A Critical Human Ecology of Water Use at the County-Level in Texas, 2002.

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Abstract

The structural factors shaping human society's relationship with water have only begun to be quantitatively explored by environmental sociologists. The current study aims to contribute to this discovery by asking the question: Why did some counties in the American state of Texas consume greater amounts of water than others in the year 2002? To help answer this question, using county-level data from two main sources (the United States Census Bureau and the Texas Water Development Board), agricultural and non-agricultural water use are regressed on a selection of variables informed by the critical human ecology approach. The results of the regression analysis indicate that these two dependent variables are positively related to critical human ecology factors. This analysis supports the argument that the societal-ecological dialectic plays an important role in the maintenance of the hydrologic cycle and freshwater provisioning services for humans, especially in the context of anthropogenic global warming.

Keywords: *water use, Texas, critical human ecology, hydrology*

Introduction

The material and non-material significance of water permeates human history. Fresh and saline waters shape the face of the planet, alter the climate, and sustain biological life (Scientific American 2007), making it possible for human societies to exist, move, change and create culture. For example, the heating of water by coal facilitated the Industrial Revolution, not only transforming human society but also our relationship to fresh and saline water resources, both in terms of the new anthropogenic additions into aquatic environments and the increased rate at which water is withdrawn (e.g., Stauffer 1999). In these ways and more (e.g., the political dimensions of water use, Green 2005; Lonergan 1997; Shiva 2002; Singh 1997), human society plays an important role in the hydrologic cycle.

Empirical tests of environmental sociological theories will help illuminate the ways in which humans actually relate to water. Yet, environmental sociologists have only begun to quantitatively explore the structural factors shaping our connection to water (e.g., Longo and York 2009). Considering our influential position in the hydrologic cycle (Yeston et al. 2006), one key question for sociologists to ask in this exploration would be: Why do some groups of people (i.e., nations, states, counties, municipalities, households, etc.) consume more water than others? The current paper is an attempt to answer this question, within the specific context of the American state of Texas at the county-level for the year 2002. Texas consumed a little over 27 million acre-feet of fresh water in the year 2000 (US Geological Survey 2005), a volume slightly more than the amount consumed by France in the same year or slightly less than 41 African countries, containing a total population about twenty times that of Texas (Pacific Institute 2008). Consumption of such a quantity of water should command the attention of environmental sociologists seeking to better understand the increasingly precarious relationship between modern human society and this finite natural resource (e.g., Barlow and Clarke 2002; Falkenmark and Rockstr^m 2004; Glennon 2002; Opie 2000; Postel 1997; Villiers 2001; Ward 1997).

Additionally, Texas has a number of features which facilitate the testing of environmental sociological theory with inferential statistics. First, there are a total of 254 counties within the state, which increases variation in the dependent variable. For example, in the year 2002, Harris county, which includes the city of Houston, consumed nearly one million acre-feet of water. This was nearly 3800 times the quantity withdrawn by Loving, the county with the smallest population in Texas. Second, Texas has a variety of geological features and ecological regions, allowing researchers to incorporate environmental variables into theoretical models. For instance, the extension of the Ogallala aquifer into the Texas panhandle has facilitated irrigation projects there. The state also has a variety of climate zones, ranging from sub-tropical conditions near the Gulf Coast to the arid regions in the western part of Texas, which includes part of the Chihuahuan

Desert. Therefore, in addition to the varying sociological factors, an analysis of county-level variation in water use in Texas can help to illuminate how this natural resource fits into the societal-environmental dialectic of modern times.

The next section of the paper will elaborate on the modern dialectic between humans and water through the perspective of critical human ecology (York and Mancus 2009). Critical human ecology informs the selection of variables to be tested in the regression analysis. This approach not only appreciates how the natural world shapes human organization, which is a traditional focus of human ecology (Duncan 1961), but also understands that the biophysical world can be dramatically altered by historical changes in human society, which in turn can impose new constraints. Critical human ecology is broadly similar to the coupled human and natural systems approach (Liu et al. 2007). Both see the importance in moving beyond traditional human ecology and building interdisciplinary bridges between the natural and social sciences in order to understand anthropogenic environmental impacts. This interdisciplinary understanding is necessary for creating a more sustainable society. Water is an important case in point. Social forces are undermining the ability of natural cycles to sustain freshwater provisioning services, upon which humans depend for survival (Millennium Ecosystem Assessment 2005). For example, the Ogallala aquifer, commonly referred to as a fossil aquifer because of its formation over geologic time, has naturally supported irrigation in an area that would otherwise not have done so (Glennon 2002; Opie 2000; Villiers 2001), ultimately providing decades of economic development for nonmetropolitan populations (Albrecht and Murdock 1986). However, since the 1950s, with the introduction of improved technology, water has been withdrawn from this aquifer at an unsustainable rate. This trend has substantially lowered the groundwater level of Ogallala in the past half-century (USGS 2007), making it more difficult to access this resource, thereby continuing to threaten the sustainability of the counties located on the aquifer (Albrecht 1988; Nickels and Day 1997). Therefore, with the understanding that modern human society plays an important role in the maintenance of the hydrologic cycle, as seen in the case of the Ogallala aquifer, critical human ecology allows us, in the present study, to theorize the hydrologic and sociological factors associated with county-level water withdrawals.

After the discussion of critical human ecology, the remaining sections will first explain what data and methodology have been used to test theory. Both critical human ecology and the STIRPAT research program (Dietz and Rosa 1994; York et al. 2003) inform the selection of variables, the latter offering two conceptual areas to the model that are nevertheless connected to critical human ecology: population density and affluence.[i] Following the data and methodology section, the results will be reported and then conclusions drawn about how well the results support the theory and what implications these have for our understanding of the modern human relationship to water.

Critical Human Ecology and Water Use in Texas

Human ecologists have focused on how environmental factors influence human sustenance activities and how changes in human organization (e.g., population growth, demographic transition) impact finite natural resources (Buttel and Humphrey 2002: 37-44; Catton 1980; Duncan 1961). Yet, York and Mancus (2009) argue that human ecology has at times been hindered by a tendency to explain the relationship between human society and nature in functionalist, ahistorical terms, a tendency partly attributed to human ecology's connection to Durkheim (e.g., Hawley 1950), who provided a functionalist explanation of population growth and the division of labor. At the same time, Durkheim's legacy had another (if not seemingly contradictory) effect on sociology as a whole, as it prioritized social facts over biophysical ones (Catton 2002).[ii] The critical tradition in environmental sociology has at times challenged the applicability of natural laws to human society, focusing only on how the environment is impacted by humans. For instance, the environmental impact of population growth has been criticized (Mies and Shiva 1993) because of the phenomenon's connection to Malthus, a political economist who advocated conservative social policies, even though this connection is not warranted (Foster 2002). Therefore, critical human ecology is an attempt to synthesize the critical social theory and human ecology traditions. Like the coupled human and natural systems approach (Liu et al. 2007), critical human ecology accepts the biophysical embeddedness of human society. However, unlike the coupled human and natural systems approach, the emphasis from critical human ecology on classical Marxism's historical materialism means that social inequality should play a central role in the way we explain human and natural systems. The emergence of class-based societies has produced significant changes in human history. These changes can bring about radically new relationships between human society and the natural world, at times undermining natural cycles, threatening both humans and the reproducibility of whole ecosystems (Foster 1999 and 2000; Mancus 2007; Moore 2003; Ponting 2007). As argued below, the hydrologic cycle can be theorized in these terms.

Water not only satisfies an immediate biological function but is also used in agriculture (Albrecht and Murdock 2002: 203-210; Singh 1997), electricity generation (Gleick

1994), industrial production, landscaping, recreation and sewage treatment. In Texas, irrigation accounted for about 60% of the total amount of water consumed in 2002 (Texas Water Development Board 2008).[iii] Municipal uses accounted for nearly 25% of the total, which includes "city-owned, districts, water supply corporations, or private utilities supplying residential, commercial (non-goods-producing businesses), and institutional (schools, governmental operations) water" (TWDB 2008). The remaining 15% went to manufacturing, steam electric, mining and livestock purposes. With a little variation in the intervening years, this county-level distribution has remained the same since 1985, with municipal consumption experiencing the greatest growth in total use during this time (See Figure 1). In 1974, the earliest year of readily accessible data on the Texas Water Development Board's website, municipal sources accounted for 11% of the total, with the difference going to irrigation, which at that point was consuming thirteen million acre feet of water annually. Therefore, the drop in total water consumption after 1974 was due to a reduction in use by irrigation. Nevertheless, irrigation still consumed the majority of total county-level water in 2002 at roughly the same volume as it did in 1985.

Both the stable trend in water use and its sectoral distribution at the county-level in Texas point toward three conceptual areas to be explored by critical human ecology in this paper: hydrology, population density and affluence. Water use depends on the natural availability of water, either in the form of surface water, groundwater or precipitation. This is clearly seen in the disproportionate use of water for irrigation in the counties located on the Ogallala. However, municipal consumption in Texas has been and will continue to be a major part of overall water use (Brown 2000). Irrigation may have declined since 1974, but increasing numbers of people will continue to need water for residential, commercial and institutional purposes. This means that municipal consumption at the county-level is likely associated with sociological factors, primarily population density and affluence. Yet, environmental variables must be considered here, too; climate and precipitation, for example, possibly play a role in basic yard maintenance for homes, businesses, schools, and other institutions with landscaping. Through the lens of critical human ecology, the next two sub-sections will describe in greater detail each of the conceptual areas to be tested with regression analysis.

Hydrology

The conceptual area of hydrology focuses on the natural and socially-constructed distribution of water in addition to the various ways humans use these resources. Precipitation and major sources of groundwater are natural, whereas, in

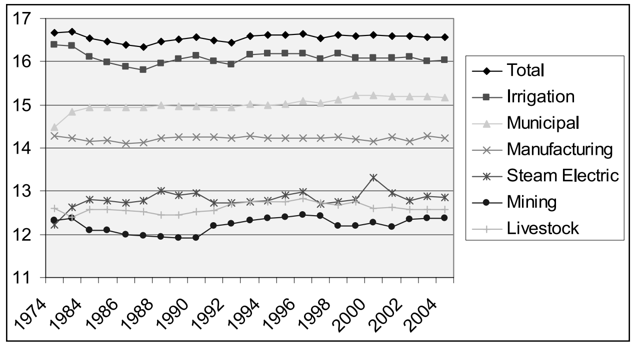

Figure 1. County-level Water Use by Sector, 1974, 1980, 1984-2004 (value on y-axis is natural log of acre feet of water use)

i Unlike STIRPAT, model specification in the current study does not formulate water use as a multiplicative function of population density and affluence per capita. STIPRAT is referenced here because of its emphasis on population pressures and affluence, two factors that, this paper argues, are connected to critical human ecology.

ii The anti-environmental interpretation of Durkheim has recently been reconsidered (Rosa and Richter 2008).

iii The US Geological Survey (2005) online database of water use does not provide county-level data for the state of Texas. The percentages are based on the county-level data made available by the Texas Water Development Board (2008) on their "Historical Water Use Information" website. Furthermore, strategies for and accuracy of data collection on water use varies between states (Water Science and Technology Board 2002), making it important to control for these differences.

iv For instance, even though many people consider Caddo Lake, located on the border with Louisiana, to be the only natural lake among thousands in Texas, its modern form is the result of human intervention in the early 1900s when oil was discovered nearby (Texas Parks and Wildlife Department 2008a).

v Water area as measured by the U.S. Census Bureau includes inland, coastal and territorial waters. This means that twelve counties have very large water area measurements because they are located on the Gulf Coast. However, removing these counties from the regression analysis did not alter the association between water area and water use.

vi The estimation was based on the default robust standard error type used in the statistical software package STATA.

Texas, surface waters have mostly been constructed by humans.[iv] Whether natural or constructed, the availability of surface water is still an important variable to consider when examining variation in water use. With this in mind, three hydrological variables are being examined in this study: the percent of total surface area in a county that is water, total annual precipitation, and a county's location on the Ogallala aquifer.

As mentioned previously, Texas exhibits a range of climate zones, generally becoming more arid as one moves westward into the Chihuahuan Desert, where the city of El Paso is located. This feature makes it possible to test the relationship between precipitation and water use at the county-level. However, precipitation data are not readily available for all 254 counties. The National Climatic Data Center (2008) provides climate information on seventeen Texas cities for the year 2002. Each of these cities falls into one of the nine ecological regions designated by the Texas Parks and Wildlife Department (2008c). For example, El Paso received almost seven inches of rain in 2002, so this value was assigned to the other westernmost counties located in the Chihuahuan Desert and Mexican Mountains in Texas ecological region. At the other extreme, Beaumont, located in the Coastal Prairies ecological region along the northern part of the Gulf Coast received about sixty-five inches in 2002. However, when there was more than one measure for a single ecological region, the counties closest to the location where the measurement was taken were given that city's precipitation value. From a human ecology perspective, controlling for the availability of surface water and groundwater, county-level water use is expected to be negatively related to precipitation, a relationship established in a previous study of a Canadian city (Cohen 1985). Counties near the Gulf Coast that receive more precipitation will require less water to be withdrawn for irrigation and municipal purposes (e.g., landscape maintenance), whereas counties further west will use more water to sustain these activities because there is less precipitation.

Surface water largely is used for municipal purposes. Just over 42% of all the surface water consumed by Texas' counties in 2002 was used for residential, commercial and institutional purposes. Only about 28% of surface water went to irrigation, whereas nearly 61% of *total* water consumption was for irrigation in 2002. Based on human ecology, the availability of surface water should open up more opportunities for water consumption. This variable will be measured as the percent of a county's total surface area that is covered by water. While water surface area certainly depends on precipitation, this measure is taken from United States Census and represents a relatively fixed, or longer-term, aspect of water availability in a county. As the relative water area increases across counties, water consumption should also increase.[v] It is important to point out that surface water tends to need at least some treatment. Nevertheless, given the wide diffusion of water treatment technologies in the modern hydraulic society (Worster 1992), having relatively nearby access to, for example, rivers, lakes and reservoirs should simply facilitate water consumption, mostly by the municipal sector.

Irrigation clearly plays an important role in overall water use, even though its consumption has been reduced by nearly 30% since 1974. The forty-six counties located on at least a part of the Ogallala aquifer represent only 17% of the total land area of all Texas counties combined but accounted for roughly 70% of all the irrigated land in 2002. Moreover, these counties represented also about 70% of the total reduction in acres of irrigated land between 1974 and 2002. The reduction in acres of irrigated land likely explains the decrease in overall water use during this time. Therefore, the natural availability of water, supplied by the Ogallala aquifer, made possible irrigation on an increasingly larger scale. This changed in 1974 when groundwater levels declined to a point that increasing withdrawals was difficult. Despite the tremendous reduction in irrigation by the counties located on this fossil aquifer since 1974, groundwater continues to be withdrawn and water levels continue to fall. Based on an analysis of 2019 wells between the years 1990 and 2000, the median water level of Ogallala declined 5.7 feet (Boghici 2008).

Location on the Ogallala seems to influence water consumption. Only 5% of Texas' population, residing in 18% of its counties, consumed slightly more than 44% of all the water in 2002. A dummy-variable will be included in the regression model to test whether or not location on this aquifer is associated with water use. Controlling for the total acres of irrigated land, having access to this source of groundwater is expected to be associated with more water consumption at the county-level. A critical human ecology perspective recognizes that the simple availability of water can influence resources use. Yet, there are also historical forces that drive this consumption. Changes in human society can rapidly alter what appear to be relatively permanent features of nature within a human time frame. This is the case with the Ogallala, a resource exploited for more than a century by European settlers (Opie 2000). However, since the 1950s, discharge of groundwater from the Ogallala has been exceeding its recharge, which means that this aquifer, formed millions of years ago, is being depleted.

Population Density and Affluence

The STIRPAT research program (Dietz and Rosa 1994; York et al. 2003) stands for stochastic impacts by regression on population, affluence and technology. It provides two conceptual areas that are consistent with critical human ecology theory. Practitioners of this research program argue that both population and affluence are important basic drivers of anthropogenic environmental impact. Previous research at the national level has operationalized these concepts as population size, or density, and gross domestic product per capita (e.g., Longo and York 2009; York et al. 2003). Based on this argument, the present study will examine the association between water use and three operationalizations of population and affluence: population density, percent of the population living in urban areas and earnings per capita at the county-level. With respect to population, instead of two measures (i.e., one for population size and one for land area), the impact of a single variable for population density is being tested.

Large scale irrigation becomes difficult in densely populated areas because of the competing land requirements for increased residential, commercial and institutional development. Even though irrigation demands so much water, the top ten most densely populated counties in Texas consumed nearly 20% of the total water in 2002. Of these, only El Paso was among the top fifty in terms of acres of irrigated land. Of the forty-six counties located on the Ogallala aquifer, only five were among the fifty most densely populated counties in Texas: Ector, Lubbock, Midland, Potter and Randall. Therefore, water use seems to depend as much on irrigation as on population density.

From a critical human ecology perspective, there are two main reasons to expect a positive association between population density and the dependent variable. First, basic human ecology theory says that more people on the same area of land simply results in more resource usage. Second, however, *critical* human ecology also looks at the structural and qualitative dimensions of increased population density. This is where the urbanization variable comes into the theory. Water use does not simply rise incrementally with greater numbers of people. The relationship between the hydrologic cycle and densely populated, urban areas is structurally different than it is in small towns and rural areas. For most of the underdeveloped world, urbanization makes it difficult to provide water to people (Falkenmark and Lindh 1993; Swyngedouw 2004). However, despite the arid climate of a large portion of counties in Texas, and the western United States in general, the modern hydraulic society (Worster 1992) has made water widely accessible. Thus, from a critical human ecology perspective, increased population density and urbanization in the United States (and other western nations) create the opposite problem with respect to the modern dialectic between humans and the hydrologic cycle: over-consumption of water (Kaika 2005).

While densely populated urban areas are also responsible for water pollution (Foster 1999; Smith 1996), this study hypothesizes that greater population density creates new demands for water consumption. Controlling for other factors, rising population density and greater urbanization across counties means more water consumption. Again, urbanization captures the qualitative dimension of increasing population density. Rural areas and smaller towns, of course, have smaller populations, but there is also less water use because of structural differences. Despite the relatively wide access to water in the United States, densely populated areas are still more likely to have the infrastructure that facilitates greater water use. Furthermore, controlling for affluence, the increased economic activity of urban areas should also encourage more water consumption. Yet, affluence and water use are also expected to be positively correlated. Affluence in this study will be measured as earnings per capita at the county-level. Controlling for population density and percent of the population living in urban areas, more affluent counties will have a greater ability to consume water.

The water needs of people living in wealthy countries are being met, but the future availability of water for all urban residents is not secure (Kaika 2005). This is an issue that is commanding the attention of western policymakers (e.g., European Union 2008). Therefore, the modern dialectic between the hydrologic cycle and population density and urbanization can be explained by critical human ecology theory. The nature of the hydrologic cycle necessitates large-scale modern infrastructure to deliver water to dense, urban populations. However, with respect to increasing population density, the current infrastructure is limited in its capacity and confronts major obstacles as urban populations continue to grow and median groundwater levels in major aquifers throughout the state of Texas show little to no improvement, with an overall slight decline (Boghici 2008).

Data and Methodology

Two main sources provided the data for the study: the U.S. Census Bureau's USA Counties and the Texas Water Development Board (2008). The Texas Water Development Board administers an annual survey to municipal and industrial entities to collect data on the volume of surface and ground water used. Precipitation data come from the National Climatic Data Center (2008). Most of the data are for the year 2002. This year was chosen because it is the most recent year for which the U.S. Census Bureau's USA Counties provides acres of irrigated land, a major part of total water use. Relative water area and percent of the population living in urban areas are from 2000 because they are recorded during the decennial census. The variable names, descriptions and sources are in Table 1. All variables have been transformed into their natural logarithms with the exception of a county's location on the Ogallala aquifer, which is a dummy variable. This makes interpretation of slope estimates straightforward, as the slope indicates the percent change in the dependent variable for every 1% change in the independent variable, controlling for all the factors in the equation.

Past applications of STIRPAT have regressed environmental impacts on different social and ecological variables (Dietz et al. 2007). In this study, the environmental impact measure is divided into two dependent variables: 1) agricultural water use and 2) non-agricultural water use, the last subtracts irrigation and livestock from the total. Based on critical human ecology theory, agricultural water use (largely for irrigation) is regressed on three environmental variables water area, location on the Ogallala aquifer, and total annual precipitation) and six sociological variables (acres of irrigated land, population density, population density squared, earnings per capita, earnings per capita squared, and percent of the population living in urban areas). The squared measures test for the presence of an environmental Kuznets curve (Nordström and Vaughan 1999: 48) in the relationship between water use and population density and affluence. Non-agricultural water use is regressed on all the above social and environmental variables with exception of acres of irrigated land because this dependent variable includes water used for municipal, manufacturing, steam electric, and mining pur-

Table 1. Variable names, descriptions and sources (All variables have been transformed into their natural logarithms)

Variable	Description	Source
Agricultural water use	Acre feet of water used by irrigation and livestock, 2002	Texas Water Development Board (2008)
Non-agricultural water use	Acre feet of water used by municipal, manufacturing, steam electric, and mining, 2002	Texas Water Development Board (2008)
Water area	Percent of total surface area that is water, 2000	U.S. Census Burea's USA Counties
Ogallala aquifer	Location on the Ogallala aquifer, 1=Yes, 0=No	Texas Water Development Board (2005)
Irrigated land	Total acres of irrigated land, 2002	U.S. Census Burea's USA Counties
Precipitation	Total annual precipitation, 2002	The National Climatic Data Center (2008)
Population density	Total resident population in 2002 divided by square miles of land area in 2000	U.S. Census Burea's USA Counties
Population density squared	Population density centered with mean then squared	U.S. Census Burea's USA Counties
Earnings per capita	Earnings per capita, 2002	U.S. Census Burea's USA Counties
Earnings per capita squared	Earnings per capita centered with mean then squared	U.S. Census Burea's USA Counties
Urban population	Total population living in urban areas, 2000	U.S. Census Burea's USA Counties

Table 2. Descriptive Statistics

Variable	Mean	SD	N	1. Ag Water	2. Non-Ag Water	3. Water Area	4. Aquifer
1. Agricultural water use	8.713	1.913	254	1.000			
2. Non-agricultural water use	8.503	1.69	254	0.004	1.000		
3. Water area	0.752	0.858	254	-0.262	0.434	1.000	
4. Ogallala aquifer	0.181	0.386	254	0.557	-0.207	-0.339	1.000
5. Irrigated land	8.224	1.892	244	0.921	-0.03	-0.329	0.565
6. Precipitation	3.361	0.582	254	-0.38	0.38	0.511	-0.470
7. Population density	2.994	1.715	254	-0.119	0.866	0.511	-0.272
8. Population density squared	8.490	1.659	254	0.208	0.157	-0.057	0.050
9. Earnings per capita	9.461	0.399	254	0.267	0.463	0.033	0.276
10. Earnings per capita squared	15.910	2.086	254	0.015	0.013	0.041	0.131
11. Urban population	3.055	1.722	254	0.15	0.616	0.176	-0.097

Table 2. Descriptive Statistics (continued)

Variable	5. Irrigate	6. Precip.	7. Density	8. Density Sq	9. Earnings	10. Earnings Sq	11. Urban
1. Agricultural water use							
2. Non-agricultural water use							
3. Water area							
4. Ogallala aquifer							
5. Irrigated land	1.000						
6. Precipitation	-0.358	1.000					
7. Population density	-0.132	0.567	1.000				
8. Population density squared	0.161	-0.134	0.118	1.000			
9. Earnings per capita	0.229	-0.051	0.319	0.280	1.000		
10. Earnings per capita squared	0.017	-0.055	0.064	0.181	0.030	1.000	
11. Urban population	0.138	0.152	0.574	-0.018	0.314	-0.120	1.000

Table 3. Regression Estimates Using Robust Standard Errors

	Agricultural Water Use				Non-Agricultural Water Use	
	Model 1		Model 2		Model 3	
Variable	**b**	**SE**	**B**	**SE**	**b**	**SE**
Water area	0.207**	0.074	0.183*	0.073	0.064	0.080
Ogallala aquifer	0.227	0.152	0.302*	0.14	-0.253	0.139
Irrigated land	0.877***	0.037	0.879***	0.037		
Precipitation	-0.22	0.126			-0.326**	0.102
Population density	-0.046	0.05	-0.093	0.048	0.785***	0.042
Population density squared	0.069*	0.032	0.08*	0.031	0.016	0.032
Earnings per capita	0.149	0.132	0.169	0.133	0.673***	0.123
Earnings per capita squared	-0.016 -0.021	0.021 0.024	-0.012	0.021		
Urban population	0.045	0.04	0.062	0.041	0.122***	0.032
Constant	0.396	1.318	-0.611	1.278	0.708	1.176
R^2		0.863		0.861		0.821

*p<0.05; **p<0.01; ***p<0.001

poses. Finally, acres of irrigated land were not provided for ten counties in 2002, making the sample size for the first dependent variable n=244 and the sample size for the second dependent variable n=254.

Initially, two models were estimated to examine the associations between the independent variables and total and non-irrigation water use. Nevertheless, considering that precipitation was highly correlated with three independent variables (water area, location on the aquifer and population density), a second model was estimated for total water use without precipitation in the equation. To determine the extent to which this collinearity increases the standard errors of the slope estimates, the variance inflation factors (VIFs) are also examined. For all three models, the results from the Breusch-Pagan / Cook-Weisberg test for heteroskedasticity indicated that the residuals were not normally distributed. Therefore, the slopes were estimated using robust standard errors.[vi]

Results and Discussion

The means, standard deviations and bi-variate correlations for all variables are reported in Table 2. There is a high degree of correlation between several independent variables: acres of irrigated land and location on the Ogallala aquifer (r=0.565), relative water area and precipitation (r=0.511), location on the Ogallala and precipitation (r=-0.47), population density and water area (r=0.511), population density and precipitation (r=0.567), and population density and percent living in urban areas (r=0.574). While VIFs should only be rules of thumb for determining the accuracy of slope estimates (O'Brien 2007), most are not above the levels normally accepted in the social sciences (DeMaris 2004). The highest VIF was 3.07.

In Model 1, agricultural water use was regressed on all three environmental variables and six sociological variables. Only water area, acres of irrigated land and population density squared were significantly related to the dependent variable in the positive direction. However, after removing precipitation from the equation in Model 2, the aquifer dummy-variable (b=0.301, p<0.05) became significantly related to water use. This means that in 2002 a county's location on the Ogallala was equivalent to a 0.301 increase in the natural log of acre feet of agricultural water consumption, controlling for the other factors in the equation. Both models do a fairly good job of explaining variation in the dependent variable (Model 1: R^2=0.863; Model 2: Adjusted R^2=0.861). According to Model 1, all significant associations were in the hypothesized direction. For every 1% increase in relative water area and acres of irrigated land agricultural water use across counties increases, respectively, by 0.207% (p<0.01) and 0.877% (p<0.001).

When water used for irrigation and livestock are subtracted from the dependent variable in Model 3, different associations emerged, still explaining a considerable portion of the variance in the dependent variable (R^2=0.821). Only one of the environmental factors was significantly related to non-irrigation water use: precipitation (b= -0.326, p<0.01). Controlling for population density (b=0 .785, p<0.001) and affluence (b=0.673, p<0.001), both of which had positive effects on the dependent variable in Model 3, the percent of the population living in urban areas was a significant, positive regressor of non-agricultural water consumption (b=0.121, p<0.001). These finding suggests that the basic STIRPAT offers a robust conceptual framework for understanding a variety of environmental impacts. In this case, precipitation, modern population pressures (i.e., population density and urbanization) and affluence account for most of the cross-sectional variation in water used for municipal, manufacturing, steam electric, and mining purposes (of which the municipal and manufacturing sectors accounted for about 86% of the total).

Conclusion

Based on the results from the regression analyses, critical human ecology theory helps explain why there is variation in the amount of water consumed by Texas counties in 2002. In terms of surface water and groundwater, the natural and socially constructed availability of this resource allows for more water use. Increasing precipitation, meanwhile, is associated with less county-level water consumption. These findings support the human ecology claim that the natural environment conditions human sustenance activities. However, an important clarification is necessary here. As previously mentioned, surface water area in Texas is largely socially constructed. Yet, even the largely socially-constructed surface water area was strongly related to total annual precipitation (r=0.511). Wetter parts of Texas seem to have more water surface area. Therefore, variation in county-level water use ultimately depends on its natural availability. Still, critical human ecology understands that modern society can have a negative impact on the natural availability of water. Such is the case with irrigation on the Ogallala aquifer. In 2002, location on the aquifer meant increased use of water for irrigation, despite the fact that groundwater levels continued to decline between 1990 and 2000 (Boghici 2008). Even though irrigation in Texas is projected to consume less water in the future (Brown 2000), it will still constitute the biggest portion of overall water use.

The slope estimates from Model 3 surprisingly showed that, when controlling for population pressures and affluence, of the environmental factors, only precipitation is related to county-level variation in non-agricultural water use. Of course, water needs to be made available to the sectors that comprise non-irrigation use, most of which is consumed by the municipal and manufacturing sectors. Nevertheless, the variation in consumption across counties was not explained by surface or groundwater availability but by population density, urbanization, affluence and precipitation. Urbanization captures a more qualitative dimension of increasing population density in modern society. While this phenomenon impedes access to water in the underdeveloped world (Falkenmark and Lindh 1993; Swyngedouw 2004), in Texas it is associated with more water use. It is important to note that modern industrial agriculture, which is dependent on large scale irrigation, has become an essential component of a mostly urban society that is geographically separated from food and fiber production (Foster 1999 and 2000). Therefore, while two environmental factors did not have a direct relationship to non-agricultural water use at the county-level in Texas, densely populated areas are not free from the conditions imposed on human sustenance by nature. This analysis confirms previous research highlighting how cities appropriate ecosystem services (e.g., Folke et al. 1997; Grimm et al. 2008).

In conclusion, modern human society is currently having a major impact on the global hydrologic cycle, in different ways, both directly and indirectly (e.g., Bradshaw et al. 2007). Anthropogenic global warming is melting ice-caps (NASA Earth Observatory 2003) and increasing the heat content of the oceans, both of which are raising sea levels (Pfeffer et al. 2008). Furthermore, global warming might be expected to reduce precipitation in the Midwest United States, potentially reducing the natural availability of water in this region (North et al. 1995). This would mean that the natural recharge of the Ogallala aquifer might possibly be reduced (Rosenberg et al. 1999). The Intergovernmental Panel on Climate Change has included some this research in their most recent assessment, suggesting that global warming poses a specific threat to the Ogallala region. With warming of at least 2.5˚C, the natural recharge of the aquifer is projected to decrease by 20% (Field et al. 2007). This phenomenon, in combination with already declining groundwater levels in the Ogallala, and other major aquifers throughout the state, as a result of industrial agriculture, could portend a major transformation in the human relation to water in Texas. Based on the results from this study, even though total water use in Texas has declined from its peak in 1974, the state still consumes vast amounts of water, the drivers of which seem to be the social forces of population density, urbanization and affluence as well as availability of precipitation, surface water and groundwater.

With respect to this study, critical human ecology (York and Mancus 2009) highlights both the interdependent relationship between social forces, the environment and water use, and, in current times, the precarious dialectic between social forces, the hydrologic cycle and human dependence on freshwater provisioning services. This theoretical framework, like the coupled human and natural systems approach, understands not only that humans depend on the natural world for sustenance but also that a sustainable relationship with nature is not guaranteed, which means that even the existence of whole societies can be threatened (e.g., Haug et al. 2003). But, unlike the coupled human and natural systems approach, critical human ecology emphasizes that only historical transformations of a social system *as a whole* can move humans into or out of a sustainable relationship with nature. Considering the projected negative impacts of global warming, especially on freshwater resources (Kundzewicz et al. 2007), such a transformation increasingly seems to be the only option that human society has to ensure its long-term survival (Foster 2009).

Endnote

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