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The impact of global climate change on water quantity and quality: A system dynamics approach to the US–Mexican transborder region

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ABSTRACT

The potential impacts of Global Climate Change (GCC) in zones where water is scarce, such as along the US–Mexico border is, and will continue to be, a key concern for the future sustainability of humanity. This paper estimates the variation in quality/quantity water due to climate change and assesses its impact on community development in the US–Mexico border region of the Rio Grande/Rio Bravo Water Basin. To estimate variation in different water quality parameters, we use a conservative model with most probable scenarios for temperature/precipitation produced by the International Panel on Climate Change. We propose a system dynamics model to understand the complex interaction of factors governing the quantity/quality of water and their effects on social and economic conditions. The model simulates, for a 70-year period, policies and decisions that have the potential to improve conditions and prevent risks that may lead to social unrest and hinder economic development.

1. Introduction

The availability of water resources is linked to the well-being of human societies that need it for industrial activities, agriculture, drinking, hygiene and recreation. Changes in the availability of water through precipitation, droughts and depletion of aquifer volumes, have significant consequences for the development of local villages and urban communities. Thus, availability and quality of water are critical risk assessment parameters, including forecasts associated with global climate change (GCC). The International Panel on Climate Change (Bates, Kundzewicz, Wu, & Palutikof, 2008), predicts a 1–5 degree centigrade temperature increase over 20–80 years in arid regions along the US–Mexico border. While water precipitation is predicted to decrease by 5–20 percent, there remains uncertainty about the trend in summer rainfall. These undetermined conditions, along with well-known influences of population growth, urbanization, land use changes, institutional robustness and resilience of water availability, make planning for changes in the availability of water resources and the depletion or recharging of aquifers particularly difficult.

The consequences of climate change are two-fold – water availability and water quality. Increases in the demand in regions of scarcity can force the use of poor or unsuitable water with drastic repercussions for industry, human health and the associated costs of health care. Established influences on water quality include population growth, urbanization and land use changes (Hunter, 2003), though the impact of global climate change remains unknown. If climate change leads to decreases in rainfall, water quantity and quality will worsen as populations increase and sanitation pollutants behave differently as a result of changes in environmental parameters. In the arid regions of the US–Mexico border, the estimation of the effects of climate change on water quality and the repercussions for this region is a critical issue for this key Latin America border crossing for trade with America, which needs to be addressed and planned for prior to problems arising. This paper models the potential impacts of global climate change on the water availability and quality in two locations along the US–Mexico border: Reynosa/McAllen and Laredo/Nuevo Laredo, and explores the consequences for community development and sustainability.

The paper is organized as follows: in the next section, we formulate the problem to be modeled by describing the socioeconomic conditions of the two sites researched, Nuevo Laredo and Reynosa, that lead to the proposed modeling approach for this study. In Section 3, we assess the complex interaction of factors governing the quantity and quality of water and their effects on social and economic conditions. For this purpose, we develop a system dynamics (SD) model to simulate, for an extended period

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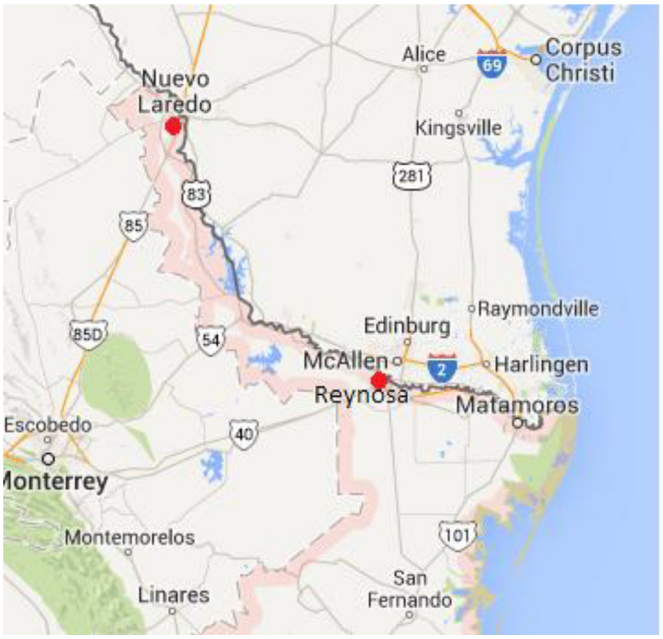

Fig. 1. Location of Nuevo Laredo and Reynosa along the US–Mexico border.

(2010–2080), the development of the main variables related to water quantity and quality. In Section 4, we examine some scenarios as a result of some changes in the level of greenhouse gas (GHG) and other control variables that represent the policies and decisions that, if implemented, would improve conditions and prevent risks that can lead to social unrest and hinder economic development. In the final section, some conclusions and further points for research to help social and economic policy-making are made.

2. Overview of the study area: formulating the problem and the modeling approach

This section details the demographic, social and economic environment of the research sites in this study. Nuevo Laredo is a border city in the Mexican state of Tamaulipas, close to El Paso, in the US and is the most important freight crossing point between Mexico and the US. Reynosa is the largest city in the state of Tamaulipas and is located across the Rio Grande (Río Bravo) from McAllen in Hidalgo County in the US state of Texas (Fig. 1).

2.1. Demographics

Nuevo Laredo covers an area of 1334.02 square kilometer (515 square miles) with a population of 395,185 in 2010. The population compound annual growth rate (CAGR) is expected to decrease from 2.12 percent in 2005–2010 to 1.16 percent in 2025–2030 (Consejo Nacional de Población (CONAPO), 2010) and this population growth is almost 80 percent larger than that for the state of Tamaulipas. This means that by 2030 Nuevo Laredo population will represent 14 percent of the whole Tamaulipas population while in 2010 it was 12.2 percent. The Reynosa metropolitan zone covers an area of 3156.34 square kilometer (1217 square miles) and includes two municipalities: Río Bravo and Reynosa itself. Altogether, Reynosa has a population of 720,125 in 2010. The population CAGR is expected to reduce from 2.76 percent in 2005–2010 to 1.39 percent in 2025–2030 (Consejo Nacional de Población (CONAPO), 2010). However, this population growth is almost 120 percent larger than that for the state of Tamaulipas, which means that by 2030 the Reynosa population will be 27.1 percent of Tamaulipas population while in 2010 it was 22.3 percent. In sum, projections show that the populations in both urban areas will continue growing and concentrate a larger proportion of people of the state of Tamaulipas.

2.2. Social

We used education, health, and housing as key indicators of social profiles (Instituto Nacional de Estadística Geografía e Información, 2009; Instituto Nacional de Estadística Geografía e Información, 2010). A comparison of the main social indicators between Nuevo Laredo and Reynosa together with the state of Tamaulipas is shown in Table 1.

To summarize these social data, both urban areas present deficiency in terms of education levels, health services, and housing conditions, as compared to the state of Tamaulipas. Even so, they show better state provision of utilities (water supply and drainage) when compared with all of Mexico, some lagging conditions are notable.

2.3. Economics

Both locations are characterized by large manufacturing and retail sectors, Nuevo Laredo also has a high transport service profile and Reynosa is home to the Petroleos Mexicanos (Pemex) oil refinery.

The economic structure of Nuevo Laredo has a high proportion of manufacturing which comprises 28.3 percent of the labor force or ~22,000 workers (Instituto Nacional de Estadística Geografía e Información, 2009). Other important sectors in the city include transportation, warehousing, and retailing. In the manufacturing sector, the most important subsectors are concentrated mainly in transportation equipment and electrical devices. Reynosa's economic structure has a higher percentage of manufacturing comprising 52.3 percent of the labor force or ~110,000 workers (Instituto Nacional de Estadística Geografía e Información, 2009). Other important sectors in the city include retailing, and in particular the mining industry which is represented by the oil and petroleum industry, including a Petroleos Mexicanos (Pemex) refinery, with 4641 workers. The manufacturing sector in Reynosa concentrates mainly on the electronic equipment, electrical devices, metal products, and equipment and machinery, with 42,232, 11,869, 7719 and 5290 workers, respectively.

2.4. Modeling approach

Nuevo Laredo and Reynosa are located in the VI Administrative Hydrological Region (RHA) Rio Bravo that covers 379,552 square kilometer and has a population of 10,982,077 inhabitants and 12,163 cubic hectometer [1] of renewable water in 2009. According to recent data in this region, water supply declined from 14,267 cubic hectometer in 2001 to 12,163 cubic hectometer, and water demand increased from 7071 cubic hectometer to 9243 cubic hectometer in the same period (CNA National Water Commission Mexico 2011). This has caused renewable water per capita per year in the region to decline between 2001 and 2009, from 1467 cubic meter to 1108 cubic meter. This fact reveals a high "*water stress*", which is a parameter that, according to worldwide standards, should not fall below of 1700 cubic meter (Gleick, 2002). Likewise, the Mexican Water National Commission (CNA) also reports a very high pressure from water consumption, measured by the percentage of water allocated to consumptive uses (household, industry, agriculture, and thermoelectricity generation) of the yearly water renewable supply. This has varied from 49.6 percent

[1] Cubic hectometer is a common aggregate measure of water supply and demand that equal 1E + 9 liters.

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