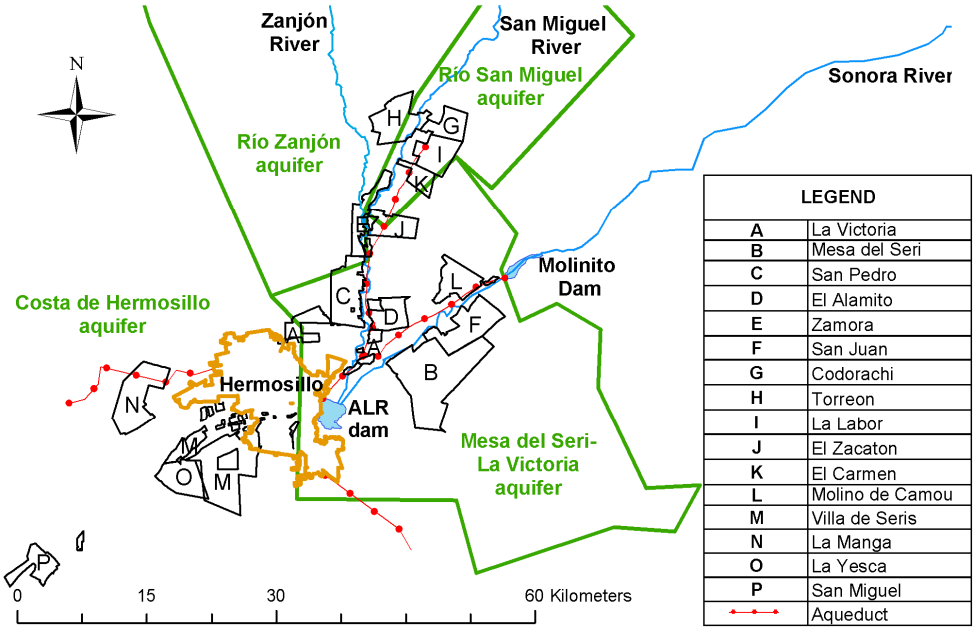

Figure 2. Study area

Source: Based on Registro Agrario Nacional and CONAGUA

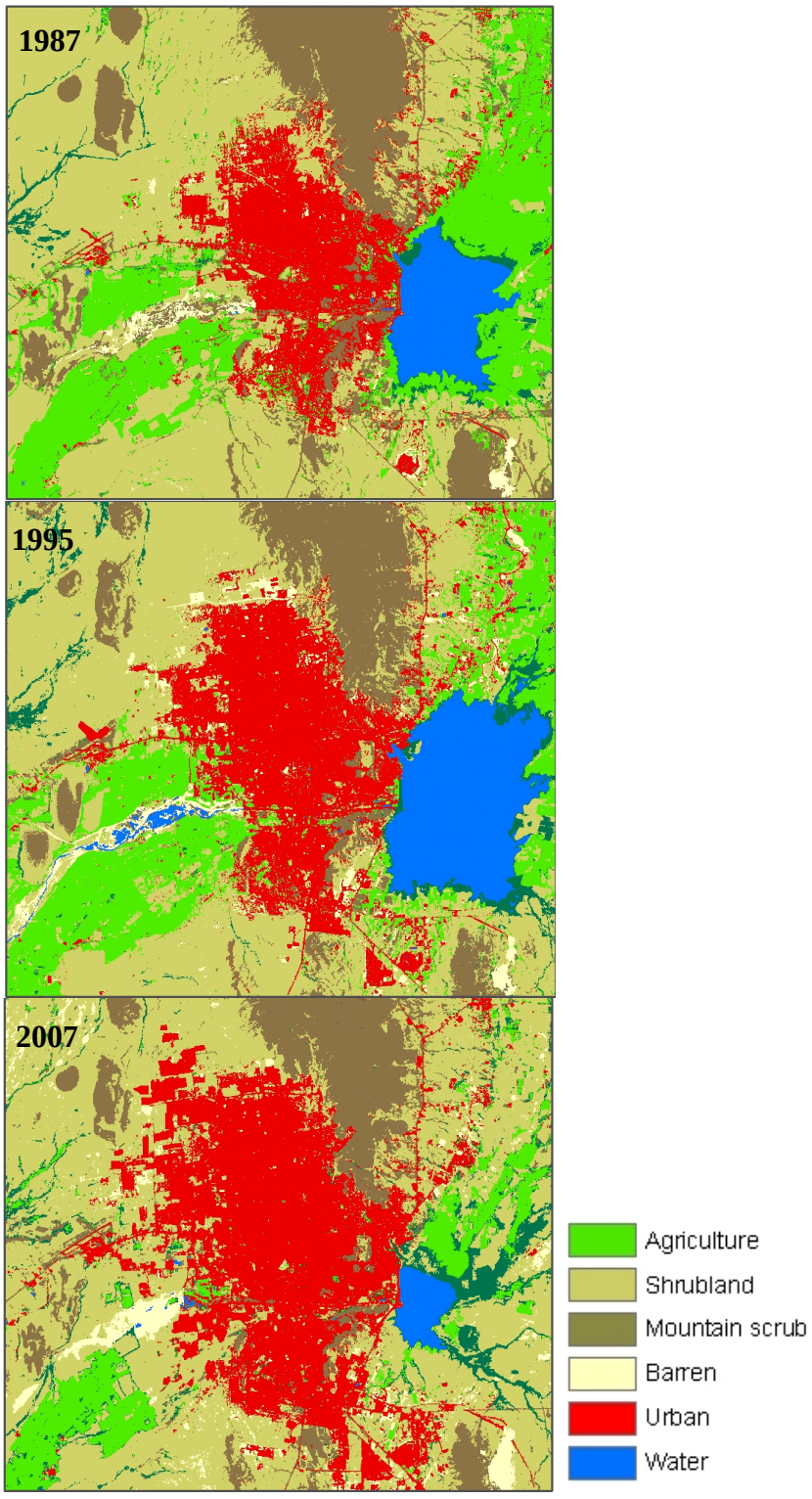

Figure 3. Land use/cover changes in Hermosillo

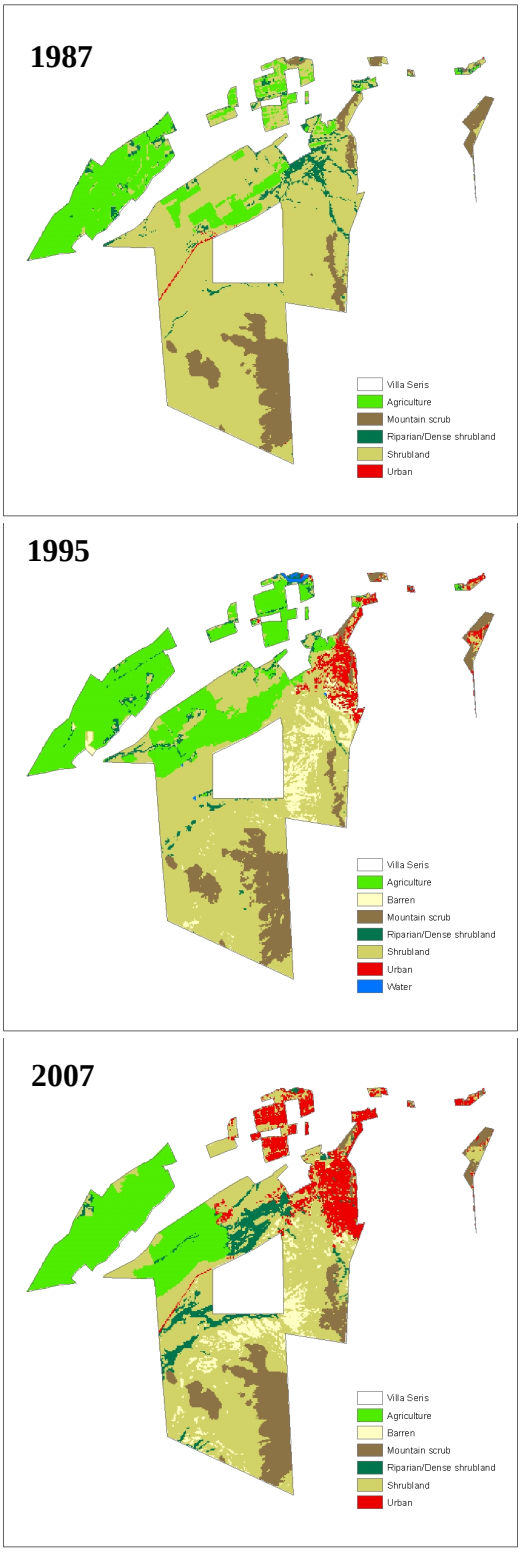

Figure 4. Land use/cover changes in Villa de Seris

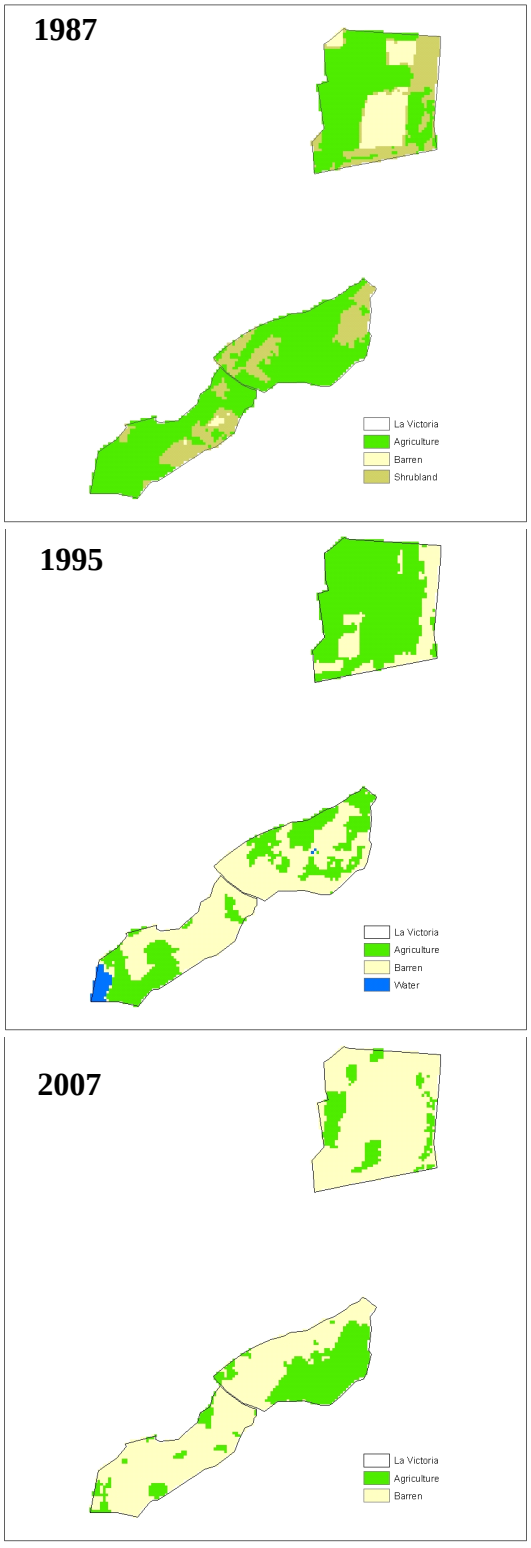

Figure 5. Land use/cover changes in La Victoria

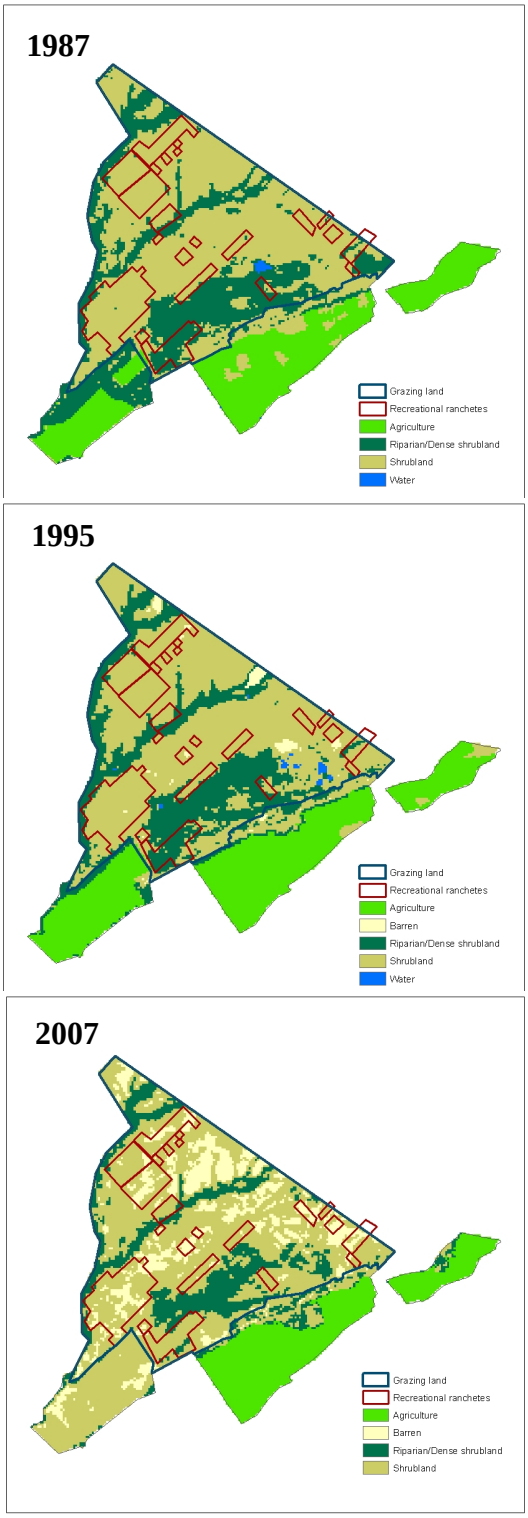

Figure 6. Land use/cover changes in Molino de Camou

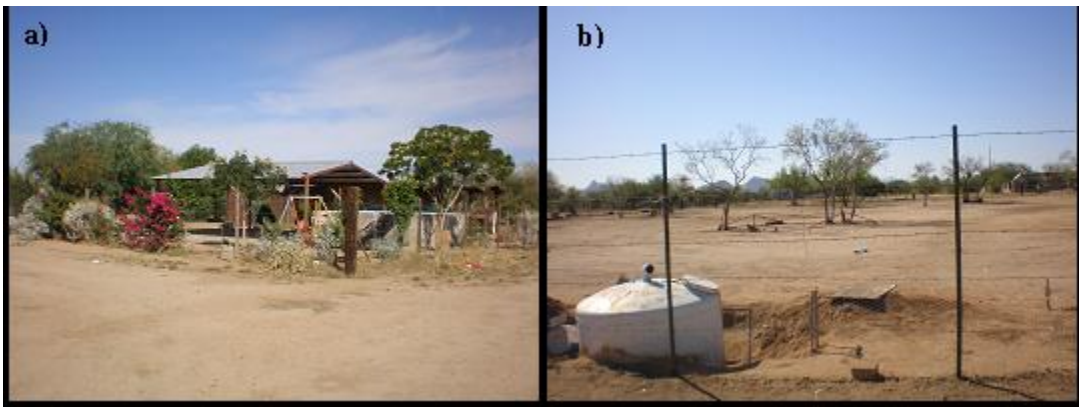

Figure 7. Recreational ranchettes