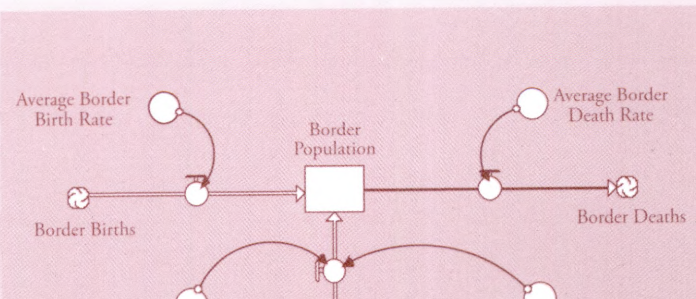
THE U.S.-MEXICAN border environment: Dynamics of Human-Environment Interactions



Edited by
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SCERP Monograph Series, no. 11
Southwest Consortium for Environmental Research and Policy

SCERP Monograph Series, no. 11

A series edited by Paul Ganster

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The Southwest Consortium for Environmental Research and Policy (SCERP) is a collaboration of U.S. and Mexican universities dedicated to addressing environmental issues of the U.S.-Mexican border region through applied research, outreach, and regional capacity building.

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The U.S.-Mexican Border Environment

Dynamics of Human-Environment Interactions

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San Diego State University Press

Published by
San Diego State University Press
5500 Campanile Drive
San Diego, CA 92182-8141
http://sdsupress.sdsu.edu

Cover photos by B+20 Project Team and Erik Lee

Printed in the United States of America

ISBN 0-925613-46-0

Previously published volumes in the SCERP Monograph Series,
The U.S.-Mexican Border Environment

No. 1 A Road Map to a Sustainable 2020
No. 2 Water Issues along the U.S.-Mexican Border
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All times are local
All monetary figures are US$ unless otherwise specified

The views of the authors contained herein are not necessarily the views of SCERP, the U.S. Environmental Protection Agency, or the Secretaría de Medio Ambiente y Recursos Naturales. They are presented in the interest of providing a wide range of policy recommendations to prompt discussion and action in the U.S.-Mexican border region.

Contents

Preface

H. L. Mencken once said that "for every complex problem, there is a solution that is simple, neat, and *wrong.*" In other words, just because a solution is simple does not mean it is a good solution, or the most appropriate, or the most long-lasting. When addressing problems in a binational or transboundary context, the complexity of two legal systems, two cultures, two languages, and economic asymmetry translates into multifaceted problems that cannot be resolved simply. In the U.S.-Mexican border region, solutions that can be perceived as simple and affordable can still be the wrong policy choices. Here, no good solution is simple.

The question, then, is how to find the good, and even optimal, solutions when addressing transboundary challenges. How can decision-makers best understand relationships and connections among seemingly disconnected concepts and players? How can policymakers and resource managers avoid making decisions that exacerbate other current or emerging problems in the U.S.-Mexican border region? Instead, how can they best be informed to make decisions that address the challenges of water scarcity in an arid environment, health in impoverished communities, protection for nature in an expanding urban setting, and air pollution from multiple sources—all in ways that do not have harmful repercussions for future generations? In sum, the issue is how to access and interpret information in a manner that promotes the best policy decisions—those that benefit the maximum number of people in the most ways for the longest time.

To avoid oversimplifying responses to challenges in the U.S.-Mexican border region, a focus on interrelationships among issues, or a systems approach, is necessary. The challenges of extraordinarily fast growth, persistent economic asymmetry, looming droughts and water shortages, the push for industrialization, and a growing middle class in the U.S.-Mexican border region all have direct impacts on economic and environmental policy. Academia is still the best group to develop solutions to those issues because of its ability to conduct unbiased and comprehensive long-term planning and truly regional thinking. Recent trends toward "sustainability science"—defined as interdisciplinary research across different scales, media (such as water, air, or soils), and a wide range of academic disciplines—afford an emerging class of natural/physical and social scientists the opportunity to deal with many difficult problems at the same time. Academia is now able to map concepts and their connections, and in the process develop a representative model that assesses the multiple impacts of one action or decision. For example, energy exploration and development has air quality, water supply, economic prosperity, community vitality, and other foreseen and unintended consequences that are not fully understood individually or collectively.

Since the early 1990s, the faculty of the universities that make up the Southwest Consortium for Environmental Research and Policy (SCERP) have set an example for binational research and policy development. Based upon that expertise and success, SCERP was challenged to answer the following seemingly simple, but actually very complex, question: What will the border look like in 20 years? The decision was made that the maximum value would be realized by all the constituencies in the region by taking the unique approach of developing a relational, or "system dynamics," model. This would allow researchers to inquire of and educate the international, national, and local decision-making and policymaking processes about direct and indirect, diffused and disparate, and immediate and delayed consequences of apparently unrelated decisions.

The model, called Border Plus Twenty Years, or Frontera Más Veinte Años (B+20/F+20), consists of a binational team of researchers from various academic disciplines. They work with a software program that outputs a series of graphs and charts based on information entered into the program and questions then asked of it. The model, which is flexible, relates many parts of an entire problem—the elements of which were identified and further defined in meetings with local decision-makers who explained their concerns and outlined their questions—and presents a series of scenarios about how the future might look in the U.S.-Mexican border region.

B+20 projects human impacts on the border environment for the next 20 years. In particular, the maps and charts used to present these scenarios are especially useful in analyzing information about border areas because they span languages, laws, and cultures and can help develop real understandings of relationships among the factors that create the scenarios. The binational model appeals and adds to the process of making decisions in both the United States and Mexico. The model helps optimize the investment of scarce resources by showing the effects of local efforts across the border, as well as the complementary effects of actions taken in unison.

B+20 has been invaluable to a handful of multinational agencies that exist to overcome binational challenges. For example, in the absence of a strategic plan for the border region by any binational organization, and following years of marginalization by national agencies, B+20 is able to inform the Border Environment Cooperation Commission (BECC), International Boundary and Water Commission (IBWC), and local agencies such as the Salton Sea Authority about ways to:

- Avoid unintended and some unforeseen consequences
- Become aware of and avert severe human health risks
- Assess transboundary effects so joint attention can forestall crisis

The model is further used to show the special case of the political boundary between a developed country and developing country, as well as the special role of the border as the place where the North American Free Trade Agreement (NAFTA) makes the most difference. Exploring and explaining the value of the border to both nations motivates funding as well as priorities. In practice, the model has been useful in informing one agency about the issues and trade-offs involved at others. For example, it tells water agencies what energy or air quality agencies are thinking about, and vice versa.

The program started as a highly ambitious and potentially risky endeavor. But so far, SCERP and the modelers have been able to avoid potentially fatal flaws that have plagued other modeling efforts and binational collaborations. B+20 has been successful because it:

- Chose a robust software platform that can be used to communicate directly with the public, show decision-makers the effects of their policies, and educate a wide range of U.S. and Mexican students (because the project team published a system dynamics manual in Spanish)
- Maintained a flexible process that accommodated the necessary planned, and also the unanticipated, changes in the make-up of the modeling team
- Started and remained bilateral and regional in concern
- Avoided the narrowness and dogma associated with each individual academic discipline and media
- Committed to and ensured relevant final products and tangible outcomes early in the process

The chapters in this volume of the SCERP Monograph Series, *The U.S.-Mexican Border Environment,* reflect the studies and analyses conducted as part of the B+20 modeling process. An Afterword is included that addresses some of the process issues raised herein. The overall content can be used to better understand the systems model the project team built and inform decision-makers of the factors that must be considered when developing solutions to complex problems in the U.S.-Mexican and other border regions.

D. Rick Van Schoik
Managing Director, SCERP
San Diego, California
August 2004

Prefacio

H. L. Mencken comentó en una ocasión "para cada problema complejo, hay una solución que es simple y equivocada". En otras palabras, solo porque una solución es simple no significa que es una buena solución, o la más apropiada, o la más duradera. Cuando se abordan los problemas en un contexto binacional o transfronterizo, la complejidad de dos sistemas legales, dos culturas, dos idiomas, y asimetrías económicas, se traducen en problemas multifacéticos que no pueden ser resueltos a través de la simplicidad. En la región fronteriza México-Estados Unidos, las soluciones que pueden ser percibidas como simples y accesibles pueden ser selecciones de dos políticas equivocadas. Aquí, ninguna solución buena es simple.

La pregunta entonces es, cómo encontrar soluciones buenas y óptimas al abordar retos transfronterizos? Cómo pueden los tomadores de decisiones entender mejor las relaciones y nexos entre conceptos y participantes aparentemente desconectados? Cómo pueden los responsables de elaborar políticas y administradores de recursos evadir la toma de decisiones que agravan otros problemas presentes o en surgimiento en la región fronteriza México-Estados Unidos? A cambio, cómo pueden estar mejor informados para tomar decisiones que aborden los cambios de la escasez del agua en un medio ambiente árido la salud en las comunidades pobres, la protección de la naturaleza en la invasión de un escenario urbano, y la contaminación del aire por múltiples fuentes—todo en maneras que tienen repercusiones dañinas para futuras generaciones? En resumen, el tema es cómo conseguir acceso y cómo interpretar información de una manera que promueva las mejores decisiones de política-aquellas que benefician el número máximo de personas en diversas formas y por el mayor tiempo.

Para poder evadir respuestas a retos sobre-simplificados en la región fronteriza México-Estados Unidos, es necesario un enfoque en interrelaciones entre temas, o un sistema de aproximación. Los retos de un crecimiento extraordinariamente acelerado, de una asimetría económica persistente, de sequías y escaseces inminentes, de una industrialización fomentada, y un crecimiento de la clase media en la región fronteriza de México-Estados Unidos, tienen un impacto directo en la política económica y ambiental. La Academia es aún el mejor grupo para desarrollar estas respuestas debido a su disponibilidad para conducir una planeación imparcial y comprensiva a largo plazo y una conciencia verdaderamente regional. Las tendencias recientes hacia una "ciencia sustentable"—definida como una investigación interdisciplinaria en diferentes escalas, medium (tales como el agua, aire, o los suelos). Y una gama variada de disciplinas académicas—se permiten a un una clase emergente de científicos fuertes y sociales la oportunidad de lidiar con muchos problemas difíciles al mismo tiempo. La Academia ahora tiene la disponibilidad de trazar conceptos y sus relaciones, y en el proceso de desarrollar un modelo representativo que evalúe los múltiples impactos de una acción o decisión. Por ejemplo, la exploración y desarrollo de la energía tiene a la calidad del aire, suministro de agua, prosperidad económica, vitalidad comunitaria, y a otras consecuencias no intencionadas ni previstas que no son completamente comprendidas individualmente o colectivamente.

Desde los 1990s, las facultades de las universidades que integran el Consorcio de Investigación y Política Ambiental del Suroeste (CIPAS), han establecido un ejemplo para la cooperación binacional y el desarrollo de política. Basado en su experiencia y éxito, el CIPAS estuvo retado a contestar las siguientes aparentemente simples, pero más bien muy complejas preguntas: Cómo se verá la frontera en 20 años? La decisión fue que el valor máximo sería realizado por todas las circunscripciones en la región al tomar un enfoque único de desarrollar una relación o un modelo de "sistema de dinámicas". Esto permitiría a los investigadores a preguntar y educar al proceso internacional, nacional y local de toma de decisiones y de elaboración de políticas sobre las consecuencias directas e indirectas, confusas y diferentes, y tardías e inmediatas de decisiones aparentemente no relacionadas.

El modelo, llamado Frontera Más Veinte Años (B+20/F+20), consiste de un grupo binacional de investigadores de varias disciplinas académicas. Este grupo trabaja con un programa computacional que proporciona una serie de gráficas y cuadros basados en información proporcionada al programa y preguntas realizadas al mismo. El modelo, el cual es flexible, relaciona muchas partes de un problema—elementos que fueron extraídos de reuniones establecidas con tomadores de decisiones quienes explicaron sus preocupaciones y establecieron sus preguntas—y presenta una serie de escenarios sobre cómo se verá en un futuro la región fronteriza de México-Estados Unidos.

F+20 demuestra los impactos humanos en el medio ambiente de la frontera para los próximos 20 años. En particular, los mapas y cuadros usados para presentar estos escenarios son especialmente provechosos para analizar la información sobre las áreas fronterizas ya que abarcan idiomas, leyes, y culturas y pueden ayudar a desarrollar entendimientos reales y relaciones entre los factores que crean los escenarios. El modelo binacional atrae y añade al proceso natural de toma de decisiones en ambos México y los Estados Unidos. El modelo ayuda a optimizar la inversión de recursos escasos al demostrar los efectos de los esfuerzos locales a lo largo de la frontera, así como los efectos complementarios de acciones tomadas en unísono.

F+20 ha sido invaluable para diversas agencias multinacionales que existen para superar los retos binacionales. En ausencia de un plan estratégico para la región fronteriza de cualquier organización binacional, y siguiendo años de marginación por agencias nacionales, F+20 puede informar a los tomadores de decisiones sobre las maneras para:

- Evadir consecuencias no intencionadas e imprevistas
- Conscientizarse y prevenir riesgos severos a la salud humana
- Evaluar efectos transfronterizos para que la atención conjunta pueda anticipar la crisis

El modelo es utilizado posteriormente para demostrar el caso especial del límite político entre un país desarrollado y un país en desarrollo, así como el papel especial de la frontera como el lugar en el cual el Tratado de Libre Comercio para América del Norte (TLCAN) hace la mayor diferencia. Explorar y explicar a ambas naciones el valor de la frontera motiva el patrocinio así como las prioridades. En la práctica, el modelo ha sido valioso en informar a una agencia sobre los temas y equilibrios involucrados en otros. Por ejemplo, informa a agencias de agua lo que las agencias de energía o de calidad del aire están pensando, y vice versa.

El programa comenzó como una tarea muy ambiciosa y potencialmente riesgosa. Pero hasta hoy, el CIPAS y los modeladores han podido evadir lagunas potencialmente fatales que han contaminado otros modelos y colaboraciones binacionales. F+20 ha sido exitoso ya que:

- Escogió una plataforma computacional fuerte que puede ser usada para comunicarse directamente con el público, demostrar a los tomadores de decisiones los efectos de sus políticas, y educar a una amplia gama de estudiantes mexicanos y estadounidenses (ya que el grupo del proyecto publicó un manual de sistema de dinámicas en español)
- Mantuvo un proceso flexible que acondicionó los cambios en el grupo de modelado necesariamente planeados y no anticipados
- Comenzó y permaneció bilateral y regional en sus preocupaciones
- Evadió la estreches y el dogma asociado con cada disciplina académica individual y medium
- Se comprometió y aseguró a principios del proceso productos finales relevantes y pronósticos tangibles

Los capítulos en este volumen de las Series de Monografías del CIPAS, El Medio Ambiente de la Frontera México-Estados Unidos, reflejan los estudios y análisis realizados como parte del proceso de modelado de F+20. Un Epílogo se incluye que aborda algunos de los temas del proceso surgidos en el mismo. El contenido general puede ser usado para comprender mejor el modelo de sistemas que el grupo del proyecto construyó y para informar a los tomadores de decisiones sobre los factores que deben ser considerados al desarrollar soluciones para los problemas complejos en la región México-Estados Unidos así como en otras regiones fronterizas.

D. Rick Van Schoik
Director, CIPAS
San Diego, California
Agosto 2004

Introduction

This volume reports the results of a Southwest Consortium for Environmental Research and Policy (SCERP) directed research project known as the Border Plus Twenty Years (B+20) Project. This multi-disciplinary, multi-institutional project was designed to produce an empirically based system dynamics model of the U.S.-Mexican border environment that could be used to guide planning and policy decisions. The principal goal for this effort is derived from the vision statement generated in 1999 at the first Border Institute convened by SCERP: To aid borderland decision-makers in finding ways to maintain a satisfactory quality of life for all residents and a healthy sustainable natural environment. To this end, B+20 was designed to build a computer-based system dynamics framework for exploring future conditions along the U.S.-Mexican border for a series of alternative 20-year futures (hence the "20" in the project name B+20).

In addition to an international border, the United States and Mexico share airsheds, watersheds, energy sources, metropolitan communities, economic ties, and transportation links. The relationship between humans and the environment in the border region is influenced both by local factors and factors from outside the region. Some of the important remote influences include the national economies of the United States and Mexico and the laws and regulatory structures generated by the respective national governments.

After four years of effort, B+20 has created a system dynamics model that can be used as a decision support tool for evaluating the consequences of different courses of action in the border region. The system dynamics model quantifies relationships between different components of the environment and human behavior. The model includes the following components: population, economy, energy, air quality, water supply and quality, land use, and human quality of life. The model links each environmental factor and provides feedback loops so that the widespread effects of changing any component of any factor may be evaluated. Because the model is able to project alternative futures, it allows decision-makers to ask "what if" questions and to evaluate the potential consequences of different policy options.

The model was developed and first applied in the tri-state Paso del Norte region for several reasons. The density of data availability, the pressing nature of the transboundary issues, and the close interdependencies between the two large cities of El Paso, Tex., and Ciudad Juárez, Chih., made Paso del Norte the optimal area for this pilot project.

This volume comprises two sections. Section I outlines the theoretical and empirical foundation used to develop system dynamics models for different geographic locations along the U.S.-Mexican border. This section explains systems thinking and the system dynamics modeling approach with specific reference to conditions affecting human-environment interactions in the border region. In addition, Section I provides border-scale insight about how to assess and model quality of life issues, institutional frameworks, and energy considerations.

In Chapter I-1, Forster and Cleveland provide an overview of the B+20 project. They describe the goals of the project, the general environmental conditions in the Paso del Norte region, and the rationale for using a system dynamics approach. This chapter also provides the necessary background for understanding the assumptions and icons employed in the object-oriented, commercially available STELLA® software, which was used to create the actual system dynamics model.

B+20 is based on the well-validated assumption that change in one component of an environmental system will produce widespread changes in other parts of the system. An environmental system also includes the humans that live in the region because humans react to environmental changes, and through their activity, cause environmental changes. Two of the most potent elements in the B+20 model—economics and demography—are essentially models of human behavior. In Chapter I-2, Sadalla, Guhathakurta, and Ledlow discuss the effects of environmental changes on human quality of life and human well-being. This chapter discusses the conceptual and methodological problems involved in quantifying and relating quality of life, and reviews empirical literature that links elements of the environment (such as air quality, water quality, transportation, economy, and population size) to quality of life.

In Chapter I-3, Peña, Fuentes, and Forster provide a historical description of land use changes in Paso del Norte. Paso del Norte is a region that has been characterized by urban growth and urban sprawl. The B+20 project has been designed as a forecasting tool that would allow a user to create different urban growth scenarios over a 20-year period of time, and to explore the environmental and economic consequences of each scenario. The Paso del Norte land use model was designed to study how economic and demographic processes trigger the demand for urban land for residential, industrial, commercial, and transportation purposes.

Van Schoik, Conner, and Lelea discuss issues related to sustainable water use in the border region in Chapter I-4. Because of its arid climate, the history of this region (like that of most of the Western United States) involves a series of conflicts over water. In this chapter, the authors note that such conflicts will be exacerbated by population growth and that the solutions to water conflicts will have widespread effects on energy production, biodiversity, regional economies, and the health of residents. The chapter provides a sensitive discussion of the political complexities of managing water resources along the border and discusses the problems that binational institutions (such as International Boundary and Water Commission-Comisión Internacional de Límites y Aguas, Border Environment Cooperation Commission, and North American Development Bank) have had in dealing with current water issues. The chapter concludes with a discussion of innovative mechanisms that could improve the long-term management of this scarce resource.

Due to recent and projected population growth in the border region, there is an increasing demand for environmentally sensitive and sustainable sources of energy. In Chapter I-5, Sweedler, Quintero Núñez, and Collins discuss significant energy issues confronting the binational region. The chapter explores the complex array of regulatory structures in the United States and those evolving in Mexico. Problems in developing a crossborder infrastructure associated with natural gas and power transfers are discussed as part of the general question of how to develop the necessary administrative and regulatory mechanisms to plan and coordinate issues related to energy in the binational region.

The B+20 system dynamics model was originally developed as a tool that would allow stakeholders with specific interests to explore the future environmental and quality of life implications of policy decisions in the U.S.-Mexican border region. As the model took shape, it became apparent that it could also be useful in classroom settings to illustrate principles that apply to a wide variety of urban environments. In Chapter I-6, Sadalla, Ledlow, and Guhathakurta suggest that this model is uniquely suited for teaching concepts from the emerging field of "sustainability science," and for teaching "systems thinking" in relation to environmental issues. Use of the B+20 model fosters an appreciation of the widespread consequences of changing one part of a dynamic system and promotes an active learning approach to education that has been shown to enhance student involvement, interest, and retention of content.

Section II of this volume presents a case study in which a system dynamics model is developed and applied in Paso del Norte, which includes Doña Ana County, N.M., El Paso County, Tex., and the municipality of Ciudad Juárez, Chih. This case study explains the structure of the system model with chapter-by-chapter, detailed descriptions of the interrelated sectors of this binational community.

In Chapter II-1, Forster outlines the narrative, or story, that underlies the B+20 system model for the Paso del Norte region. This narrative is founded on a historical overview of air basins, watersheds, regional economies, cultural contexts, human health issues, and efforts toward binational cooperation. This chapter provides background and context for the Paso del Norte human-environment system and outlines how various components of the system are dynamically interrelated in the B+20 model. An idealized map of the Paso del Norte system model is presented and discussed in combination with anticipated scenarios for demographic, economic, and environmental futures.

In Chapter II-2, Guhathakurta and Sadalla describe the structure of the quality of life sector included in the B+20 model. They note that at present, the quality of life sector in the model is an "output" or result indicator based on the parameters supplied by other sectors of the same model. The quality of life sector of the model is limited to those aspects of quality of life that have been empirically linked to and derived from the other elements of the B+20 model. The chapter describes the underlying model structure that links health and health costs (as components of quality of life) to water supply, water contaminants, and air quality.

Demographic change is one of the two most potent drivers (the other being economy) in the B+20 model. Demographic changes in a region have widespread, well-documented affects on other environmental components and on quality of life. In Chapter II-3, Peach provides a historical description of population growth and demographic change in El Paso and Ciudad Juárez. The chapter analyzes various methods of population projection and describes the B+20 population model.

In Chapter II-4, Erickson begins a discussion of the economic sector of the model with the assertion that "any model that seeks to explain the interaction between human populations and the environment must take into account economic activity. For a given population, the level of economic development will determine the impact of human activity on the environment." The B+20 model supports this assertion in that economic changes are seen to have widespread impacts on all other model sectors. In this chapter, Erickson discusses the economy of the Paso del Norte region and its relationship to national economies, business cycles, and the development of the maquiladora industry. Assumptions underpinning the basic structure of the economic sector are specified.

Paso del Norte is an arid region with little rainfall and high evaporation rates. In Chapter II-5, Forster and Hamlyn describe water availability and water use in the region. The chapter describes the specific ways in which water is obtained from the hydrologic system and used in urban and agricultural activities that, in turn, affect the quality of life in Paso del Norte. Modeling the hydrologic system in relation to other environmental components aids in understanding the complexity of this resource base and allows the evaluation of alternative development scenarios.

The U.S.-Mexican border region consists of an environment with a shared airshed, shared watersheds, and shared natural resources that are managed by two different governmental and legal systems. In Chapter II-6, Peña and Fuentes analyze the legal and constitutional framework of land use planning in the United States and Mexico by examining the role and function of each level of government. The chapter also focuses on water management schemes in both countries. Understanding the water rights system is necessary to identify the obstacles to sustainable water and land use policies for the border that would enhance the quality of life of border residents. The chapter also includes a discussion of possible alternative water management strategies in a binational region.

In the Paso del Norte air basin, airborne pollutants emitted from each city mix with emissions from surrounding non-urban land and circulate within a complex transborder air basin. In Chapter II-7, Quintero Núñez and Forster describe the attempt to model the effects of future air quality conditions on economic activity, human health, and quality of life in Paso del Norte. Current physical and socioeconomic conditions in the region are described, as are air quality standards, monitoring, and exceedences. The chapter includes a discussion of potential future methods of managing the shared airshed in the region.

Many people had a hand in developing this project. Craig Forster was the project leader during its four-year duration and had the task of keeping the project members organized, goal directed, and productive. He was also responsible for integrating the model sectors provided by individual teams into a coherent functioning model. In addition to the team members who have authored chapters in this volume, B+20 relied on the expertise of a number of consultants who expended considerable time and energy on different components of the project. Bill Grant of Texas A&M University advised group members on modeling assumptions and effective modeling procedures. Valuable conceptual and methodological input was provided during team meetings by Phil Emmi of University of Utah, Christopher Brown of New Mexico State University, Jim Williams of New Mexico State University, Ed Baldson of San Diego State

University, Hector Arriola of Universidad Autonóma de Baja California, Mike Kjelland of Texas A&M University, and Carlos Rincón of Environmental Defense in El Paso.

The modeling team is also indebted to stakeholders and community organizations that provided input and constructive advice concerning the form of the final product. Tarla Rai Peterson and Rebecca Royer from the University of Utah facilitated team meetings and helped manage the complex social dynamics that occurred when professionals from different academic disciplines were forced to confront and try to understand the perspectives, theoretical orientations, and goals of their colleagues. For the duration of the project, D. Rick Van Schoik, as the Managing Director at SCERP, provided both short-term guidance and a long-range perspective concerning the ultimate goals and potential utility of B+20.

Additional SCERP staff who participated in the publication of this volume include Gabriela Carrillo, Assistant Managing Director, who provided Spanish translations, and SCERP's Managing Editor, Amy Conner, who edited and coordinated production. Universities that participate in B+20 include University of Utah, San Diego State University, Arizona State University, New Mexico State University, Texas A&M University, University of Texas at El Paso, Universidad Autonóma de Baja California, and Colegio de la Frontera Norte.

Introducción

Este volumen reporta los resultados de un proyecto de investigación dirigida de un Consorcio de Investigación y Política Ambiental del Suroeste (CIPAS), conocida como Proyecto Frontera Más Veinte Años (F+20). Este proyecto multi-disciplinario y multi-institucional fue diseñado para producir un sistema de modelo de dinámicas basado empíricamente en el medio ambiente de la frontera de México-Estados Unidos, el cual pudiera ser utilizado para guiar la planeación y la toma de decisiones. El objetivo principal para este proyecto se deriva de la visión generada en 1999 en el primer Instituto Fronterizo convocado por el CIPAS: Ayudar a los tomadores de decisiones de la franja fronteriza a encontrar y preservar una calidad de vida satisfactoria para todos sus residentes y un medio ambiente sustentable y saludable. En este orden de ideas, F+20 fue diseñado para construir un esquema de trabajo de un sistema de dinámicas basado en programas computacionales para explorar futuras condiciones a lo largo de la frontera México-Estados Unidos en una serie de futuros alternativos de 20 años (de allí el número "20" en el proyecto F+20).

En adición a una frontera internacional, México y los Estados Unidos comparten cuencas de aire, cuencas de agua, fuentes de energía, comunidades metropolitanas, vínculos económicos y relaciones de transporte. La relación entre humanos y el medio ambiente en la región fronteriza está influenciada de factores locales fuera de la región. Algunas de los influencias externas incluyen las economías nacionales de México y los Estados Unidos, y las leyes y estructuras reglamentarias generadas por los gobiernos nacionales respectivos.

Después de un esfuerzo de cuatro años, F+20 ha creado un modelo de sistema de dinámicas que puede ser usado como una herramienta de apoyo a decisiones para evaluar las consecuencias de cursos de acción diferentes en la región fronteriza. El modelo de sistema de dinámicas cuantifica las relaciones entre diferentes componentes del comportamiento humano y del medio ambiente. El modelo incluye los siguientes componentes: población, economía, energía, calidad del aire, suministro y calidad de agua, uso de suelo, y calidad de vida humana. El modelo une a cada factor ambiental y proporciona lazos de retroalimentación para que los efectos generales del cambio de cualquier componente de cualquier factor puedan ser evaluados. Debido a que el modelo puede proyectar alternativas de futuros, permite a los tomadores de decisiones preguntarse "que si" y evaluar las consecuencias potenciales de diferentes opciones de políticas.

Este volumen comprende dos secciones. La Sección I delimita los fundamentos teóricos y empíricos usados para desarrollar el modelo de sistema de dinámicas para diferentes ubicaciones geográficas a lo largo de la frontera México-Estados Unidos. Esta sección explica el enfoque del modelado de sistemas de pensamiento con referencias específicas a condiciones afectando las interacciones humano-ambientales en la región fronteriza. Adicionalmente, la Sección I proporciona una información a escala-fronteriza sobre cómo evaluar y modelar los temas de la calidad de vida, de esquemas de trabajo institucionales y de consideraciones de energía.

En el Capítulo I-1, Forster y Cleveland proporcionan una visión general del proyecto F+20. Describen los objetivos del proyecto, las condiciones ambientales generales en la región del Paso del Norte, y la lógica de usar un enfoque de sistema de dinámicas. Este capítulo también proporciona los antecedentes necesarios para entender los íconos y suposiciones aplicados en el programa objetivo-orientado y disponible comercialmente de STELLA®, que fue usado para crear el sistema de modelo de dinámicas real.

F+20 está basado en la suposición validada que el cambio en un componente de un sistema ambiental producirá cambios generales en otras partes del sistema. Un sistema ambiental también incluye a los humanos que viven en la región ya que los humanos reaccionan a los cambios ambientales, y a través de su actividad, causan cambios ambientales. Dos de los elementos más potentes en el modelo F+20—la economía y la demografía—son esencialmente modelos de conducta humana. En el Capítulo I-2 Sadalla, Guhathakurta, y Ledlow discuten los efectos de los cambios ambientales en la calidad de vida humana y en el buen estado humano. Este capítulo discute los problemas conceptuales y metodológicos involucrados en la operación del concepto de de la calidad de vida, y analiza extensivamente la literatura empírica que une los elementos del medio ambiente (tales como la calidad del aire, calidad del agua, transporte, economía, y tamaño de la población) a la calidad de vida.

En el Capítulo I-3, Pena, Fuentes, y Forster proporcionan una descripción histórica del cambio del uso del suelo en el Paso del Norte. Se proporciona también una descripción histórica del crecimiento de El Paso y Ciudad Juárez. El Paso del Norte es una región que ha sido característica del crecimiento urbano y de desorganización urbana. El proyecto F+20 ha sido diseñado como una herramienta de proyección que permitiría al usuario crear diferentes escenarios de crecimiento urbano por un periodo de tiempo de 20 años, y explorar las consecuencias ambientales y económicas de cada escenario. El modelo de uso del suelo de el Paso del Norte fue diseñado para explorar cómo el proceso económico y de desarrollo provoca la demanda de tierra urbana para propósitos residenciales, industriales, comerciales y de transporte.

Van Schoik, Conner, y Lelea discuten en el Capítulo I-4 temas relacionados con el uso sustentable del agua en la región fronteriza. Debido a su clima árido, la historia de esta región (como en la mayor parte del oeste de los Estados Unidos) involucra una serie de conflictos sobre el agua. En este capítulo, los autores notan que tales conflictos serán agravados por el crecimiento de la población y que las soluciones a los conflictos sobre el agua tendrán efectos generales en la producción de energía, biodiversidad, economías regionales, y en la salud de los residentes. El capítulo proporciona una discusión sensible sobre las complejidades de la administración del agua a lo largo de la frontera y discute los problemas que las instituciones binacionales (tales como la Comisión Internacional de Límites y Aguas, la Comisión de Cooperación Ambiental Fronteriza, y el Banco de Desarrollo de Norte América) han tenido al lidiar con temas actuales de agua. El capítulo concluye con una discusión sobre mecanismos innovadores que pudieran improvisar a largo plazo la administración de este recurso escaso.

Debido al reciente y proyectado crecimiento de la población en la región fronteriza, existe una creciente demanda por fuentes ambientalmente sensibles y sustentables de energía. En el Capítulo I-5, Sweedler, Quintero Núñez, y Collins discuten temas significantes de energía que confrontan a la región binacional. El capítulo explora el surtido complejo de diferentes estructuras regulatorias en los Estados Unidos y aquéllos evolucionando en México. Los problemas en el desarrollo de una infraestructura transfronteriza asociados con el gas natural y con la transferencia de energía son discutidos como parte de la pregunta general de cómo desarrollar los mecanismos regulatorios ya administrativos necesarios para planear y coordinar temas relacionados con la energía en la región binacional.

El modelo de sistema de dinámicas F+20 originalmente fue desarrollado como una herramienta que permitiría a las personas con intereses específicos explorar futuras implicaciones ambientales y de la calidad de vida de las decisiones de política en la región fronteriza de México-Estados Unidos. Al tomar forma el modelo, fue obvio que también podría ser usado en los salones de clase para ilustrar principios aplicables a una amplia gama de ambientes urbanos. En el Capítulo I-6, Sadalla, Ledlow, y Guhathakurta sugiere que este modelo está especialmente diseñado para la enseñanza de conceptos de áreas emergentes de "ciencia sustentable", y para la enseñanza de sistemas de pensamiento en relación con los temas ambientales. El uso del modelo F+20 promueve una apreciación de las consecuencias generales de cambiar una parte del sistema de dinámicas y promueve el enfoque de aprendizaje activo a la educación que ha demostrado realzar la participación e interés de los estudiantes así como la retención del contenido.

La Sección II de este volumen presenta una caso en el cual se desarrolla y aplica un modelo de sistema de dinámicas en las ciudades hermanas de la región fronteriza del Paso del Norte, que incluye Las Cruces, N.M., El Paso, Tex., y Ciudad Juárez, Chih. Este caso explica la estructura del modelo de sistema con descripciones detalladas de cada capítulo sobre los sectores interrelacionados de una comunidad binacional de ciudad-hermana.

En el Capítulo II-1, Forster delimita la narrativa o historia que subraya el modelo de sistema de F+20 para la región del Paso del Norte. Esta narrativa está fundamentada en una visión general histórica de cuencas de aire, cuencas de agua, economías regionales, contextos culturales, temas de salud humana, y esfuerzos hacia la cooperación binacional. Este capítulo proporciona un antecedente y contexto para el sistema humano-ambiente del Paso del Norte y delimita como varios componentes del sistema están interrelacionados dinámicamente en el modelo de F+20. Un mapa ideal del modelo de sistema del Paso del Norte se presenta y discute en combinación con escenarios anticipados para futuros demográficos, económicos y ambientales.

En el Capítulo II-2, Guhathakurta y Sadalla describen la estructura del sector de la calidad de vida incluida en el modelo de F+20. Notan que hoy en día, el sector de la calidad de vida en el modelo es un indicador de salida de información basado en los parámetros proporcionados por otros sectores del mismo modelo. El sector de la calidad de vida del modelo está limitado para aquellos aspectos de la calidad de vida que han sido unidos empíricamente a otros elementos del modelo F+20. El capítulo describe la estructura subyacente del modelo que une a la salud y al costo de la salud (como componentes de la calidad de vida) al suministro y contaminantes del agua, y a la calidad del aire.

El cambio demográfico es uno de los dos conductores más potentes (el otro siendo la economía) en el modelo del F+20; los cambios demográficos en una región afectan de manera general y documentada a otros componentes ambientales y a la calidad de vida. En el Capítulo II-3, Peach proporciona una descripción histórica del crecimiento de la población y del cambio demográfico en El Paso y Ciudad Juárez. El capítulo analiza varios métodos de proyección de la población y describe el modelo de población de F+20.

En el Capítulo II-4, Erickson comienza una discusión del sector económico del modelo afirmando que "cualquier modelo que busca explicar la interacción entre la población humana y el medio ambiente debe tomar en cuenta la actividad económica. Para cualquier población, el nivel de desarrollo económico determinará el impacto de la actividad humana en el medio ambiente. "El modelo F+20 apoya esta afirmación en cuanto que los cambios económicos han generado impactos generales en los demás sectores del modelo. En este capítulo, Erickson discute la economía de la región del Paso del Norte y su relación con las economías nacionales, ciclos de negocios, y el desarrollo de la industria de la maquiladora. De igual manera se especifican las suposiciones que apoyan la estructura básica del sector económico.

El Paso del Norte es una región árida con poca lluvia y alto índice de evaporación. En el Capítulo II-5, Forster y Hamlyn describen la disponibilidad y uso del agua en la región. El capítulo describe las formas específicas de obtención del agua a través de sistemas hidrológicos y la manera en que es usada en actividades urbanas y agrícolas que a su vez, afectan la calidad de vida en el Paso del Norte. Modelar el sistema hidrológico en relación con otros componentes ambientales, ayuda a entender la complejidad de esta base de recurso y permite la evaluación de escenarios de desarrollo alternativos.

La región fronteriza México-Estados Unidos consiste de un medio ambiente comunal con una cuenca de aire, cuenca de agua, y recursos naturales compartidos que son administrados por dos diferentes sistemas legales y gubernamentales. En el Capítulo II-6, Pena y Fuentes analizan el marco legal y constitucional de la planeación del uso de suelo de México y los Estados Unidos al examinar el papel y función de cada nivel de gobierno. El capítulo también se enfoca en esquemas de administración del agua en ambos países. Es necesario entender marco jurídico del agua para poder identificar los obstáculos del agua sustentable y de las políticas de uso de suelo para la frontera que pudiera realzar la calidad de vida de los residentes fronterizos. El capítulo también incluye una discusión de posibles alternativas de estrategias de administración del agua en una región binacional.

En la cuenca de aire del Paso del Norte, los contaminantes aerotransportados fueron emitidos por cada mezcla de ciudades con emisiones de tierras vecinas no urbanas y circulan dentro de una cuenca de aire transfronteriza compleja. En el Capítulo II-7, Quintero Nuñez y Forster describen el intento de modelar los efectos de futuras condiciones de la calidad del aire sobre la actividad económica, salud humana, y sobre la calidad de vida del Paso del Norte. Se describen condiciones físicas y socioeconómicas actuales en la región, así como también se describen los estándares de la calidad del aire, el monitoreo y los excesos. El Capítulo incluye una discusión de futuros métodos potenciales de administración de la cuenca de aire compartida de la región.

Muchas personas han contribuido al desarrollo de este proyecto. Craig Forster fue el líder del proyecto durante sus quatro años de duración y tuvo la tarea de mantener a los miembros del proyecto organizados, productivos y orientados al objetivo. También fue responsable de integrar los sectores del modelo coherente y funcional. En adición a los miembros del grupo que han sido autores de Capítulos en este volumen, F+20 se apoyó en la experiencia de un número de consultores que aportaron tiempo y energía considerable en diferentes componentes del proyecto. El Bill Grant de Texas A&M University asesoró a miembros del grupo en suposiciones de modelado y procedimientos de modelado efectivo. Información valiosa y conceptual fue proporcionada durante las reuniones de de trabajo por el Phil Emmi de la Universidad de Utah, el Jim Williams de la Universidad Estatal de Nuevo Mexico, el Ed Baldson de la Universidad Estatal de San Diego, el Héctor Arriola de la Universidad Autónoma de Baja California, el Mike Kjelland de Texas A&M University, y el Carlos Rincón de la Defensa Ambiental en El Paso.

El grupo de modelado también está endeudado con las personas interesadas y organizaciones comunitarias que proporcionaron información y asesoría constructiva en torno a la forma del producto final. La Tarla Rai Peterson y Rebecca Royer de la Universidad de Utah facilitaron las reuniones de trabajo y ayudaron a administrar las dinámicas sociales complejas que ocurrieron cuando profesionales de diversas disciplinas académicas fueron forzados a confrontar y tratar de entender las perspectivas, orientaciones teóricas, y los objetivos de sus colegas. Por la duración del proyecto, D. Rick Van Schoik, como Director del CIPAS, proporcionó orientación en un corto plazo y perspectiva amplia en torno a los objetivos primordiales y en la publicación de este volumen.

Otro personal del CIPAS que participó en la publicación de este volumen incluye a Gabriela Carrillo, Subdirectora del Consorcio, quien proporcionó traducciones al español, y la Directora de Edición, Amy Conner, quien editó y coordinó la producción.

Entre las universidades que participaron en F+20 se incluyen la Universidad de Utah, la Universidad Estatal de San Diego, la Universidad Estatal de Arizona, la Universidad Estatal de Nuevo

Mexico, Texas A&M University, la Universidad de Texas en El Paso, la Universidad Autónoma de Baja California, y el Colegio de la Frontera Norte.

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Dynamics of Human-Environment Interactions in the U.S.-Mexican Border Region

Craig B. Forster and Natasha L. Cleveland

ABSTRACT

The Border Plus Twenty Years (B+20) Project makes possible the exploration of the consequences of alternative "what-if" scenarios in the U.S.-Mexican border region. The project team developed a computer-based modeling framework for supporting interdisciplinary, bilateral decision-making in the region. The goal of the B+20 team is to provide a modeling framework for decision-making that will increase the likelihood of improved transborder cooperation and help lead to a sustainable future for those living along the U.S.-Mexican border.

The modeling framework provides a series of "micro-borderlands" where alternative policy options can be explored, via the computer-based model, by framing a series of hypotheses or questions and then using the model to quantitatively compare the consequences of the various alternatives. This process provides a valuable framework for the bilateral discussions needed among stakeholders and decision-makers planning the future of the border.

Water availability and quality, air quality, human health, and ecosystem health are key elements of the border's human-environment system that suffer as a consequence of high population growth rates and rapidly expanding urban areas. The dynamics of these human-environment interactions can be explored using systems thinking and system dynamics modeling approaches that quantitatively capture simplified versions of these complex interrelationships.

An important advantage of system dynamics modeling approaches is that the "stories" built into the resulting models can be traced by users lacking advanced mathematical or modeling skills. The use of object-oriented, commercially available system dynamics software enables models to be constructed by linking stocks and flows in a structure that reflects a holistic understanding of the system.

Over the past 30 years, many models have been created to study single-city, regional, single-nation, and multi-national issues that involve population growth, economic development, and the environment. Quantitative models of human-environment dynamics in binational borders, however, are lacking.

Dinámicas de Interacciones Humano-Ambientales en la Frontera México-Estados Unidos

Craig B. Forster y Natasha L. Cleveland

Resumen

El Proyecto Frontera Más Veinte Años (F+20) hace posible explorar consecuencias de escenarios alternativos de "que si" en la región fronteriza de México-Estados Unidos. El grupo del proyecto desarrolló un esquema de trabajo de modelado basado en programas com-

putacionales para apoyar la toma de decisiones interdisciplinarias y bilaterales en la región. El objetivo del grupo F+20 es proporcionar un modelo de esquema de trabajo para la toma de decisiones que incremente la probabilidad de mejorar la cooperación transfronteriza y que ayude a llegar a un futuro sustentable para quienes viven a lo largo de la frontera México-Estados Unidos.

El modelo del esquema de trabajo provee una serie de "micro-límites fronterizos" en los que se pueden explorar opciones de políticas alternativas, vía el modelo armando una serie de hipótesis o preguntas y usando el modelo para comparar cuantitativamente las consecuencias de las diversas alternativas. Este proceso proporciona un esquema valuable para las discusiones bilaterales requeridas entre las personas interesadas y los tomadores de decisiones que planean el futuro de la frontera.

La calidad y disponibilidad del agua, la calidad del aire, la salud humana, y la salud del ecosistema son elementos claves del sistema humano-ambiental de la frontera que sufre como consecuencia del gran crecimiento de la población y del rápido crecimiento de las áreas urbanas.

Las dinámicas de estas interacciones humano-ambientales pueden ser exploradas usando sistemas de pensamiento y enfoques de modelado de sistemas de dinámicas que capturen cuantitativamente versiones simplificadas de estas complejas interrelaciones.

Una ventaja importante del enfoque de modelado de sistema de dinámicas es que las "historias" construidas hacia los modelos resultados pueden ser rastreadas a través de usuarios sin habilidades matemáticas o de modelado. El uso de programas de sistema de dinámicas comercialmente disponibles y orientadas al objeto, permite la construcción de modelos al unir las reservas y su tránsito en una estructura que refleje un entendimiento holístico del sistema.

Durante el transcurso de los pasados 30 años, muchos modelos han sido creados para estudiar factores municipales, regionales, nacionales y multinacionales, que involucran el crecimiento de la población, el desarrollo económico, y el medio ambiente. Sin embargo, los modelos cuantitativos de dinámicas humano-ambientales en las fronteras binacionales carecen de estos modelos.

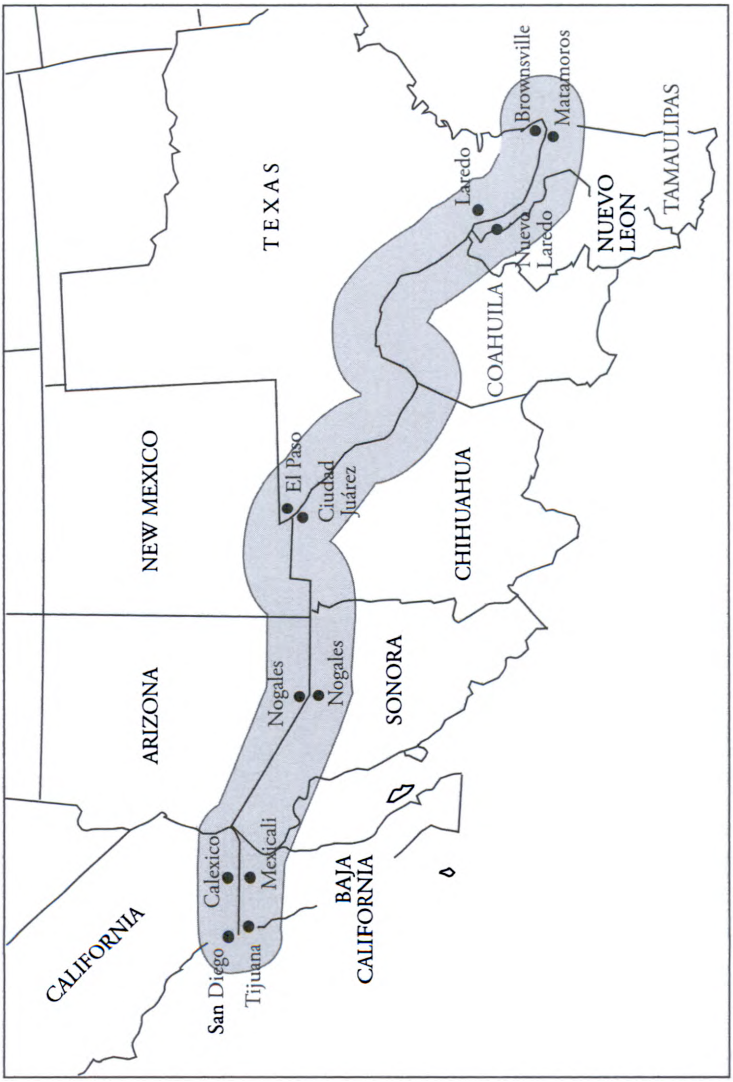
INTRODUCTION

How will human and ecological conditions look on the U.S.-Mexican border 10 years, 20 years, and 30 years in the future? Will quality of life improve if current policies and practices are continued, or are changes needed to improve border conditions? In pondering the future of the border region, would it help to explore alternative futures by playing "what if" games that test possible outcomes of proposed strategies? The Border Plus Twenty Years (B+20) Project is designed to provide such an environment for enabling the exploration of the consequences of alternative "what if" scenarios in the U.S.-Mexican border region.

The B+20 Project team developed a modeling framework for supporting interdisciplinary, bilateral decision-making in the U.S.-Mexican border region, which measures 3,200 kilometers (km) in length and 200 km in width (Figure 1). The principal goal for this effort is derived from the vision statement generated at the first Border Institute convened by the Southwest Consortium for Environmental Research and Policy (SCERP) (1999): To aid border decision-makers in finding ways to maintain a satisfactory quality of life for all residents and a healthy, sustainable natural environment. To this end, the B+20 Project is tasked with providing a framework for exploring future conditions for a series of alternative 20-year futures—hence the "20" in the project name "Border+20." As recommended by Kinsley, Lovins, and Spalding (2002), the team uses a systems thinking approach to map key elements of the border human-environment system and build system dynamics models that quantitatively represent complex links, flows, and feedbacks between and within system elements.

The goal of the B+20 team is to provide a modeling framework for decision-making that will increase the likelihood of improved transborder cooperation and help lead to a sustainable future for those living along the U.S.-Mexican border. The modeling framework provides a series of "micro-borderlands" where alternative policy options can be explored by framing a series of hypotheses or questions, then using the model to quantitatively compare the consequences of the various alternatives. Possible questions of interest to border stakeholders and decision-makers include the following:

Figure 1. The U.S.-Mexican Border Region



Source: U.S.-Mexico Chamber of Commerce

1. How should limited financial resources be expended in attempting to maintain and improve quality of life on the U.S.-Mexican border? For example, can stringent water conservation and recycling efforts postpone capital investments in central water treatment plants to release the funds needed to ensure that all households are connected to a potable water supply? Or, would the available funds perhaps have maximum beneficial impact on quality of life in the border's twin cities if they are instead used to pay for the technological or transportation infrastructure improvements needed to reduce air pollutant emissions?
2. If funds available to a twin city for infrastructure development could be spent anywhere without their use being restricted to one side of the border or the other, how might the funds be used to maximum advantage? For example, how might taxes collected from Mexican shoppers in U.S. retail stores be redirected to improve conditions in the Mexican communities where shoppers live?
3. Options for increasing border urban water supplies include transferring water currently used by border agriculturalists to border urban centers. What economic consequences might result in cases where agricultural operations underpin the local economy? How should uncertainties about water availability in future climate regimes, combined with transborder differences in institutions that control water rights, be accounted for when designing and implementing future policies for water transfers?
4. Border twin cities typically share common airsheds and similar air quality. Given a common interest in improving air quality, what mix of emission reduction policies might be implemented on each side of the border to obtain the best air quality outcomes? For example, what are the relative merits of reducing emissions from brick kilns through technological improvement, paving unpaved roads to reduce particulate emissions, reducing border wait times through changes in U.S. border security procedures, or reducing the age of the vehicle fleet through vehicle purchase incentive plans?

Well-defined answers to the above questions are unlikely to be found because uncertainty about the future abounds, data are sparse, and relationships between human health and environmental conditions are difficult to identify, much less quantify. Yet, the process of building model structures that represent the factors involved, combined with the ability to quantitatively compare the implications of alternative policy options, provides a valuable framework for the bilateral discussions needed among stakeholders and decision-makers planning the future of the border.

Transborder Issues and Challenges in the U.S.-Mexican Border Region

The 3,200 km U.S.-Mexican border spans the North American continent with 14 principal twin-city communities distributed along it. The total population in the U.S. border region is 6.3 million; the highest county population—2.8 million—is in the west coast county of San Diego, Calif. A total of 5.6 million people live in the Mexican border region; the highest *municipio* (the Mexican equivalent of a U.S. county) population is in Tijuana, B.C., San Diego's twin city, which has 1.3 million people. The rapid population growth the border is currently experiencing leads to projected 2020 populations of 8.7 million and 10.0 million in the U.S. and Mexican border regions, respectively (Peach and Williams 2004). Thus, the current total border population of approximately 11.9 million people is likely to increase by more than 60% to 18.7 million in 2020.

Most population growth will occur in the existing transborder twin cities where intense interaction between human activity and the environment is concentrated. At the same time, long, desolate stretches of desert between the principal twin cities are essentially unpopulated, leading to significant difficulties in restricting the illegal flows of people and drugs from Mexico to the United States. The tremendous rate of population growth in the border region is derived from moderate natural population increase, combined with people migrating to work in the economically attractive border region (Peach and Williams 2000).

Geographic conditions vary substantially along the border. High, north-south-oriented mountain ranges in the western border region separate border communities located at elevations ranging from sea level (at both coastal and inland communities) to 1,234 meters (m). In the east, community elevations are generally less than 300 m above sea level. The border region has semi-arid to arid desert climates. Precipitation ranges from less than 10 centimeters (cm) per year in some inland communities to 70 cm per year on the east coast. With the exception of the west coast communities of San Diego and Tijuana, annual average maximum temperatures are about 29°C and average minimum temperatures measure nearly 16°C. Cooler temperatures on the west coast yield an annual average maximum of 21°C and an average minimum of 14°C in San Diego and Tijuana. The specter of future natural and anthropogenic climate variability suggests that declining precipitation rates and increasing temperatures may cause additional stress on border water supplies, energy sources, natural resources, and ecosystems. Yet, knowledge of future climatic conditions is highly uncertain, thus decision-making must account for how a range of possible climates in the future might affect human-environment dynamics on the border.

Economic growth stimulated by border attributes, such as attractive differences in wages and enforcement of environmental laws, has been substantial since the 1940s (Peach and Williams 2000). In 1994, implementing the North American Free Trade Agreement (NAFTA) between Canada, the United States, and Mexico further stimulated economic growth. Unfortunately, the conditions that stimulate economic growth at the border have yielded low per capita incomes and high unemployment rates when compared to elsewhere in the United States. Although per capita incomes in the Mexican border communities are much greater than elsewhere in Mexico, Mexican border minimum wages are approximately 10% of their U.S. twin-city counterparts (Peach and Williams 2000). High rates of economic and population growth coupled with low incomes has meant that many environmental problems have developed in the U.S.-Mexican border region because public financial resources cannot meet rapidly expanding infrastructure needs. The current U.S. economic recession, combined with increasing attractiveness of low wages in countries such as China, raises concerns that the border's economic expansion of past decades may slow while the border population continues to grow. Economic stagnation in the border region would exacerbate current environmental problems and deteriorating human quality of life because access to the funding needed for infrastructure development will be further eroded.

Water availability and quality, air quality, human health, and ecosystem health are key elements of the border's human-environment system that suffer as a consequence of high population growth rates and rapidly expanding urban areas. In the arid climate of the border region there is increasing competition for the scarce water resources needed for human consumption, agricultural production, industrial activity, and ecosystem health. Average per capita water use in the U.S. border region (615 liters per capita per day) is approximately 41% greater than that of the Mexican border region (435 liters per capita per day) (Westerhoff 2000). Because water use is correlated with standard of living, efforts to improve the quality of life in the border region could lead to an increase in average per capita rates of water use, unless counteracting measures such as efficient water conservation and recycling are introduced. Bilateral planning for efficient water use and system-wide wastewater treatment is required if twin cities are to develop a sustainable water supply future while also reducing the prevalence of water-borne disease. Ultimately, border population growth and its consequences will be concentrated in and around twin cities. Thus, it is important to develop a systemic understanding of urban ecosystems in general (Nilon, et al. 2003) and border urban ecosystems in particular.

Non-enforcement of environmental regulations, or inadequate regulations, in some Mexican border communities allows excessive air pollution, which in turn causes the air quality in some twin cities to exceed U.S. national standards, despite relatively low emissions from the U.S. side. Imaginative approaches are needed to develop cost-effective reductions in the binational air emissions that affect quality of life and human health on both sides of the border. Natural ecosystems in the border's desert environments have been severely punished by human activity. Yet in many cases, well-managed desert ecosystems can provide cost-effective solutions to water supply challenges encountered in human communities (Committee on Sustainable Water Supplies for the Middle East 1999). For example, water supply development has eliminated many natural riparian areas that at one time provided natural water treatment in addition to habitat for indigenous flora and fauna. Artificial wetlands recently constructed in eastern California's Imperial Valley region help remove the suspended solids introduced to surface water by the irrigation runoff associated with agricultural activity. A systems thinking and modeling approach will assist decision-makers in evaluating the relative merits of various options proposed to mitigate the degradation of natural systems on the border and improve the quality of life for people living in the U.S.-Mexican border region.

Modeling the Dynamics of Human-Environment Interactions

The dynamics of human-environment interactions at the U.S.-Mexican border can be explored using systems thinking and system dynamics modeling approaches that quantitatively capture simplified versions of the aforementioned complex interrelationships. Although all models are, by definition, simplifications of real systems, the process of developing and applying simplified quantitative models of complex systems yields two key benefits:

- The process of building a quantitative model requires that all system components and their links be formally evaluated for their role and function in the system (this is not often accomplished with qualitative, descriptive models)
- A quantitative model provides a coherent framework for comparing the outcomes of alternative future scenarios proposed for the system (without computed outcomes, clear comparisons cannot be made)

An important advantage of system dynamics modeling approaches is that the "stories" built into the resulting models can be traced by users lacking advanced mathematical or modeling skills. Thus, even though the mathematical and numerical underpinnings cannot be fully explored by all users, the fundamental assumptions made to represent the model system can be readily reviewed and understood by all users.

A systems approach is valuable for exploring various aspects of U.S.-Mexican border issues. For example, it is frequently noted that infrastructure development in the water, sewer, housing, and transportation sectors of the U.S.-Mexican border region is proceeding too slowly to keep pace with the rapid population growth. Yet, it is not clear where limited funding currently available for infrastructure development should be spent to obtain the greatest quality of life benefits for the binational community. Suggestions made for improving quality of life at the border include paving unpaved roads, connecting houses to water supplies and sewers, increasing sewage treatment capacity and the level of treatment, reducing brick kiln emissions, reducing border wait times, conserving and recycling water, eliminating aged personal and commercial vehicles from the border fleet, and modifying housing development practices. Implementing one or more of these strategies creates cost and quality of life implications that can ripple throughout the community to create both intended and unintended consequences. The systems thinking approach provides a conceptual framework for defining how a system dynamics model should be structured. The resulting models enable users from a range of backgrounds to anticipate the possible nature and magnitude of the alternative outcomes, discover unanticipated consequences, and assess which options might create the greatest benefit for the least cost.

Systems Thinking and System Dynamics Modeling

Systems thinking approaches enable the integration of scientific principles with the environmental and sociological impacts of technology and policy. Deaton and Winebrake (2000) outline six characteristics of systems thinking:

1. Systems thinking begins with a global description and moves toward the specific. This is the opposite of traditional reductionist thinking where a researcher would first focus on unraveling the detailed aspects of small components of a system before attempting to resolve how the larger system operates as an aggregate combination of the smaller components. On the U.S.-Mexican border, the national-level transborder exchanges

and interactions must be addressed before drilling down to look in closer detail at how individual urban border communities operate. At the local scale, the interaction within trans-border twin cities across a range of interrelated factors—including population, economy, land use, transportation, housing, water supply and quality, air quality, and quality of life—must be accounted for, rather than focusing on only one factor or one part of the twin city.

2. Systems thinking focuses on dynamic processes. The behavior of the system reflects ongoing change in the underlying processes that drive system evolution. For example, changing rates of migration to the border from elsewhere in Mexico reflect changing local economic conditions in both the migrants' hometowns and in the border cities that, in turn, reflect the dynamic evolution of the interrelated U.S. and Mexican national economies.
3. Systems thinking seeks a closed-loop explanation of how things work. The boundaries of a system should be defined so that the key behaviors of the system are defined by processes that operate within the boundaries. Some external factors are often required to fully describe the operation of a system. However, those factors should be few and exert only a small impact on the behaviors of greatest interest. For example, although the mechanics of national-level demographics of the United States and Mexico must be considered in a border system, the mechanics of global population growth can likely be ignored.
4. Systems thinking identifies feedback loops. A feedback loop represents a closed-loop circle of cause and effect whereby changes in one part of the system cause effects in other parts of the system that then act to update and change conditions in the original part of the system where the change was initiated. For example, a rapidly growing population might cause increased air pollutant emissions that ultimately lead to increased death rates and a slowing of population growth. This is a counteracting, or negative, feedback loop. Meanwhile, road building associated with urban population growth causes the urban area to expand at an ever-growing

rate as construction of new road systems intended to reduce traffic congestion enables commuters to travel progressively greater distances between work and home while promoting increased traffic congestion. This is a reinforcing, or positive, feedback loop.

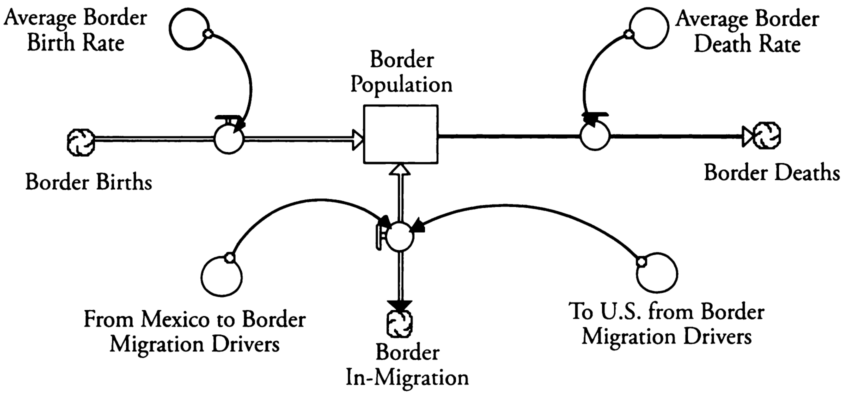
5. Systems thinking looks for checks, balances, and the potential for runaway processes. Factors that control competing processes can help either stabilize or destabilize a system. For example, improving health conditions in a community can lead to both increased birth rates and reduced death rates that destabilize a community by producing increased rates of net population growth. A systems thinker would search for ways to improve health conditions while also searching for a mechanism to maintain birth rates at current or reduced levels.
6. Systems thinking focuses on causal relationships. Thus, the systems thinker searches to define cause-effect relationships rather than relying on apparent correlations where there is no direct relationship between cause and effect.

A systems thinking approach is used to develop system dynamics models by telling the stories that explain the system behaviors of principal interest to decision-makers and stakeholders, then converting the stories into their mathematical equivalent as supported by on-the-ground data. Several aspects of the U.S.-Mexican border's story are outlined above. The stories are represented in model structures using the small suite of graphical icons commonly found in system dynamics modeling software. For example, the population of a border community can be viewed as a stock, or reservoir, of people that increases, decreases, or stabilizes depending upon a variety of interacting factors. Migration of people to or from the population stock can be viewed as flows of people per unit of time. Births and deaths can be viewed as flows of people into or out of the population stock. Flows of people can also increase, decrease, or stabilize depending upon a variety of interacting factors. Migration of people to the Mexican border region reflects both push and pull forces that cause people to leave their homes elsewhere in Mexico in search of a better economic future. Thus, economic activity induced at the border through trade with the United States draws people to the border, while political unrest and the absence of economic opportunity induce people to leave their homes elsewhere in Mexico.

Other stocks and flows can be identified in the evolving border story. Growth in the population "stock" is accompanied by growth in the stocks of urban land area, road lane miles, vehicle miles traveled, households, personal vehicles, commercial vehicles, sewage treatment plants, maquiladoras, water treatment plants, and air pollution sources. Accumulations in and dissipations from each stock are controlled by the material "flows" of people, money, vehicles, water, and goods that are affected by changing dynamics in economic activity, birth/death/migration rates, urban development patterns, infrastructure development, tax structures, border security, and climate.

The use of object-oriented, commercially available system dynamics software (such as STELLA®, Powersim®, and Vensim®) enables models to be constructed by linking stocks and flows in a structure that reflects a holistic understanding of the system. This is best performed in a group model-building activity so that people with different backgrounds can contribute the varied perspective and understanding required to make appropriate links both within and between disparate model elements. A sample model structure for a simple border population model is shown in Figure 2. Stocks are represented as rectangular icons and flows are represented by water tap icons. The cloud-like icon at the end of the water tap represents the exogenous source, or sink, of flowing material (e.g., people) that need not be explicitly accounted for in the model. Information indicating the magnitude of the flows and computed results of system evolution are represented as circular converters. A variety of simple-to-complex relationships can be represented by equations contained within the converter icons. Soft information based on qualitative understanding of the system, or possible impacts of policy interventions, can be included in the model structure using graphical relationships that represent how experts in that disciplinary area think the specific system element might operate. The arrow-shaped information connectors transfer computed information from one icon to another.

Figure 2. A Simple System Model Structure for Tracking the Evolution of Demographic Change in the U.S.-Mexican Border Region

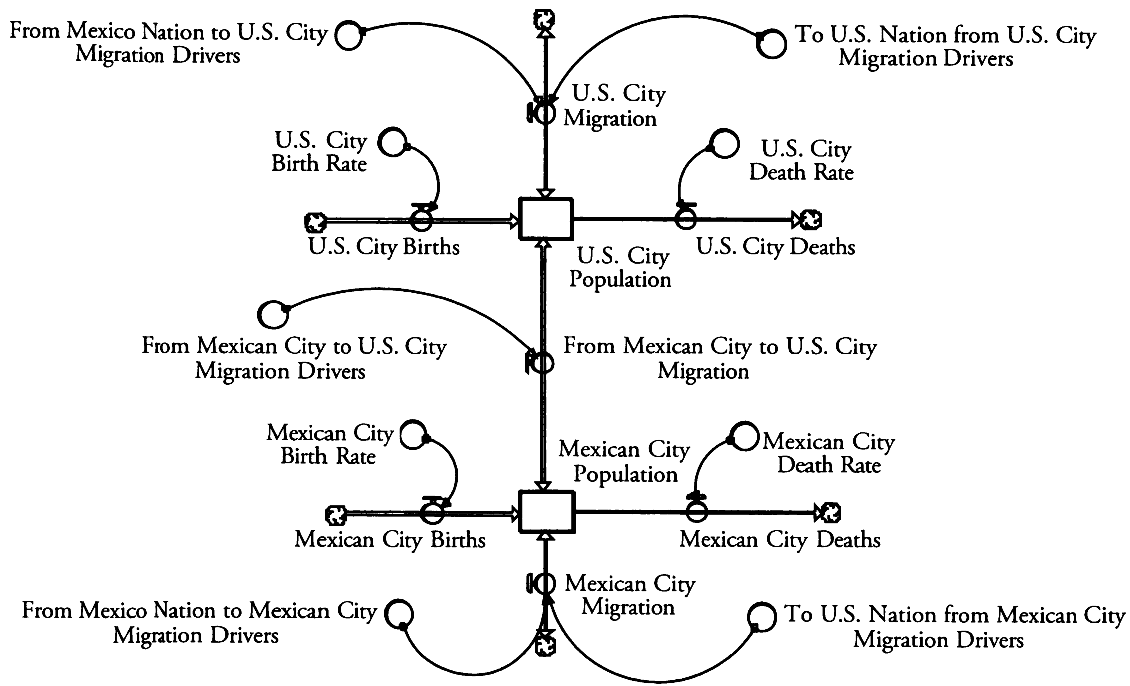


Note: The stock of Border Population is affected by flows of people into (Border Births, Border In-Migration) and out of (Border Deaths) the population stock. Model structure created using STELLA®.
Source: Authors

In Figure 2, the number of people in the stock of Border Population is affected by migration flows, deaths, and births. An exogenous source of babies generated according to the Average Border Birth Rate leads to the flow of newborns into the population stock. An exogenous sink of decedents controlled by the Average Border Death Rate accommodates the flow of deceased from the population stock. Although not explicitly shown in Figure 2, both birth rates and death rates vary as a function of time due to changing demographic trends. For example, implementing policies that lead to improved health conditions might produce reduced death rates while improved educational attainment policies might produce reduced birth rates. The border migration drivers differ depending on whether one is considering the arrival of Mexican nationals from elsewhere in Mexico to the border or the departure of U.S. and Mexican nationals from the border to other locales in the United States. This differential perspective is required because the Mexican border region has greater economic opportunity than most other places in Mexico. In contrast, the U.S. border generally has less economic opportunity than most other places in the United States. Ultimately, migration drivers will vary through time as local economic conditions change in response to national-level economic changes in both the United States and Mexico. This aggregate view of the evolving border population is represented by using birth rates and death rates averaged for both U.S. and Mexican population cohorts. In addition, neither age nor gender differences are accounted for in this simple, aggregated model of the evolving border population. This issue will be revisited in a subsequent discussion of the population sectors incorporated into the B+20 model (Chapter II-3).

A more evolved model structure is shown in Figure 3 to represent the fact that the B+20 team was interested in studying the population dynamics of individual border communities of El Paso, Tex.-Ciudad Juárez, Chih., San Diego-Tijuana, and Mexicali, B.C.-Calexico, Calif., where local conditions that affect quality of life can be explored. Although modeling the entire border may be valuable to explore certain broad-scale questions, such a model cannot help explore the questions that typically arise as people try to respond to the dynamics of change in the specific airshed and watershed of a border twin city. Thus, two parts of a twin city are represented in Figure 3—the U.S. city and the Mexican city. Although the basic structure is unchanged from the aggregate border population model of Figure 2, new structural elements are introduced to account for differences in birth and death rates in each city and to represent the various factors that cause people to migrate to and from the twin cities, either between the cites or to and from elsewhere in the United States and Mexico. The model structure shown in Figure 3 has a number of features in common with the local population sector of the Paso del Norte system model outlined in detail in Section II. Other sectors of the Paso del Norte model that affect, or are affected by, the population sector include national and local economies, land-use, transportation, water supply, water demand, air quality, national populations, and infrastructure development. The resulting Paso del Norte model is an integrated model of population growth, economic development, and environmental change that has attributes in common with other models developed to explore relationships at single-city, regional, single-nation, multi-

Figure 3. A More Complex System Model Structure



Note: This structure might be used to track the evolution of demographic change within twin cities at the U.S.-Mexican border. Model structure created using STELLA®.
Source: Authors

nation, and global scales. Previous integrated models, however, have not attempted to explicitly account for the human-environment dynamics of border twin cities.

If completed as functional system dynamics models, the icon structures shown in Figures 2 and 3 would lead to a system of nonlinear, ordinary differential equations that are solved simultaneously using standard numerical methods. It is important to note that the object-oriented programming language used to create the icon structures shown in Figures 2 and 3 enables the stories of diverse stakeholders and decision-makers to be incorporated into a model without requiring a detailed understanding of the underlying mathematics and numerical techniques. The ability to readily confirm that the stakeholder's stories are incorporated in the model enhances the probability that the model results will be used in policymaking. It is critical, however, that at least one person in the model development team have this understanding in order to ensure that the final model structures produce reasonable computed results.

Models of Human-Environment Dynamics

Over the past 30 years, many models have been created to study single-city, regional, single-nation, and multi-national issues that involve population growth, economic development, and the environment. Quantitative models of human-environment dynamics in binational borders, however, are lacking. The B+20 project team has been building on the experience of previous modeling efforts to create a new suite of models specifically tuned to the interrelated social and environmental complexities found in the U.S.-Mexican border region. Several integrated models of population, development, and environment are briefly outlined to help explain the approach adopted by the B+20 project team. A subsequent section describes how the systems thinking and modeling approach underlying these models can be used to capture the interrelationships and complexities of human-environment dynamics in the U.S.-Mexican border region.

Sanderson (1994) and Lutz, et al. (2002a) provide useful summaries of several population, economy, and environment modeling studies. The most notable, or perhaps notorious, of these models is the World3 system dynamics model produced by Meadows, et al. (1972) for the Club of Rome. Developed to explore issues of global sustainability over a century, this system dynamics model contains separate sectors that represent global population, pollution, resources, agriculture, and capital. Meadows, et al. (1972) explored alternate futures under different conditions of total food supply, total resource base, and the ability of technology to improve production and efficiency. Computed outcomes based on business-as-usual scenarios typically show a collapse of global population and industrial capacity sometime within the 100-year projection time period because the population would grow beyond a level that could be sustained by projected food availability. Twenty years into the 100-year projection period, Meadows, et al. (1992) note that there is little evidence that the attitudes and policies needed to control growth and reduce the likelihood of a global collapse have been adopted. Key intervention strategies suggested by the World3 model would involve slowing growth and improving technology at rates not currently being attained. Unfortunately, at the global scale, many of the parameters needed to constrain the World3 model are unknown and unknowable (Sanderson 1994). Furthermore, the lack of specificity leads to overly general results that are difficult to interpret and incorporate in policy recommendations. Because changes in model parameters create a range of possible outcomes, the model user may create any desired outcome by changing pertinent parameters (Meadows, et al. 1992; Sanderson 1994). This non-specificity led to significant debate about the plausibility of the outcomes indicated by the World3 model. Although widely criticized, the World3 model provides valuable insight by graphically illustrating how the global system might operate under different future growth scenarios.

Location-specific models lead to less debate because the models are more closely tied to reality and are based on parameters specific to the modeled region. Because the results from such models are more credible and meaningful to stakeholders, they provide valuable support for policymaking. This is the intent in focusing the B+20 project team on border twin cities, rather than modeling pan-border processes. Sanderson (1994) and Lutz, et al. (2002a) outline several location-specific models developed to explore relationships and interactions between population, the economy, and the environment. Soon after the World3 model results were published (Meadows, et al. 1972), Picardi (1974) developed and applied a suite of models to study the effects of past and potential future policies on sustainable development in a portion of the Sahel in Niger, where the inhabitants depend on livestock for food and other purposes. The model provides valuable support for policymaking because the abrupt economic and environmental collapse experienced in the region during the early 1970s was mimicked by the overshoot and collapse behavior computed by the model. Explorations made with the model indicate that the collapse occurred through unsustainable use of common grazing land, rather than as a direct consequence of a severe drought, though the timing of the drought influenced the timing of the collapse. In addition, the model results show that interventions implemented to improve conditions ultimately worsened the effects of the drought. Finally, Picardi (1974) shows that progressive elimination of the interventions over several decades would produce better conditions than if the interventions were retained.

During the 1990s, the International Institute for Applied Systems Analysis (IIASA) completed a series of modeling case studies on Mauritius, Cape Verde, and the Yucatan peninsula, as well as in Botswana, Mozambique, and Namibia using variants of the Excel-based PEDA (Population, Environment, Development, Agriculture) model (Lutz, et al. 2002b). Although many site-specific aspects of the model studies differ, all include a population framework that distinguishes age, sex, and education while focusing on the interactions between changes in population size and distribution, natural resource degradation, agricultural production, and food security (Lutz and Scherbov 2000). The PEDA models have been used to explore well-defined questions of critical interest to stakeholders and decision-makers from each region. In each case, valuable insights were obtained that aid policymakers in planning for the future. These successes suggest that similar success can be obtained by exploring well-defined U.S.-Mexican border questions using appropriately crafted system dynamics models within a community engagement context.

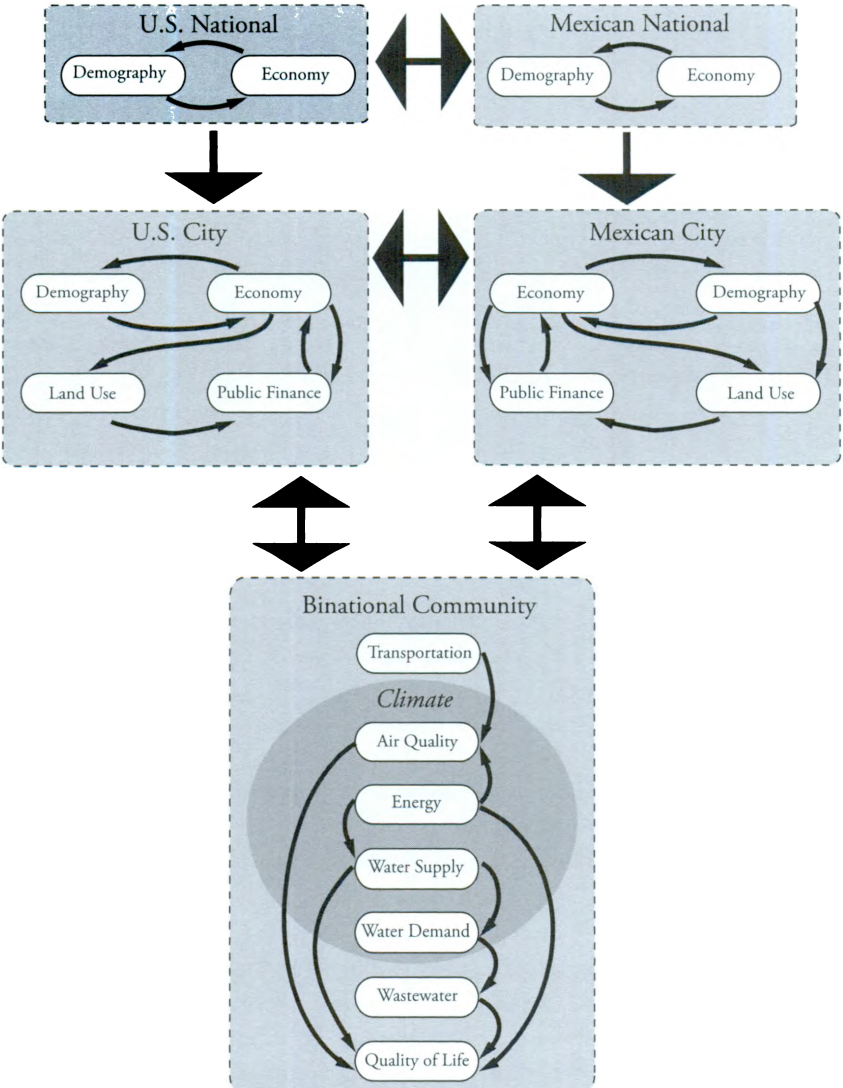
The Border+20 Project

A Systems View of the U.S.-Mexican Border

The principal elements of a binational, human-environment system model are shown in Figure 4. Changes in national populations and economies drive change in two twin cities that, in turn, interact through a common border community. Ultimately, local changes in both the economy and population are influenced by the way border inhabitants respond to concerns about human health and other aspects of quality of life that then reflect conditions evidenced at the national level. At the same time, quality of life is strongly influenced by the changes in transportation, energy, water supply, wastewater treatment, and air quality that are driven, in turn, by changes in population and economic activity. There are two parts to each model element—one on the U.S. side of the border and one on the Mexican side. The binational system model structure explicitly distinguishes between processes operating on each side of the border and the processes that cause the transfer of "stuff" across the border. An important contribution of the systems approach is it accounts for the links, feedbacks, and interactions across the border that are not always considered by decision-makers working independently on each side of the border.

"Stuff" flowing across the border and within the border community includes water (good and poor quality), air (polluted and otherwise), disease, money, products (food, agricultural, commercial, manufacturing, and entertainment, among others), waste products, social capital, services, electricity, fuels, vehicles, light, sound, ideas, community spirit, flora, and fauna. In many cases, human activity at the border restricts the flow of "stuff" across the border with the most active restrictions occurring at the ports of entry found in twin cities. Notable exceptions include the transborder movement of groundwater in binational aquifers, migration of air pollution in binational airsheds, and the movement of indigenous flora and fauna within and through regional ecosystems. The movement of other "stuff," however, is restricted by the physical, eco-

Figure 4. Overview of Human-Environment Links in a U.S.-Mexican Border System



Note: In the interest of clarity, the details of links between internal components of one sector and those of adjacent sectors (e.g., the influence of public finance on transportation, water supply, and wastewater treatment infrastructure) aggregate into the two-way arrows that link aggregate sectors of the system.
Source: Authors

nomic, legal, and spiritual presence of the border. Over time, climate and other characteristics of the border system evolve through both natural variability and the effects of man.

A thought experiment proposed by the B+20 project team asks: "How might the border human-environmental system change if all restrictions on transborder flows were removed?" Once this scenario is thoroughly mapped, it would be valuable to compare it to one where all flows that can be controlled are severely restricted. Several different outcomes could be envisioned for each scenario. It is hoped that such an exercise would help define a mix of bilateral policies that would lead to a sustainable future for border inhabitants. For example, removing all restrictions on human migration across the border might cause massive movement of Mexican citizens to the United States. Although one should expect an initial period of enhanced migration, people will only migrate across the border as long as conditions in the new location are clearly preferable to those in their home community. As people move from place to place, their behavior modifies the demographic and economic conditions at each location while consuming natural resources. At the same time, ties to one's home community are difficult to break—and perhaps even more difficult when it is easy to travel home frequently in the absence of border restrictions. In the absence of performing a quantitative, multifaceted calculation, however, it is difficult to guess the resulting demographic and economic conditions. At this stage in the B+20 project, however, the team is focused on more localized geographic targets with smaller-scale questions aimed at better informing decision-making in specific twin cities.

Two general options exist for developing system models of human-environment interactions on the U.S.-Mexican border:

- Contract with advanced modeling teams to adapt and combine existing system dynamics modules to fit the specifics of a border region
- Develop border-specific models and modules using commercial model-building software

Adopting the first option would cause the B+20 project team to act as an advisory group that could influence and inform, but not necessarily become proficient in, model development. The

Millennium Institute provides such a service with its Threshold 21 (T21) Integrated Computer Development Model. The Millennium Institute (2003) reports "...the T21 model enables integrated, comprehensive development and policy planning." In addition, "...T21 is transparent, collaborative, interconnected, valid and customizable with a core that can be applied to most countries and regions." The T21 model has been used to simulate alternate sustainable development futures at the single-nation scale in Bangladesh, China, Ghana, Guyana, Italy, Malawi, Somaliland, Tunisia, and the United States. A national water system model is also available. The Sustainable Development Research Initiative (SDRI) within the Institute for Resources, Environment and Sustainability provides similarly advanced modeling services with an emphasis on developing interactive gaming environments (QUEST™) for users to explore "what if" scenarios for the futures of a region. Gaming environments have been developed for the Georgia and Lower Fraser basins of British Columbia, Canada. Envision Sustainability Tools, Inc., has developed additional applications for regions in Mexico, Indonesia, Malaysia, Canada, New Zealand, and England. Although building models from scratch leaves the team unable to take direct advantage of the advanced T21 or QUEST™ modules that might be readily adapted for application in the border, border researchers are able to develop and hone their own system thinking and modeling skills. As a consequence, the B+20 project team has built an original model of human-environment interaction on the U.S.-Mexican border.

Several system dynamics model-building environments, including STELLA®, Vensim®, and Powersim®, are available and use a simple, visual programming language to create complex model structures. Although superficial aspects of these model-building programs differ, their fundamental properties are similar. The B+20 project team uses STELLA® in large part because several team members already had experience with the software. STELLA® software is best applied to aggregate views of the system of interest where modeling the detailed spatial patterns of change is not critical to developing the insight needed for policymaking. The B+20 models involve only a small number of aggregated spatial units—the two nations and three land-use types associated with each U.S. and Mexican twin city. As the need for spatial disaggregation is identified, the fundamental relationships and model structures developed with STELLA® can be transferred to other programming environments such as SIMILE (Muetzelfeldt and Taylor 2001; Simulistics 2003) or Spatial Modeling Environment (SME) (University of Maryland Institute for Ecological Economics 2003), which provide detailed representation of spatially explicit changes in a system dynamics modeling context. The user-friendly capabilities of SIMILE and SME have increased significantly over the past few years and continue to evolve in ways that suggest they will provide good options for the spatially explicit modeling that is impossible with STELLA® and similar software.

Interdisciplinarity, the B+20 Project Team, and Team Dynamics

In pursuing the goals of the B+20 project, it was necessary for SCERP to create a new interdisciplinary research team drawing on the resources of the various institutions involved in SCERP. The B+20 project team comprises researchers from U.S. and Mexican academic institutions that are members of the consortium. Disciplinary expertise represented by the team members included border studies, hydrology, air quality, energy supply and demand, water resources supply and demand, urban planning, psychology, economics, demography, sociology, ecology, earth science, human health, and communication. For many team members, this was their first broadly interdisciplinary research project. During the first years of the project, several team members became inactive while new researchers joined the team. At the same time, the remaining team members became increasingly able to work together.

Conclusion

The B+20 project team has developed operational system dynamics models for Paso del Norte and for the Salton Sea hydro-ecosystem using STELLA® software. Stakeholders have been engaged intermittently in discussions of the Paso del Norte model and stakeholder engagement will continue as the model becomes increasingly tuned to the specifics of the community and is disseminated for use. As the

Paso del Norte model became finalized, the B+20 project team shifted focus to the Mexicali-Imperial Valley community. Lessons learned when developing the Paso del Norte system model and the model structures created are transferable to the Mexicali-Imperial Valley community, with some modification. Although many fundamental aspects of the two border communities have similar model representations, such as national economy, local economy, population, land use, and air quality, differences between the two hydrologic systems requires markedly different hydrologic model structures. In Paso del Norte, key water features are the Rio Grande/Río Bravo and several groundwater aquifers. In the Mexicali-Imperial Valley, key water features include the Colorado River, Salton Sea, and several groundwater aquifers. Development of the Salton Sea hydro-ecosystem model has been proceeding in the background to provide the hydrologic and ecosystem modeling framework that must underlie integrated models of human-environment interaction in the Mexicali-Imperial Valley community.

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I-2

Environment and Quality of Life: A Conceptual Analysis and Review of Empirical Literature

Edward Sadalla, Subhrajit Guhathakurta, and Susan Ledlow

ABSTRACT

This chapter describes the conceptual and empirical underpinnings of a system dynamics model of the relationship between environmental changes and quality of life (QoL) indicators in the U.S-Mexican border region. The objectives of this aspect of the Border Plus Twenty Years (B+20) project were to:

- Conceptualize the "quality of life" construct
- Survey existing empirical literature and identify links between QoL indicators and elements of the environment
- Suggest a set of indicators appropriate for measuring dimensions of the QoL of residents of U.S.-Mexican border communities
- Incorporate the indicators in the B+20 system dynamics model

Underpinning this project is the assumption that forecasts of environmental change must take into account the effects of such change on residents of a region because such human impact is intrinsically important and because changes in QoL in a region will feedback and influence the environment.

El Medio Ambiente y la Calidad de Vida: Un Análisis Conceptual y Revisión de Literatura Empírica

Edward Sadalla, Subhrajit Guhathakurta, y Susan Ledlow

Resumen

Este capítulo describe los apoyos conceptuales y empíricos de un modelo de sistema de dinámicas de la relación entre los cambios ambientales y los indicadores de la calidad de vida (CdV) en la región fronteriza México-Estados Unidos. Los objetivos de este aspecto del proyecto Frontera Más Veinte Años (F+20) fueron:

- Conceptualizar el término "calidad de vida"
- Encuestar la literatura empírica existente e identificar las relaciones entre los indicadores de la CdV y los elementos del medio ambiente
- Sugerir una serie de indicadores apropiados para medir las dimensiones de la CdV de los residentes de las comunidades de la frontera México-Estados Unidos
- Incorporar los indicadores en el modelo de sistema de dinámicas F+20

Apoyar este proyecto supone que proyecciones de cambios ambientales deben de tomar en cuenta los efectos de dicho cambio en los residentes de una región ya que dicho impacto humano es intrínsicamente importante y debido a que los cambios en la CdV en una región realimentaría e influenciaría al medio ambiente.

Conceptualizing Quality of Life

At first glance, the quantitative study of quality of life (QoL) appears to confront significant theoretical and methodological obstacles. Quality is intrinsically a value term that seems to refer more to a matter of opinion than to extant, quantifiable features of a region. Further, there are a number of ways to conceptualize QoL, many of which emphasize the subjective, relative, culturally dependent nature of the construct. The diversity of possible referents for the term is associated with an equally large number of possible measurement approaches, leading to the suspicion that any given measurement of QoL is arbitrary and potentially misleading.

Nonetheless, it can be seen that measurement of QoL is essential to the analysis of human environment interactions. In the current project, QoL is a generic term that refers both to the human impact of environmental changes and to the way in which such impacts are evaluated. It is clear that environmental changes can have both local and far-reaching effects on humans, and that the impact of environmental changes in many cases depends upon how such changes are evaluated. Despite the difficulties involved, the conceptualization and measurement of QoL is essential to the understanding of human-environment interactions.

It is important to note that evaluation is fundamental both to human cognition and to environmental planning. Studies of human cognition (such as Osgood and Tzeng 1990) have repeatedly found that evaluative terms are the most common elements found in studies of semantic space. Humans are apparently incapable of cognizing environments without applying evaluative or qualitative constructs.

Environmental planning, like naturally occurring human cognition, typically involves the assessment of quality. The following questions describe some basic elements involved in any planning process:

- What is likely to occur?
- Will it be good or bad?
- What are some alternative courses of action?

The second question refers to the qualitative assessment of a future scenario. When evaluation concerns the impact of environmental changes on humans, "quality of life" becomes an unavoidable issue.

A Biocultural Approach

The model of QoL proposed in this chapter can be characterized as a biocultural approach. It is based on the assumption that there are biologically based aspects of human nature that characterize members of all cultures, in addition to culturally specific characteristics. A complete description of QoL in the border region would require knowledge of both biological universals and cultural variables. Assume that, for the purposes of the present study, appropriate descriptions of QoL can be constructed by using variables that characterize QoL in all cultures and by adding variables that the cultures in question have in common.

The goal of this research project was to evaluate and model the relationship between environmental changes and QoL in the U.S.-Mexican border region over a 20-year period. For the purposes of the present study, QoL must be conceptualized in a manner that allows empirical assessment of:

- Changes over time of QoL in the border region
- Changes in QoL on the U.S. side of the border
- Changes in QoL on the Mexican side of the border
- Convergence or divergence of the QoL of residents on each side of the border

Cultural Relativism and Quality of Life

The binational region that is the focus of this project is characterized by multiple cultures. Culture was defined in 1871 by one of the founding fathers of anthropology, E. B. Tylor, as "that complex whole which includes knowledge, belief, art, morals, law, custom and other capabilities and habits acquired by man as a member of society." Culture may be built upon demographic variables (nationality, ethnicity, age, gender, place of residence, language), status variables (education, income), or it may be organized in relation to political or religious belief systems.

Culture includes value systems that define QoL, thus the relevant indicators of QoL are likely to vary from culture to culture. Even when different cultures regard the same indicator as relevant to QoL, they may hold different opinions of its importance. For example, one culture may place a high priority on "gender equality" as a QoL indicator, another culture may regard it as desirable but relatively unimportant, while a third culture may not even use the category.

The problems of specifying the units that are appropriate to between-group comparisons are not unique to studies of QoL. Similar issues have been confronted in the disciplines of linguistics, anthropology, and psychology. To be explicit about the methodology used in the current approach, general approaches to cross-cultural and between-group measurement (the etic-emic distinction and the idiographic-nomothetic distinction) will be reviewed and three specific models of QoL considered.

Etic-Emic and Idiographic-Nomothetic Distinctions

The terms "etic" and "emic" (derived from the suffixes of the linguistic concepts of phonetic and phonemic, respectively) were developed by Pike (Pike 1982; Pike 1987; Headland, Pike, and Harris 1990) to distinguish between general, universal classification systems and classification systems specific to a culture or group. An etic category system, like the phonetic alphabet used by linguists, is a universally applicable classification system for categorizing behavior. An etic system is the creation of the researcher—a classification scheme ready to be applied to data encountered in any given context. For example, a researcher who takes an etic approach to the study of QoL might assume that such dimensions as health, education, social equality, employment, and leisure are useful, measurable indicators of QoL. Such a scientist would use these concepts regardless of the population or cultural group being studied.

Phonemic categories involve the subset of the phonetic alphabet that is meaningful to a linguistic community. Emic has thus been used to refer to constructs and categories that reflect locally defined meanings, cultural uniqueness, and "point of view." Emic systems are discovered by the researcher through observation of the distinctions made by local speakers. If the researcher in the previous example took an emic approach to the study of QoL, he would not assume that health, education, social equality, employment, and leisure were concepts relevant to every population or cultural group. The emic researcher would attempt to uncover culturally specific concepts of QoL and might find that some cultures do not place a high value on education or leisure.

With respect to the concept of QoL, researchers have alternated between etic and emic approaches, primarily because there are both similarities among and differences between cultures concerning what constitutes QoL. With respect to the current investigation, an emic analysis would reveal that QoL definitions vary with geographic region and with culture group. Further, an emic analysis would probably show that QoL concepts change over time within a region.

A closely related distinction, which has emerged from the study of personality traits, is the distinction between nomothetic and idiographic assessment methodologies. Nomothetic approaches assume that a set of traits may be defined in advance and used to study and categorize individuals in any given culture or society. Idiographic approaches assume that no a priori set of categories can be applied to an individual or group, but rather that assessment must precede the development of a category system. Idiographic categories are developed inductively through observation and are not assumed to apply to any groups other than the one for which they were developed. Both nomothetic assessment and etic category systems approach a new situation with units prepared in advance, ready to be assessed in that situation, whereas both idiographic and emic approaches lead to the development of category systems only after a particular sociocultural context has been analyzed.

An emic-ideographic analysis is, for these reasons, poorly suited for cross-cultural comparisons. Such comparisons require that the same yardsticks be applied in different contexts. The emic-ideographic view is monocultural, its units derived from the analysis of only one individual, one group, or one culture at a time. In contrast, the etic-nomothetic approach is highly appropriate to cross-cultural measurement in that its units are derived by comparing many systems and by abstracting from them a single scheme that can be applied to multiple cultures.

Etic-Nomothetic Methodology and the Biocultural Model

Etic-nomothetic approaches to QoL contain the commonalities abstracted from emic analyses. In terms of the biocultural approach previously outlined, an etic-nomothetic methodology captures the common elements of human nature that characterize QoL in all cultures, as well as the overlap in conceptions of QoL that members of particular cultures have in common. As noted above, long-term goals involve QoL comparisons across cultures and over time. Such comparisons are not possible under the idiographic, emic assumptions that the constituent indicators of QoL vary by region, by culture, or are subject to change over time. Regional assessment of cultural variation in the concept of QoL is beyond the scope of this project. In the following pages, the QoL indicators that have been suggested by various cultural groups are reviewed in various international contexts. The review will show sufficient commonalities to justify the use of etic-nomothetic categories of QoL, which will be proposed for the purposes of this study.

Models of Quality of Life

The literature on QoL contains a variety of implicit models of the construct. To be explicit about the conceptualization employed in the current project, three general approaches to defining QoL will be reviewed: the Hedonic Quality model, the Preference Satisfaction model, and the Value/Ideal models.

Hedonic Quality

Hedonic Quality approaches assume QoL is related to the types of conscious experiences common among inhabitants of an area. Conscious experiences such as feelings of pleasure, happiness, satisfaction, or other positive emotions are said to characterize high QoL. Conversely, low QoL is defined by a predominance of negative emotions.

It is possible to study hedonic tone or hedonic quality empirically. A typical study asks residents to record the emotion or emotions they experience at various intervals during the day. Some studies use behavioral indicators of hedonic quality such as facial expression, frequency of laughter, or even frequency of consumption of tranquilizers or antidepressants. To date, such studies have primarily explored the impact of socioeconomic class. Although this literature is tangentially related to the current topic, it suggests that hedonic quality is ambiguously related to social class and environmental quality. In a number of studies, members of lower income classes have been found to laugh more, worry less, and consume fewer sleeping pills, tranquilizers, and antidepressants than members of higher income classes who presumably have more positive environmental circumstances. In general, however, a systematic body of literature that relates dimensions of the environment to specific emotions or hedonic quality does not exist.

Preference Satisfaction

Preference Satisfaction models define QoL in terms of the extent to which people get what they want, regardless of the extent to which the outcome produces positive emotions. High QoL from this perspective consists of the consistent satisfaction of desires and preferences. Low QoL is associated with the frustration of desires and preferences. For example, if an individual or group desires to watch television and is allowed to watch television, a preference satisfaction framework would suggest that QoL has been improved. Literature that suggests watching television typically has an emotionally depressive effect (Kubey and Csikszentmihalyi 2002) is irrelevant from this standpoint. Similarly, if an individual or group desires to smoke cigarettes and are allowed to do so, preference satisfaction theories suggest that QoL has been improved. Long-term consequences to health or the environment are not relevant when the criterion for QoL is preference satisfaction.

From this perspective, QoL in a region is an aggregation of individual preferences. Since preference measurement is well established in the social sciences, QoL may be addressed by current empirical techniques. Conceptually, aggregate QoL would be related to the ratio of preferences satisfied relative to preferences not satisfied.

Value/Ideal Models

Value or ideal models define QoL in terms of explicit, specific, normative values. Such theories assume that there exists a set of QoL indicators that characterize every region and are somewhat independent of the specific emotional experiences or preferences of any given group. The measurement approach is both etic and nomothetic in that it does not require assessment of any specific group's conception of QoL; it is assumed that the same set of values can define QoL in a variety of cultures and geographical locations. A classic example of a QoL dimension in this approach would be health. From the perspective of an "ideal" model, good health is an indicator of high QoL and poor health is an indicator of low QoL, irrespective of local preferences or local hedonic consequences. Environments that promote good health are said to promote QoL, and conversely, environments that have negative health impacts are said to lower QoL. Other common value domains used to define "ideal" indicators include economic and material well-being, physical health and longevity, mental and emotional health, community health, education, class, and gender equality. These value domains will be discussed in greater detail later in the chapter.

As noted above, "ideal" QoL indicators are thought to reflect both universal conceptions of QoL and commonality between cultures. It should be noted, however, that in some instances "ideal" models conflict with the preferences of subsets of a local population. An example of such an indicator might be "gender equality in access to education." While an ideal model might regard this as a QoL indicator across populations or cultures, local preferences might actually deem such equal access undesirable.

An "ideal" model of QoL is most appropriate for the current project. Ideal indicators have been designed to allow assessment of the rate and degree to which environments are becoming more or less supportive to humans. How is it clear that progress is being made toward the ideal of improving the QoL in a region? How can the rate of progress toward that ideal be assessed? How can the changes in QoL over time on both sides of the border be compared? The role of ideal indicators is to provide an answer to these questions. The indicators should be relevant and applicable to the specific geographic scale—local, regional, national, or international. A successful indicator allows end users of the modeling effort to grasp the human impact of the whole system quickly.

Relationship Between Quality of Life Models and Sustainability Indicators: The Importance of "Ideal" Models

The Border Plus Twenty Years (B+20) Project is concerned with both "a healthy and sustainable natural environment" and an "adequate QoL for all border inhabitants." As such, QoL indicators selected by the project must be constructed with sustainability in mind and may designate criteria that take into account the individual, the social group, and the environment.

The following premise is suggested in this section: QoL models based on either hedonic quality or preference satisfaction will not lead to sustainable environments. Ideal models of QoL, because they can include sustainability as a fundamental value, can lead to the development of sustainable environments. From a Darwinian point of view, there are components of human nature that make it difficult for humans to construct sustainable environments as well as components that encourage thinking about sustainability. Biologically based tendencies that constitute obstacles to sustainability include a human tendency to employ a short-term time perspective, a basic desire for increased status in hierarchical social systems, and a tendency to identify with one's local group and local environment (tribalism or territoriality). The first of these to illustrate the relationship between QoL models and sustainability will be considered.

Short-Term Time Perspective

One reason humans have difficulty constructing sustainable environments is that sustainability is about long-term benefits to the environment that generally come at the expense of short-term satisfactions for humans currently occupying the region. Evolution encourages precisely the opposite tendencies. Humans are adapted to the environment of the Pleistocene era. The environment of evolutionary adaptation posed significantly different problems for human ancestors than are faced by modern humans. During this time period, which constitutes approximately 95% of human history, world-wide planetary population was somewhere between 2 million people and 10 million people. The hunter-gatherers of the Pleistocene were nomadic; they consumed the resources of a region and then moved on. It was adaptive to over-consume food and other resources so that periods of scarcity, such as during winter or drought, could be survived. Humans who could solve immediate problems survived and reproduced. In the Pleistocene, there was no evolutionary advantage that accrued to individuals who conserved the environment.

Evolution has shaped the human mind to respond positively (to prefer, and to experience, hedonic quality) to short-term reinforcements and to have preferences for short-term rather than long-term benefits. As Dawkins (2001) notes, "Short-term genetic benefit is all that matters in a Darwinian world ... The values that will have been built into us will have been short-term values not long-term ones."

Empirical evidence generally supports the notion that humans are predisposed to think and react in terms of the immediate future. Decades of research on human learning have shown that immediate reinforcements and immediate consequences have a far greater impact on human learning and human behavior than do delayed reinforcements or delayed consequences. Emotions such as fear or anger are much more likely to occur when the anticipated threat is imminent. Conversely, delayed threats are unlikely to engender much emotional response. Thus, people repeatedly build in floodplains, on earthquake fault lines, and in areas repeatedly threatened by hurricanes.

Modern humans, however, live in a world in which the long-term threat from unsustainable environments or unsustainable economies may be more serious than immediate threats. Humans are entering this world with a set of desires and emotional responses that have been produced by millions of years of evolution, and are generally unsuited to cope with these problems. If QoL is conceptualized in terms of emotional responses or in terms of preferences, sustainable environments are unlikely.

Fortunately, evolution has also equipped humans with a remarkable ability for foresight and planning. More than any other species, humans are capable of anticipating the future results of present actions and delaying immediate gratification for future gratification. Human history, from the construction of the pyramids to current technological successes such as space flight, illustrates that humans are capable of setting long-term goals and achieving them.

Such considerations argue for the use of "ideal" indicators of QoL as opposed to hedonic quality or preference satisfaction indicators. The latter are associated with short-term outcomes, while ideal indicators can include sustainability as a value.

A Survey of "Ideal" Quality of Life Indicators

There has been an increasing interest in developing generally applicable QoL indicators in the last 20 years. The assessment of QoL has received special attention from several international organizations including the United Nations, the World Bank, the World Health Organization, and the International Labor Office. New and modified indicators of QoL for many regions of the world appear continuously in journals such as *Social Indicators Research*. Table 1 displays QoL indicators recommended by various groups.

Diener (1995) reviewed the process of selecting indicators for a QoL index and found, not surprisingly, no standard method of selection. He consequently proposed seven categories of "universal values" that had been developed by Mukherjee (1989) and Schwartz

Table 1. Survey of Indicators

UN	OECD	Philippines	Japan
Health Food Education Employment Housing Social security Clothing Recreation Human freedoms Population Income and expenditure Communication and transport	Nutrition Clothing Shelter Health Education Leisure Social security Social environment Physical environment Social status Education	Health, nutrition Learning Income Employment Environmental resources Housing, utilities Public safety Justice Political values Social mobility	Health Education, learning Employment Quality of work Leisure Income Spending Material environment Crime Law enforcement Family Community life Class, social mobility

Finland	Sweden	India	U.S. (Calvert-Henderson)
Health Education Physical environment Inequality Housing, habitat Working conditions	Work, working conditions Economic resources Political resources Schooling Health, medical care Family origin, family relations Housing Nutrition Leisure time and pursuits	Population Health, nutrition Housing Education Labor, employment Income, expenditure, wealth	Education Employment Energy Environmental health Human health Human rights Income Physical infrastructure National security Public safety Recreation Shelter

Source: Authors

(1994). Schwartz arrived at seven value domains from a comprehensive list of 45 values derived from an extensive literature review. He then sampled 41 cultural groups in 38 nations and assembled from other sources 38 samples of schoolteachers and 35 university students. The seven value domains provided in Table 2 were gleaned from these samples.

In another comprehensive effort based on an extensive literature review, Mukherjee derived four value domains that contain elements similar to Schwartz's list. The elements classified by Mukherjee are indicated in Table 3.

Among the myriad indices measuring QoL, the Physical Quality of Life Index (PQLI) has received considerable attention. The initial version of PQLI was published early in 1977; expanded technical explanations followed (Morris 1979). PQLI (like the Human Development Index of the United Nations) was developed as an alternative to the gross national product (GNP) as a measure for a

Table 2. QoL Elements Classified by Schwartz

Value Regions	QoL Elements
Masterly (Success, capable, ambitions)	Length of life Infant mortality rate Families at risk
Affective autonomy (Enjoying life, pleasure, exciting life)	Suicide rate Self-rated health
Intellectual autonomy (Curious, broad-minded, creative)	College education
Egalitarian commitment (Equality, social justice, freedom)	Unemployment rate Poverty rate
Harmony (Protective of environment, aesthetic appreciation, unity with nature)	Residential density Environmental toxins index
Conservation (Social order, self-discipline, family security)	Violent crime rate
Hierarchy (Wealth, social power, authority)	Per capita personal income

Source: Schwartz 1994 and 1996; Diener 1995

Table 3. Elements of Quality of Life Classified by Mukherjee

Mukherjee's Value Regions	QoL Elements
Survival of the species	Suicide rate Length of life Infant mortality Self-rated health
Security in the life-span of humans	Families at risk Violent crime rate Environmental toxins index
Material prosperity for well-being	Per capita personal income Unemployment rate Poverty rate Percent households with 1.1 or more persons per room
Mental progress to unfold potentials of all	Percent with 4 or more years of college

Source: Mukherjee 1989

region's socioeconomic development. The study team argued that while there are some general correlations among per capita income and longevity, health, and literacy, among other factors, the relationships are not obvious in many countries. Moreover, there were glaring exceptions in cases where countries with high per capita incomes fared poorly in many other human development indices and vice versa. Thus, the objective of PQLI was to develop a measure that would address the distributional effects of income growth but also be effective across cultural and structural differences among countries. In this respect, this measure is particularly helpful in the case of binational regions having two distinct economies and cultures.

The PQLI ultimately settled on three apparently universal concerns. First, health seemed to be a primary concern in all cultures as longevity and good health were generally prized in almost every culture. Second, infant mortality was a rallying issue for government action across many regions and countries. Third, literacy was widely accepted as a surrogate for individual capacity and social participation. On the basis of these assumptions, three indicators were selected for inclusion in the PQLI—infant mortality, life expectancy at age one, and basic literacy.

While the three indicators by themselves do not explicitly illustrate the distributive effects of development among social groups, an improvement in these indicators does indicate the change in proportion of the people sharing the benefit. This is quite obvious with infant mortality and literacy because an improvement in either of these measures would indicate that the benefits of development have become more widespread. In summary, the simple three-indicator index has served as an effective proxy for the stage of development of a region.

Characteristics of Indicators

QoL indicators must meet conventional standards for reliability of measurement and must be capable of being validated. Blair (2000) has carefully considered the criteria that should be applied to border environmental indicators or sustainability indicators. His conclusions, presented in Table 4, were considered in the selection of QoL indicators for the B+20 project.

Aggregation of Quality of Life Indicators

It is critical to distinguish between measurement models designed to yield an aggregate index of QoL and models designed to yield a variety of relatively independent QoL indicators. In relation to the current systems model of the environment, aggregate QoL would be a global index that quantifies the total human impact of various environmental changes. Aggregate QoL would clearly be useful for planning or political decisions because it would allow decision-makers to gauge the overall effect of various alternative choices on the residents of a region. It would be useful, for example, to know how changes in the U.S. or Mexican economies affect overall QoL in the border region or how policy decisions regarding water distribution or immigration policy impact QoL.

Table 4. Requirements for Indicators

Criterion	Comment
Sensitive to change	Quick response to change; and permitting a trend to be established with a time scale tailored to the problem
Policy-relevant	Focused on issues and problems pertinent to the government agencies in the region
Valid	Theoretically sound; that is, measures the phenomenon intended and valid in relation to goals
Reliable	Data is consistent over time and can be replicated by different observers with sound collection methods
Clarity	Concept readily understood by community; preferably clear in value so no uncertainty about which direction is good and which is poor
Measurable	Technically feasible to collect data at reasonable cost; also, long term measurement of the indicator should be likely
Realistic	Broadly accepted by the community; the results should not be so controversial that implementation would be impossible
Publishable	Attractive and clear to local media so that they are publicized

Source: Blair 2000

There are however, significant obstacles to the quantification of aggregate QoL. QoL is clearly a multidimensional construct. As an example of the difficulty of aggregation, consider The Binational Quality of Life Indicators Project (2001), which specifies nine classes of indicators: demographic, public safety and crime, economic, education, health and healthcare, environmental, housing, transportation, and governance. These diverse components are not scaleable in terms of a common metric. For such disparate components to be aggregated, it is necessary to know their relative magnitudes of importance. For example, how should health indicators be weighted in relation to the economic indicators? Since there is currently no accepted method for weighting the various dimensions of QoL, aggregation is more likely to obscure real relationships between environment and QoL than it is to clarify them.

A similar logic can be applied to aggregating individual QoL measurements into scale scores. Consider the following operational measures related to health: infant mortality rate, adult mortality rate, life expectancy, lung disease, cardiovascular disease, gastrointestinal disease, daily calorie intake, and physicians per capita. Accurate aggregation of such disparate measures into a global health index would require knowledge of both their relative importance and the degree of correlation between measures. Further, the global health index would be unable to depict important relationships—lung disease is related to air quality, gastrointestinal problems to water quality, and calorie intake and physicians per capita to economic factors.

For this reason, the B+20 team's approach has been to use specific operational measures that have been designated as QoL indicators. Each specific index of QoL is linked in the STELLA® model with environmental antecedents and consequences. This approach allows decision-makers to see the human consequences of environmental changes in detail.

Conclusions Drawn from the Literature on Quality of Life Indicators

It is clear from the previous survey of QoL indicators that there is significant overlap in models of QoL indicators and considerable overlap in the indicators themselves within the models. Implicit in many of these models is the recognition that QoL is not simply related to environmental sectors—in many cases QoL is defined by quality of the environment. Residents with poor air quality, poor water quality, poor housing, or poor regional economies are, by definition, low on a host of QoL indicators. In other instances, QoL indicators such as infant or adult mortality rates are related to human responses to environmental sectors such as air quality or water quality.

The challenge for this project is to propose a set of value domains relevant to the project goals, applicable across the cultures within the border region, and readily measurable. The QoL indicators selected for this study must take into account both the commonalities among the prevalent models of QoL and the criteria outlined by Blair in Table 4. They must be selected with sustainability in mind. Given the scope of the B+20 Project, the QoL indicators included in this study are also restricted to:

- Aspects of human health or behavior that may be described by data
- Environmental features for which current descriptive statistics are available
- Aspects of human health or behavior that have been empirically linked to environmental sectors

Given these constraints, a set of six value domains has been developed that draws heavily on the work of Diener (1995), Mukherjee (1989), and Schwartz (1994; 1996), but which the B+20 team believes speaks more directly to the needs of the B+20 Project. The value domains and related indicators are presented in Table 5. Note that neither the value domains nor the indicators are considered to be an exhaustive list.

As previously discussed, the indicators will not be aggregated but rather used individually as needed to assess the impact on QoL of particular sector components.

Relationships Between Quality of Life Indicators and Sector Components

The primary goal of the present project is to model dynamic relationships between environmental components and QoL indicators. While there are many environmental factors that affect QoL, this chapter limits its discussion to those elements of the environment that have previously been identified as most significant by the B+20 Project (Figure 1). This modeling effort is based on an empirical literature review that documents links between the environment and QoL. In the following sections, the literature that underpins this model is reviewed and the relationship between QoL indicators and

Table 5. B+20 Value Domains and Indicators of Quality of Life

Value Domain	Sample QoL Indicators
Economic and material well-being	Per capita income Income variance Poverty rates Unemployment rates Home ownership rates
Physical health and longevity	Infant mortality Life expectancy Access to prenatal care Access to health insurance Communicable disease rates Environmental disease rates
Mental and emotional health	Suicide rates Access to mental health care Surveys of perceived happiness
Community health	Civic participation Number of parks and green spaces Access to transportation Access to communication Homicide rates Burglary rates Rapes Drug crimes
Education	Literacy rates Average years of schooling Achievement test scores Participation in higher education Dropout rates
Class and gender equality	Poverty rates Income variance Ratio of female to male average years of schooling Ratio of women's literacy to men's Ratio of women's employment to men's

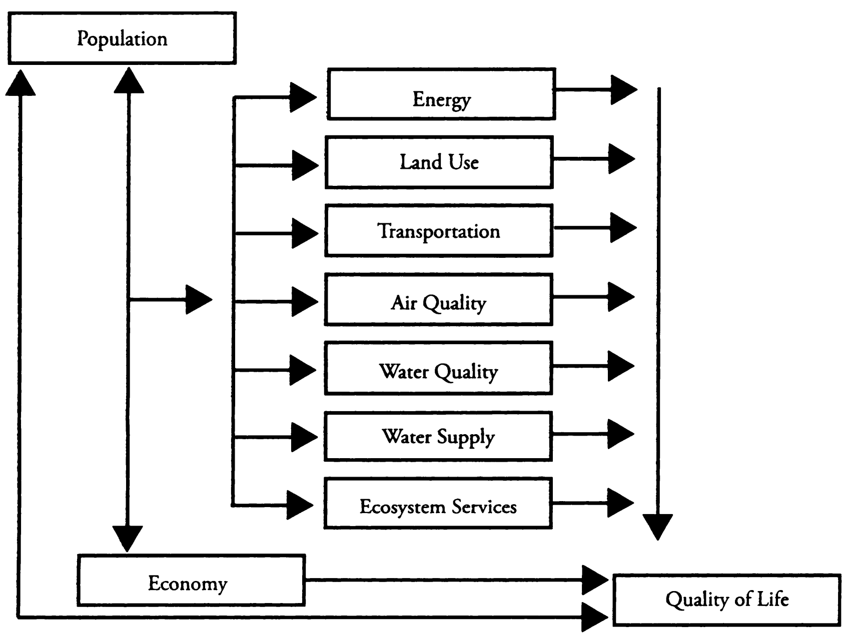
Source: Authors

four environmental factors—air quality; water quantity, quality, and infrastucture; transportation and land use; and economics—is specifically addressed. The challenge is to select indicators that are both relevant to these factors and representative of the QoL indicators commonly accepted in current literature.

Air Quality and Quality of Life

The Air Quality Sector focuses on particulate emissions from both static and mobile sources in the border region. Air quality is influenced by population size, economic factors, airshed dynamics, and border policy (border impedances will increase the number of cars producing pollution while waiting). The model depicts how industrial development, population growth, and postulated changes in vehicle ownership might ultimately affect air quality in a binational community.

Figure 1. SCERP System Dynamics Model



Source: Authors

Air quality—or its converse, air pollution—has a substantial human health impact. Air pollutants have been linked to lung disease, cardiovascular disease, and overall mortality rate. The increased rate of health problems, in turn, has an economic impact in terms of health costs and missed days at work and school.

Air pollution has been shown to contribute to lung disease, which is the third leading cause of death in the United States (Centers for Disease Control 1995). Airborne pollutants can affect areas far from those in which they are emitted, so the human impact of pollution sources must take into account both the quality of emissions, the magnitude of emissions, and their pattern of dispersal. Air toxics consist of 188 specific pollutants, many of which have been associated with negative health effects. Eighty-nine air toxics have a cancer potency value, and 16 of them account for 97% of the estimated excess cancer instances in California, with only four of them accounting for more than 70% of the estimated cases. It has been estimated that in 1990 there were more than 8,600 excess cancer cases in California, mostly due to these air toxics (Morello-Frosch, et al. 2000).

PM_{10} Levels, Lung Disease, and Mortality

Considerable research has been directed at air pollution (or particulate matter) with an aerodynamic diameter of less than 10 microns (μm), referred to as PM_{10}. Between 1987 and 1994, PM_{10} was positively associated with rates of death from all of the 20 most populated cities in the United States (Samet, et al. 2000). PM_{10} levels are positively correlated with heart attacks, strokes, lung disease, asthma, and overall mortality rates (Hester and Harrison 1998; Samet, et al. 2000)

In 1992, the national standards for PM_{10} were exceeded in 16 counties in which an estimated 9.1% of the population of the entire United States resided. Acute and chronic exposure to air pollution, namely PM_{10}, is associated with an increased risk of premature death, and it is estimated that 700,000 avoidable deaths will occur by 2020 because of PM_{10} (Samet, et al. 2000). Table 6 displays the health risks of PM_{10}.

Table 6. Combined Effect Estimates of Daily Mean Particulate Pollution

Indicator	% Change in Health Indicator per Each 10/µg/m^3 Increase in PM_{10}
Increase in daily mortality	
Total deaths	1.0
Respiratory deaths	3.4
Cardiovascular deaths	1.4
Increase in hospital usage (all respiratory)	
Admissions	0.8
Emergency department visits	1.0
Exacerbation of asthma	
Asthmatic attacks	3.0
Bronchodilator	2.9
Emergency department visits	3.4
Hospital admissions	1.9
Increase in respiratory systems reports	
Lower respiratory	3.0
Upper respiratory	0.7
Decrease in lung function	
Forced expired volume	0.2
Peak expiratory flow	0.2

Source: Dockery and Pope 1994

Although less research has been directed at other particle sizes, it has been suggested that particles with diameters of less than 10 µm pose an even greater health risk because they are more easily inhaled deep into the lungs and are more likely to be trapped in lung tissue.

Ozone, Sulfur Dioxide, Carbon Dioxide, and Health

The border region is generally characterized by abundant sunlight. As population and traffic increases in this region, ozone pollution is likely to increase. Ozone pollution occurs when hydrocarbons and nitrogen oxides from automobiles and other sources react together in the presence of sunlight. The National Ambient Air Quality Standard for ozone levels is 0.12 parts per million (ppm) averaged over one hour; this standard is met if this value is not exceeded more than once per year. In 1991, the U.S. Environmental Protection Agency (EPA) standard for ozone was exceeded in 98 areas in the United States, exposing 140 million people to excess ozone levels. During the summer months, it is estimated that an increase of 10 parts per billion in the ozone level will cause a 0.41% increase in the rate of death (Samet, et al. 2000).

Sulfur dioxide causes respiratory problems, which, while rarely fatal, do impair QoL. Sulfur dioxide does not have a significant effect on the relative rate of death of those exposed, but the respiratory problems it causes (such as asthma) are serious (Samet, et al. 2000). In 1991, 50 areas in the United States exceeded national recommended levels for sulfur dioxide. It has been estimated that the number of people exposed to sulfur dioxide in excess of the guidelines established by the World Health Organization will rise from an already high 650,000 people in 1990, to 14 million in 2020 (Streets, et al. 1999).

As noted above, variables that impact health also influence the region's economy. Sick residents incur direct health care costs and miss days of work. In a study of air quality and health in Shanghai, it was estimated that by the year 2020, air pollution would cost $500 million annually (Streets, et al. 1999). It should be noted that many of the consequences of air pollution's impact on QoL are themselves sources of stress. Increased health care costs and reduced leisure time may, in turn, further reduce QoL.

Table 7 displays an overview of the relationship between air quality variables and QoL indicators. These indicators meet Blair's criteria of appropriateness and the restrictions for the B+20 Project.

Table 7. Relationships Between Air Quality and Quality of Life

Air Quality Variables	Possible QoL Indicators	Consequences
PM_{10}	Cardiovascular disease rates Cardiovascular deaths Heart attack rates Stroke rates Hospitalizations for asthmatic attacks Lung disease rates Respiratory deaths	Health care costs Missed work or school Lost leisure time
Ozone	Lung disease rates Respiratory problems	Health care costs
Sulfur dioxide	Hospitalizations for asthmatic attacks Lung disease rates Respiratory deaths	Health care costs Missed work or school Lost leisure time
Carbon monoxide	Not described	
Nitrogen dioxide	Not described	

Source: Authors

Water Quantity, Quality, and Infrastructure

Intuitively, it seems plausible that the quantity of water in a region should increase the QoL of residents of the region. Increased water stocks should be associated with cheaper water for home use, industrial use, recreation, and landscaping. There should be economic consequences as well as aesthetic consequences to water availability.

The border that separates the United States and Mexico separates several watersheds shared by the two countries. The supply of water in the region has historically been influenced by border policies and politics, but the flow of waste and contamination follows a topography independent of the border itself. The history of this region is a history of conflicts over access to water, water quality, water distribution, and the effects of contamination, which originates on either side of the border.

The lower Colorado River and the upper Gulf of California comprise a water supply and distribution system relevant to the Mexicali, B.C.-Calexico, Calif. (Imperial Valley) region and the San Diego, Calif.-Tijuana, B.C., region. On the Mexican side, the Colorado River delta and the upper Gulf of California comprise a wetland and marine ecosystem that provides an important habitat for many migratory and local species. The region serves as a combined fresh- and salt-water nursery that has long supported the fishing industry along the coasts of Baja California and Sonora. The marshy ciénegas of the delta, along with the Salton Sea on the U.S. side of the border, form an important haven for waterfowl on the Pacific Flyway, a north-south avian migratory route that runs from Alaska to Central America. Decisions made about water use thus have impacts on biodiversity, economic opportunities, and the QoL indicators related to these sectors.

The Project on Water and Quality of Life at the California-Mexico Border, coordinated by the University of California Institute for Mexico and the United States (UC MEXUS), reports:

> The complex of interconnected ecosystems nominally protected by the biosphere reserve designation is fed by and dependent upon water from the Colorado River. This critical water supply is diminishing in the face of increasing demands on both sides of the border for agriculture and industry. Colorado River water is claimed by many states, and by the time the watercourse reaches Mexico, much of its content has been dammed, diverted, and consumed, despite international treaties governing the supply to the downstream user. Native American tribes, Mexican indigenous groups, ejidal farmers, and fishermen have legal, economic, and cultural claims on Colorado River water, and their needs and rights are overwhelmed by agribusiness, manufacturing, and urban consumption.

Groundwater aquifers in the border region have been affected by population growth, industrial and agricultural use, and water policy. Wells pump the water out for agriculture and industry, and effluents seep back into the underground supply. Contaminants in both surface and groundwater flow across the border and into the Gulf of Mexico or the Salton Sea. The Salton Sea has been affected by decreased inflow and by the build-up of pesticides from agricultural runoff. The quality and quantity of Salton Sea water is diminishing to the point that migratory species and local ecosystems are affected. For example, in 1996 and 1997 there were a substantial number of deaths of brown pelicans that inhabited the region. Some projections forecast that the Salton Sea will become incapable of supporting marine life in the next 20 years. Whether this projection proves true is uncertain, but the increasing levels of pollution in the Salton Sea will likely affect biodiversity and aesthetic and recreational QoL indicators in the region.

Water Infrastructure

The most significant relationships between water and QoL appear not to stem from water quantity *per se*, but rather from variables related to water infrastructure—the wells, pumping stations, pipes, and sewers that deliver water to residents and remove wastewater. Water infrastructure is frequently included in QoL indicator inventories as part of the housing infrastructure. The Instituto Nacional de Estadística, Geografía e Informática (INEGI), for example, records as a measure of "well-being" *(bienestar)* data on the percentage of houses with piped-in water, sewers or septic systems, and bathrooms. The rationale here is that residents who have piped water, drains, and bathrooms *de facto* have higher QoL; however, it is also true that such infrastructure influences other QoL indicators, such as health.

Turbidity

It has long been known that drinking water contamination can be associated with gastrointestinal disease. Recently it has been shown that some of what is considered "endemic" gastrointestinal illness is actually waterborne. Children and the elderly are at the highest risk for gastrointestinal disease. Drinking water turbidity, a measure of the cloudiness of the water, is commonly used as a proxy measure for the risk of microbial contamination of public drinking water. Several studies have shown a correlation between turbidity levels and microbial contamination of treated water, although it should be noted that water can be clear and still be contaminated. Schwartz, Levin, and Goldstein (2000) found an association between daily fluctuations in drinking water turbidity and subsequent hospital admissions for gastrointestinal illness in the elderly. Because hospitalizations represent a small percentage of total morbidity, the relationship between water turbidity and gastrointestinal illness appears to be substantial.

Significant differences in drinking water turbidity exist between U.S. cities and communities along the U.S.-Mexican border. While such water quality problems have been documented in U.S. cities, the contamination is slight and primarily affects individuals with weakened immune systems. It is unlikely that San Diego or El Paso, Tex., the U.S. cities targeted in this study, have significant health problems due to water contamination. In contrast, many of the *colonias marginales* adjacent to El Paso and San Diego that house workers attracted to the maquiladora industries have significant water problems (Sadalla, Swanson, and Velasco 2000). Such communities on both the U.S and Mexican sides of the border typically rely on questionable water delivery systems (for example, trucked-in water pumped directly from groundwater sources) and have water with significant turbidity.

A recent survey of residents of *colonias* in Nogales, Son. (Sadalla, Swanson, and Velasco 2000) documented that 24% of residents reported the water they use looks cloudy or contains sediments. The majority (93%) of *colonia* residents who do not have piped-in water buy water from private trucks that service the area. The most common storage method (used by 82% of the residents who buy water from trucks) is the use of portable containers outside the residence. Of the residents who buy water from trucks, 47% reported consuming it directly without treating it, 37% reported boiling it before consumption, and 16% reported adding a disinfectant such as chlorine before consumption. Water quality in such communities is therefore likely to be associated with significant gastrointestinal infections.

Nitrates

Research has also been directed at nitrate contamination of groundwater. The potential impact of nitrate contamination on human health has led government agencies to limit the amount of nitrates allowed in drinking water. While nitrates are essential for life and occur naturally in soil and water, excessive quantities of these chemicals can be lethal in some circumstances. Humans and animals convert excess nitrates into a toxic contaminant during the digestive process. These nitrites (NO_2) react with the hemoglobin in red blood cells and create methemoglobin. Excess methemoglobin causes the blood to turn from a bold red color to a deep brown, giving the skin a bluish hue called cyanosis. Such blood cells do not carry oxygen to body cells, causing babies and individuals with compromised immune systems to develop methemoglobinemia, often called "blue baby syndrome." Without immediate treatment the body will eventually suffocate. Adults and older children have relatively greater abilities to absorb excess nitrogen and excrete it, minimizing the risk of toxicity and methemoglobinemia.

The National Cancer Institute has also linked excessive nitrogen in the human diet to gastric and stomach cancer and non-Hodgkin's lymphoma (NHL). The National Cancer Institute studied the amount of nitrates consumed daily in tap water by Nebraska residents who were diagnosed with NHL and found a relationship between the amount of nitrates consumed and development of the disease. Future studies are crucial to determine the degree of risk associated with nitrate ingestion (Ward, et al. 1997).

Specifying unsafe levels of nitrogen concentration in water is difficult because of the confounding effect of the intake of nitrogen from food. Roughly 80% of an average person's daily nitrate intake of 75 milligrams (mg) to 100 mg comes from vegetables, while only 10% to 20% comes from drinking water. Vegetarians and vegans have much higher nitrate intakes, frequently up to 250 mg per day. However, nearly half of the daily nitrate intake for individuals who drink water with more than 10 milligrams per liter (mg/L) comes from drinking water. In 1962, the U.S. Public Health Service developed drinking water standards, which were later adopted by EPA, in an attempt to control nitrate-polluted water. Present standards require that public water systems have no more than 10 milligrams per liter (mg/L).

While research is presently focused on long-term effects from the presence of nitrogen in the water supply for humans, this chemical also affects plants, animals, and marine life. When excess nitrates are present in the soil (due to over-fertilization, manure, and/or sewage), plants soon develop high levels of nitrates. The remaining nitrogen stays in the ground until it is washed away by irrigation, rainwater, or snowmelt. These plants are then fed to the livestock, horses, cows, sheep, pigs, and chickens, which are also susceptible to methemoglobinemia. Since nitrates are extremely water-soluble and leach into the ground, they eventually make their way into aquatic ecosystems (Cherry, Schmidt, and Soucek 2001).

Table 8 displays an overview of the relationship between water quality variables and QoL indicators. These indicators meet Blair's criteria of appropriateness and the restrictions for the B+20 Project.

Table 8. Relationships Between Water Quality and Quality of Life

Water Quality Variables	Possible QoL Indicators	Consequences
Quantity/availability	% of houses with piped-in water % of houses with sewers or septic systems % of houses with bathrooms	Personal and community health
Turbidity	Hospitalizations for GI tract infections	Health care costs Missed work or school Lost leisure time
Nitrate contamination	Cyanosis rates in newborns Methemoglobinemia rates Gastric and stomach cancer rates Non-Hodgkin's lymphoma rates	Health care costs Missed work or school Lost leisure time

Source: Authors

Transportation and Land Use

A number of indicators have been used to measure the quality of a transportation system. Engineers address the level of service a roadway provides to motorists and vehicle miles traveled (VMT). The National Environmental Protection Act and other regulations have provided ways to measure the impact of a transportation system on the environment. Environmental Impact Studies (EIS) require a broad evaluation of construction projects.

It is, however, important to note that measures of the quality of a transportation system do not necessarily measure its impact on the people using the system. A high-quality highway does not necessarily guarantee a higher QoL for people using the highway; in fact, the increased travel time and traffic congestion that frequently results from new highway construction may actually lower QoL. Transportation systems influence QoL directly by affecting physical and mental health and environmental aesthetics such as noise, leisure time, and social interaction. They also affect QoL through their impact on other environmental components such as air quality, land use, and economy, which in turn influence QoL. This section discusses indicators designed to describe relationships between land use, transportation, and QoL.

Land Use: The Cost of Urban-Suburban Sprawl

Sprawl is the unplanned expansion of development at low densities away from the urban center. The private marketplace optimizes each individual development in ways not necessarily the most efficient or desirable from the overall public viewpoint. Sprawl development is characterized by the following five components:

- Housing subdivisions and areas that are exclusively residential
- Shopping centers, strip centers, shopping malls, and big-box retail (such places are used exclusively for shopping and are distinguished from traditional counterparts by a lack of housing or offices, and the parking lot between the building and the roadway)
- Office parks and business parks consisting of places used only for work

- Civic institutions, public buildings, town halls, churches, and schools, among other institutions (in traditional neighborhoods these buildings often serve as focal points, but in sprawl development their location is based on the assumption of massive automotive transportation)
- Roadways

Sprawl increases costs by making automobile travel a necessity. Because each piece of land serves only one type of activity, and because daily life involves a wide variety of activities, the residents living in areas of sprawl spend an unprecedented amount of time and money moving from one place to the next. Because most of this motion takes place in singly occupied cars, even a low-density area can generate the traffic of a much larger traditional town.

Sheer distance often precludes the most inexpensive and environmentally friendly forms of transportation—walking or bicycling. Metropolitan areas dominated by a uniform spread of subdivision, office parks, and strip malls are harder to serve with transit and necessitate driving between every destination.

While the government builds the roads, private individuals buy fuel and maintain the automobiles needed to drive them. Transportation is a major component of household spending as families end up owning small fleets of vehicles. Such high up-front expenses make it difficult to economize on travel. According to the Federal Highway Administration, three-quarters of all automobile expenses stem from the fixed cost of simply owning a car, regardless of how much it is driven. The average American household devotes 18 cents of every dollar it spends to transportation. In metro areas with low real estate values, households spend more on transportation than shelter. The vast majority of that spending—98%—is for the purchase, operation, and maintenance of automobiles. Most American families spend more on driving than on health care, education, or food. People occupying the lower socioeconomic levels spend proportionally more on transportation.

Example: Transportation in San Diego

In San Diego, the average household travels 24,415 miles by car annually. Some 88.8% of trips are taken by car, 0.4% by transit, 5% by foot, and 0.6% by bicycle. Transportation is the second leading cost of household expenditures (Table 9) (U.S. Bureau of Labor Statistics 2002).

Costs of Congestion and Impedance

Two transportation variables are most commonly linked to QoL indicators: travel time and "impedance." Impedance is "anything that frustrates the goal of arriving at a given time at a particular destination—for example, distance, slow speed, or traffic congestion" (Koslowsky 1997). Both variables tend to increase with growth in population. Table 10 depicts recent increases in congestion in the United States.

Table 9. Breakdown of All Household Expenditures for San Diego Residents

Expense	Annual Cost	% of Total Expenditures
Transportation	$6,319	15.8%
Shelter	$10,037	25.1%
Food	$4,979	12.5%
Utilities	$1,990	5.0%
Other household	$3,361	8.4%
Insurance and pensions	$3,869	9.7%
Health care	$1,791	4.5%
Entertainment	$1,938	4.9%
Apparel and services	$1,941	4.9%
Education	$834	2.1%
Miscellaneous	$2,464	6.2%

Source: U.S. Bureau of Labor Statistics 2002

Table 10. Urban Congestion Indicators for 70 Urban Areas

Year	Average Roadway Congestion Index	Annual Delay per Eligible Driver (person-hours)	Wasted Fuel per Eligible Driver (gallons)	Annual Fuel Wasted per Urban Area (million gallons)
1982	0.91	16	23	39
1986	1.01	22	32	54
1990	1.07	27	39	68
1992	1.09	30	44	76
1994	1.11	35	51	84
1995	1.12	37	54	91
1996	1.14	40	58	96

Source: Texas Transportation Institute 1998

Congestion is associated with a variety of increased costs. In the United States, congestion has been estimated to cost $78 billion per year in wasted time and burned gasoline (Texas Transportation Institute 1998). Table 11 depicts an estimate of other social costs of congestion.

Table 11. Social Costs per Vehicle-Mile (1982 Price)

Travel time	$0.12
Air pollution	$0.03
Noise pollution	$0.00
Excess fuel comsumption	$0.11
Traffic accidents	$0.13
Total	$0.38

Source: Khisty and Kaftanski 1986

Impedance *per se* has been associated with a variety of negative economic outcomes. The direct results of delay include sub-optimal vehicle use, higher vehicle operating costs, and reduced productivity due to the additional labor costs associated with longer trips made by employees during business hours. Delay also leads to increased delivery costs and recruitment and turnover problems in congested areas (Cambridge Systematics, Inc. 2002). These costs are assumed to be significant, but they are difficult to quantify. A survey of U.S. business leaders indicated that traffic conditions affect employee morale, productivity, punctuality, and emotions (Lomax, et al. 1988).

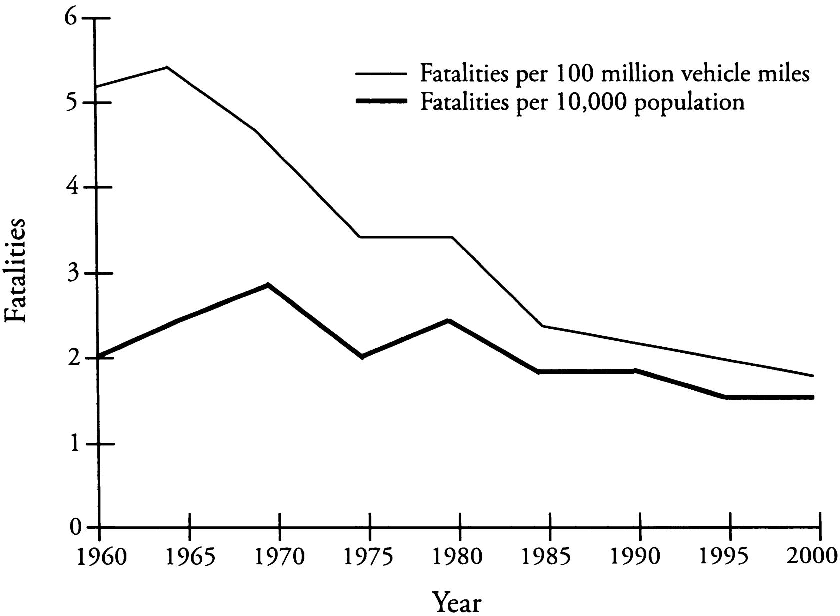
Transportation and Physical Health Indicators

In 1995, the U.S. Bureau of Transportation Statistics estimated that VMT was 9,220 per capita. This amount of travel by car is associated with a significant risk of accident. U.S. Bureau of Census data indicate that motor vehicle accidents are the leading cause of death for people ages 1 to 24. In terms of distance traveled, the cost of accidents to cars in passenger-kilometers is virtually the same as the cost of accidents to trucks in ton-kilometers and about 10 times higher than that of buses.

Transportation professionals measure road risk based on crash and fatality rates per unit of vehicle distance travel (such as per hundred million vehicle-miles or vehicle-kilometers). According to the figures published in the Federal Highway Administration report "Highway Statistics," total VMT in the United States increased by 59% from 1980 to 1995. Most of this increase is attributed to increasing trip and commuter distances, reflecting an increasing segregation between jobs and housing. Figure 2 depicts traffic fatalities per VMT and per capita.

When crashes and fatalities are measured per capita, such as per 10,000 population, as with other health risks, there has been surprisingly little improvement over this period. This is despite massive investments in safer roads and vehicles, tremendous increases in the use of seatbelts and other safety devices, reductions in drunken driving, and improvements in emergency response and trauma care.

Figure 2. U.S. Traffic Fatalities



Source: BTS 2000

Stokols, et al. (1978) initiated a study of the relationship between transportation variables and QoL health indicators. In their initial study, the degree of impedance encountered by travelers was indexed in terms of two situational parameters: distance traveled and time spent in transit. As predicted, subjective reports of traffic congestion and annoyance were greater among high and medium impedance commuters than among low impedance individuals. Both commute time and commute distance were found to be positively correlated with increases in systolic and diastolic blood pressure. The study indicates that these transportation variables are stressors that may have significant long-term health effects.

Evans and Carrere (1991) reported a high degree of association between exposure to peak traffic conditions and elevation of certain urinary catecholamines. Catecholamines include the stress hormones epinephrine and cortisol. An imbalance of these endocrine messengers alters physical homeostasis. Epinephrine affects blood sugar by promoting lipolysis and depressing insulin. Elevated insulin can, in turn, result in an imbalance of free fatty acids and blood sugar, causing increased susceptibility to cardiovascular problems. Epinephrine also increases contractility of the heart, making each beat increasingly forceful. Long-term exposure can predispose the heart to cardiac hypertension or heart disease (Brown 1997).

Congestion increases impedance and also reduces commuting speed. Slow driving speeds have been correlated with increases in systolic and diastolic blood pressure (Schaeffer, et al. 1988; Kluger 1998).

Carbon monoxide, sulfur dioxide, and other particulates can accumulate in areas of high traffic congestion, making the air less safe. Presumably, remaining stationary in traffic exposes the lungs to an increase in air toxics. Elevated heart rates have been empirically linked to air pollutants inhaled by drivers (Kluger 1998). Current evidence thus suggests that increases in commuting time and distance have a negative affect on health.

Transportation and Mental Health Indicators

In addition to its consequences for physical health, impedance can also cause negative psychological states and moods. Chronic exposure to congestion can increase negative mood states, reduce tolerance for frustration, and can lead to impatient driving behavior (Novaco, Stokols, and Milanesi 1990). Transportation-related stress, including impedance, can make people adopt undesirable or inappropriate (aggressive) behaviors (Yago 1983).

Two factors appear to mediate mental health consequences of congestion—the opportunity for social support and the presence of another person—and thus lessen the effects of impedance. "Interestingly, single-drivers, as compared to car-pool drivers, did have significantly higher scores on hostility and anxiety measures" (Koslowski 1997). Kluger (1998) found that lack of commute choices and commute variability were correlated with the strain measures even after controlling for length.

Transportation and Social Interaction Indicators

American adults spend on an average 72 minutes every day behind the wheel. According to time diary studies, this exceeds the time spent cooking or eating and is more than twice the time that parents spend with their children on average (Putnam 2000). In the United States, children who live in conditions of urban sprawl—and need to be driven to most social activities—watch three to four times more television per week than those who live in more high-density, vertical settlements. Putnam also shows that for every additional 10 minutes spent commuting, there is a 10% drop in civic engagement in activities like scouting, clubs, and community work. Because time is a finite resource, driving time can cause decrements in social interaction and leisure QoL indicators. Simply stated, any time spent behind the wheel could have been used elsewhere.

In societies with inequalities in the distribution of wealth, there are also inequalities in travel time. Macek, Khattak, and Quercia (2001) found than urban families with lower incomes had longer commute times than their suburban counterparts, and that commute time was negatively correlated with the probability of being employed. These types of workers may find less time to spend with their friends and family or to devote to social activities, which leads to a decreased QoL.

Meaningful social interactions also occur in places of employment. A variety of studies have indicated that impedance leads to decreased job satisfaction. "For employees in general, women and men who spent a longer time commuting expressed greater intention to quit the firm" (Burke 1995). The depression in employee loyalty can decrease motivation to socialize with coworkers. Kluger (1998) hypothesizes that commute impedance causes, among other things, negative attitudes toward commuting and decrements in performance. The greater the distance or time of commute, the more likely that the employee will be strained, and hence, less efficient.

Summary of the Impact of Transportation on Quality of Life

The transportation variables with the greatest impact on QoL are VMT, travel time, congestion, and impedance. Each of these variables is associated with urban growth and each is exacerbated by sprawl. QoL consequences of these transportation factors include diminishing:

- Physical health (death and injury due to accidents, increases in blood pressure, increases in cardiovascular disease)
- Mental health (decreases in mood; increases in irritability, hostility, impatience; decreased job satisfaction; decreased frustration tolerance)
- Social interaction (decreased time with family, friends, leisure, and community activities)
- Economic well-being (increased transportation costs)

Additionally, these transportation variables affect air quality, land use, and the local economy, which in turn lead to impacts on other QoL indicators. Table 12 displays an overview of the relationship between transportation and land use variables and QoL indicators. These indicators meet Blair's criteria of appropriateness and the restrictions for the B+20 Project.

Economic Sector

A central feature of all lists of QoL indicators involves values related to material well-being. Indeed, economic factors may well be the most significant environmental antecedents of QoL. Economic resources, income, expenditures, wealth, productivity, and employment occupy central positions in virtually all descriptions of QoL. Substantial research has been directed at the impact of regional economies on the residents of a region. Simply stated, the question is "does life get better during economic growth?" Conversely, does life get worse during economic contractions? What QoL indicators respond to economic fluctuations?

Table 12. Relationships Between Transportation and Quality of Life

Transportation/ Land Use Variables	Possible QoL Indicators	Consequences
Sprawl	Average commuting time Average distance commuted Increases in numbers of exclusively residential subdivisions Increases in numbers of shopping centers, strip malls, and big box retail outlets Increases in numbers of office parks and business parks Blood pressure levels Levels of urinary catecholamines Increased incidences of aggression (road rage) Average time spent in social interactions (family, community, etc.)	Reduced leisure time Decreased use of public transportation Increased air pollution Increased physical stress levels Increased mental stress levels Increased health care costs Increased transportation costs Reduced civic engagement Reduced time spent with family, increased family and marital stress
Congestion and impedence	Average commuting time Average delay Blood pressure levels Levels of urinary catecholamines Increased incidences of aggression (road rage) Average time spent in social interactions (family, community, etc.)	Wasted fuel Reduced business productivity Increased delivery costs Reduced leisure time Decreased use of public transportation Increased air pollution Increased health care costs Increased transportation costs Reduced civic engagement Reduced time spent with family, increased family and marital stress
Transportations risks	Motor vehicle crash rates Motor vehicle fatality rates	Injury Death

Source: Authors

Examining economic growth in the border region presents a number of challenges. From a national perspective, the economic disparity between the United States and Mexico is enormous. In 2000, the per capita gross domestic product (GDP) for the United States was \$32,778 while the per capita GDP in Mexico was \$5,036 (United Nations Statistics Division 2002). Economic comparisons of the two countries along the border are difficult in spite of the fact that the region is becoming increasingly economically integrated. Local comparisons are especially problematic. On the Mexican side, the border runs along the states of Tamaulipas, Nuevo León, Coahuila, Chihuahua, Sonora, and Baja California. On the U.S. side, the area consists of 48 counties in the states of Texas, New Mexico, Arizona, and California. Data for states and sub-state levels *(municipios)* are not as readily available for the Mexican side as they are for the U.S. side, and often these data are defined differently in the two countries (Sharp 1998).

It is clear, however, that the population along the border is growing dramatically. For example, the birth rate along the Texas border is growing faster than in the rest of the state by more than 40%. In addition, net migration to the area by the year 2020 is estimated to be more than 1 million people. While economic growth in the region is greater than the rest of the state, the prosperity of the region is not expected to improve due to high unemployment and a continued influx of unskilled workers willing to work for low wages. This situation has been characterized by the Texas Comptroller of Public Accounts as "growth without prosperity" (Sharp 1998).

The population on the Mexican side of the border is growing even more rapidly (in no small part due to the maquiladora industry). In 1920, the U.S. city in four out of five pairs of twin cities along the border was larger. By 1990, all the cities on the Mexican side were much larger than those on the U.S. side (Sharp 1998). From the Mexican perspective, the region represents a land of opportunity where 1,500 maquiladoras have created nearly 500,000 jobs (Border Low Income Housing Coalition 2002). From a U.S. perspective, the border region is economically and socially troubled.

Some of the poorest counties in the United States are located in this border area. More than a third of U.S. border families live at or below the poverty line. An estimated 350,000 people live in *colo-*

nias—un-zoned, semi-rural, unincorporated communities, many of which have no access to public drinking water, paved roads, or wastewater systems. The unemployment rate along the border is 250% to 300% higher than in the rest of the country (U.S.-Mexico Border Health Task Force 2002).

The rapid growth in the region also comes with an increase in crime. Drug-related crimes are particularly high in the border region. Armed encounters between border patrol officers and traffickers increased in Texas and drug law violations doubled along the border during the 1990s. In 1996 there were approximately 60 violent crimes and 660 property crimes every day (Sharp 1998).

Per Capita Income

Current literature on growth does point to a positive relationship between income per capita and indicators of well-being such as health (Barro and Sala-i-Martin 1995; Pritchett and Summers 1996). Unfortunately, research on economic development and QoL relies heavily on the use of cross-sectional data, which essentially means that nations at different levels of development are compared. Such cross-sectional data obviously have serious comparability problems. Methods of data collection, definitions of income and wealth, and reporting rates vary widely from country to country. Therefore, such data do not directly bear upon the question of how life in a particular country or region might change during a period of economic growth.

Time series data on per capita income for particular nations or regions are sparse, and when data from economic history are available, the impact of rising per capita income is mixed. As a prime example of this problem, Easterly (1999), using a data set with multiple nations and four time periods (1960, 1970, 1980, and 1990), analyzed changes in 81 QoL indicators. Using cross-national data, he found significant, positive improvements in 32 of the 81 indicators. Using a fixed-effects estimator (controlling for country effects), he found significant improvements in only 10 of the indicators. Using a first-difference estimator (analyzing changes from one time period to the next), he found improvements for only six indicators. Yet, he remains optimistic about the use of cross-sectional data, primarily because he believes there is strong evidence that improvements in QoL often lag behind economic development for decades.

The economic history literature has also documented long lags between rising per capita income and improved QoL. Morris (1996) studied three episodes of rapid capitalist development and concluded that four to five decades passed before the majority of the population got "delivery of the goods." Fogel (1994) believes that the gain in nutrition in Organisation for Economic Co-operation and Development (OECD) countries between 1910 and 1980 "was due to a series of investments made as much as a century earlier" (Easterly 1999).

Economic Development v. Crime Rates

Economic development is related to crime, but not all crime is affected in the same way by development. Using cross-national data, Bennett (1991) found that industrial development is positively correlated with theft rates. His research suggests that the generation of wealth and the acquisition of more consumer goods combined with variance in income lead to greater opportunities for property crimes. However, proximity of targets to a crime-committing population is also a relevant predictor of theft. In a study based on the National Crime Victimization Study and on neighborhood-level homicide data, Levitt (1999) found that "property crime victimization has become increasing concentrated on the poor." Grant and Martínez (1997) found that "[w]hen crime is examined across time and space, the unemployment rate has a powerful effect on crime rates, particularly property crimes."

Influential work by Wilson (1987; 1996) suggests that the economic restructuring of inner cities has produced social dislocation, which has in turn produced a host of social ills, including violent crime and property crime. Wilson also relates diminishing economic opportunities in inner cities to juvenile delinquency. Bellair and Roscigno (2000) found that unemployment and underemployment were related to drug use and fighting in adolescents. The proportion of juveniles in the population has also been positively correlated with both homicide and theft (Benett 1991). As the border region is a rapidly growing industrial region with a young population and a great deal of poverty, rapid increases in both violent and property crimes might be expected.

A recent investigation by Daly, Wilson, and Vasdev (2001) indicates that the Gini Index of Income Inequality (Sen 1973)[1] is a better predictor of homicide than average income. While previous research on inequality and homicide had already shown a positive relationship between inequality and homicide (Krohn 1976; Krahn, Hartnagel, and Gartrell 1986; Gartner 1990), that research was confounded by the problem of a strong correlation between low average income and high income inequality; those nations and regions that are poorer have greater inequality in average income and higher homicide rates. Daly, Wilson, and Vasdev used data from Canadian provinces with a positive correlation between average income and income inequality and found strong support for their hypothesis. Interestingly, Gartner (1990) found that the Gini Index is a better predictor of the number of adults murdered than it is for children murdered. It is also more predictive of men's rather than women's murder rates.

Table 13 displays an overview of the relationship between economic variables and QoL indicators. These indicators meet Blair's criteria of appropriateness and the restrictions for the B+20 Project.

Endnote

[1] Gini scores range from 0.0 to 1.0. A Gini of 0.0 would mean that all households in the sample have equal incomes. A Gini of 1.0 would mean that one household had all the income. In other words, the higher the Gini score, the greater the income inequality.

Table 13. Relationships Between Economic Variables and Quality of Life

Economic Variable	Possible Related QoL Indicators
Per capita income	Physical Health and Longevity Infant mortality Life expectancy Rates of health insurance Rates of prenatal care Community Health Access to transportation Access to communication Burglary rates Drug crimes Education Literacy rates Average years of schooling Achievement test scores Participation in higher education Dropout rates Class and Gender Inequality Ratio of female to male average years of schooling Ratio of women's literacy to men's Ratio of women's employment to men's
Income inequality	Community Health Homicide Rape

Source: Authors

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I-3

Modeling the Institutional Framework Governing Land Use and Water Rights in the U.S.-Mexican Border Region

Sergio Peña and Cesar Fuentes

ABSTRACT

There are differences and similarities between planning systems in the United States and Mexico, as well as policy alternatives for land use and water management that allow border communities to improve their quality of life. This analysis supports the ongoing construction of a system dynamics model of border communities under the Border Plus Twenty Years (B+20) project. Here, the constitutional framework of land use planning is analyzed by examining the role and function of each level of government. As well, water management schemes in both countries are detailed. Understanding the water rights system is important for identifying the obstacles to sustainable border policies that would enhance the quality of life of border residents.

Modelado del Marco Institucional Gobernando el Uso del Suelo y los Derechos del Agua en la Región Fronteriza México-Estados Unidos

Sergio Peña y César Fuentes

RESUMEN

Existen diferencias y similitudes entre los sistemas de planeación en México y los Estados Unidos así como alternativas de políticas para el uso del suelo y la administración del agua que permiten a las comunidades fronterizas mejorar su calidad de vida. Este análisis apoya la creación continua de un modelo de sistema de dinámicas de las comunidades fronterizas dentro del proyecto Frontera Más Veinte Años (F+20). En este trabajo se analiza el marco constitucional de la planeación del uso del suelo al examinar el papel y la función de cada nivel de gobierno. De igual manera, se detallan los esquemas de la administración del agua de ambos países. Es importante comprender el marco jurídico del agua para identificar los obstáculos de las políticas de una frontera sustentable que podrían incrementar la calidad de vida de los residentes de la frontera.

LEGAL FRAMEWORK FOR LAND USE PLANNING IN THE U.S.-MEXICAN BORDER REGION

Land use is the "glue that ties together the environment and the economy" (Herzog 2000), thus land use planning is relevant. The legal planning framework in both the United States and Mexico must be understood before coordinated urban planning policies can be designed. The topic itself poses a great challenge because of the differences between the two countries, not only in the degree of development but also in governments and legal traditions. Whereas the United States has had more than two centuries of democracy, Mexico has just begun to experience true democracy. As well, the legal system of the United States is based on case law or common law, while Mexico's system is based on civil law.

In Herzog's (2000) model, land use decisions have important effects on the built environment (which encompasses housing and economic, among other, activities) and how urban systems operate and grow. At the same time, the built environment—a product of human action—affects the natural environment (including air, water, and other natural resources). The impact of human action on the natural environment along the border in both countries is referred to as "transborder spillover" (Herzog 2000; Blatter and Norris 2000). This spillover is a focus of attention for policymakers in both countries, particularly since the North American Free Trade Agreement (NAFTA) was signed in 1993. Policies designed to manage or minimize transborder spillovers—such as air pollution and untreated sewage discharges into rivers and oceans—must incorporate a land use component. Therefore, it is important to understand the institutional framework and identify the actors or levels of government that have the legal jurisdiction to make decisions about land use.

The Institutional Framework of Land Use

To understand the complexity of managing urban areas that extend beyond national boundaries, one must understand the legal framework of land use decisions in both Mexico and the United States. The most important elements of this are the constitutional framework and the roles of the federal government, the state, and local communities. As will be demonstrated, land use planning in the United States has followed an incremental legalistic model where the judicial system, through legal cases, helped clarify property rights issues. Mexico followed the clientelistic-discretional approach where the social and political context and the interests of the ruling political party shaped planning.

The constitution is the most important legal document from which all laws and regulations are derived and which every federal, state, or municipal governmental unit must follow. The constitution defines the sphere of action and constraints on government by granting certain inalienable rights to every citizen, such as freedom of speech and freedom of religion, both of which are granted by the Mexican and U.S. constitutions. Land use regulations are also framed by the constitution. Two questions emerge about land use decisions: Which level of government has the jurisdiction and *a priori* legal standing to regulate land uses? And, what kind of constitutional powers are granted to government to regulate land uses?

In the United States, local governments have jurisdiction over land uses. This right is recognized in the 10th Amendment to the U.S. Constitution, which states "the powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people." Notably, this amendment only recognizes two units of government—the federal and the state—and is silent about local units of government such as counties or cities, where most land use decisions are made. This issue was clarified in 1868 in *Merrian v. Moody's Executors,* which set forth what is commonly known as Dillon's rule.[1] The rule gives authority to local governments to exercise powers indispensable for accomplishing its governing function.

Similar to the 10th Amendment to the U.S. Constitution, Article 24 of the Mexican Constitution declares that powers not explicitly assigned to federal agencies are reserved to the state. But unlike the U.S. Constitution, Article 73, Section XXXIX-C of the Mexican Constitution states that Congress has the power to legislate issues regarding urban settlements. Making use of this authority, the Mexican Congress in 1976 passed the first law for urban settlements, known as Ley General de Asentamientos Humanos (LGAH). This law is the first general law on urban planning. According to Azuela (1989), urban planning is an issue of coordination among the three levels of government. Additionally, a 1983 reform of Article 115 of the Mexican Constitution signaled a landmark change for urban planning and land use decisions. This reform was part of a strategy to promote decentralization policies; it gave more responsibilities to local governments in the context of the 1980s' economic crisis (Rodríguez 1997) and government fiscal crisis (Peña and Cordova 2001). In Section V of the same article, the constitution gives power to the municipalities to regulate land uses.

Of the constitutional powers granted to governments to regulate land uses, two are the most important: police power and eminent domain. Police power gives governments legal authority to pass laws and regulations to protect their communities. Eminent domain is the legal power to take land for a legitimate public purpose. From this perspective, a land use regulation is justified as an act to pursue a legitimate public interest or social function. The state, through police power and eminent domain, tries to balance the public and private interest. For example, a law could be designed to regulate the use of a public good, such as air, to protect the rights of people to breathe or enjoy clean air.

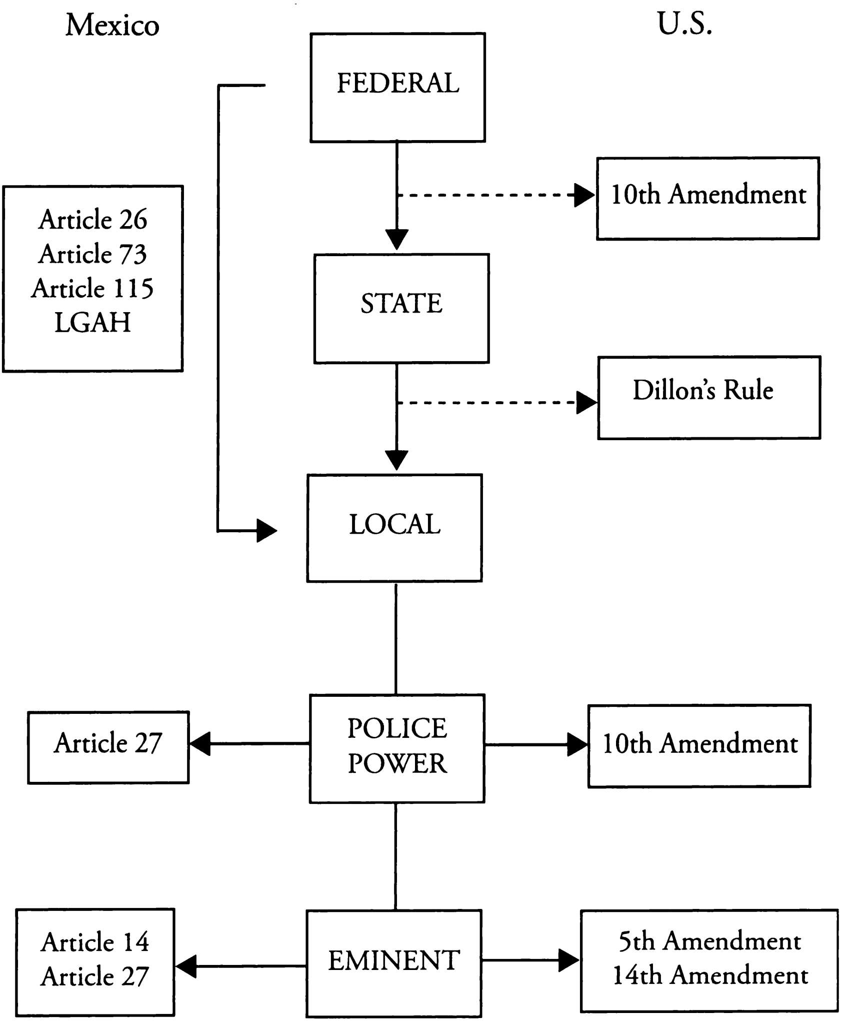
The U.S. Constitution's 10th Amendment grants police power to local governments to pass laws that ensure "the comfort, safety, morals, health, and prosperity of its citizens..." (Black 1991). This power also allows local governments to regulate land use and impose public control on private property, including actions to ensure comfort, safety, and public health.

U.S. governments are further bound by the 5th and 14th Amendments. The 5th Amendment, often known as the "taking clause," recognizes that "no person...[shall] be deprived of life, liberty, or property, without due process of law; nor shall private property be taken for public use, without just compensation." The 14th Amendment requires that no property be taken without due process of law; furthermore, every person is entitled to equal protection under the law. A fundamental difference between police power and eminent domain is the clause with respect to just compensation. If property value is affected by police power, owners are not entitled to compensation; under eminent domain, they are entitled to compensation. In cases such as *Pennsylvania Coal Co. v. Mahon* in 1922 and *Lucas v. South Carolina Coastal Council* in 1992 (Duerksen and Roddewig 1994), the courts had to determine whether an action by government using police power could be considered, for all practical purposes, to be a taking. The court agreed in *Pennsylvania Coal Co.* that government regulation claiming legitimate public purpose could go "too far" and, therefore, the action in question constituted a taking. In *Lucas,* the regulation had denied "all reasonable uses" and, consequently, should be considered a taking, thus entitling the affected parties to compensation.

Article 27 of the Mexican Constitution explicitly deals with the topic of property rights. In general terms, this article states that land and waters within the national territory belong to the nation and the nation has the right to transfer land to individuals to create private property. Furthermore, the article recognizes the nation's right of public domain to take away land for a public purpose after compensating the affected party. The third paragraph of Article 27 states that, "at all times the nation has the right to impose on private property the type of tenure that the public interest dictates, as well as to regulate for the social benefit to improve living conditions of the rural and urban population..." In brief, Article 27 gives the federal government power to control and regulate land to foster the public interest. The power to take or confiscate land can be exercised by executive decree or through a federal agency. As examples, the confiscation of oil companies' property in 1938 was achieved through a decree by President Lazaro Cardenas, while agrarian reform, which confiscated large landholdings, was carried out by a federal agency. Similar to the 14th Amendment of the U.S. Constitution, Article 14 of the Mexican Constitution establishes that no person can be deprived of life and property without a trial following due process and based on existing laws prior to the act.

From the constitutional point of view, both countries share similar principles of land uses. The interpretation and application of the laws with respect to police power and eminent domain are what differentiate the two legal systems. In the United States, the judicial system defines the planning profession's actions concerning land uses when a controversy arises about government use of police power or eminent domain. The judicial branch decides whether an action constitutes a legitimate public interest. For example, in 1926 the U.S. Supreme Court in *Village of Euclid v. Amber Realty Co.* upheld zoning as a proper exercise of police power, thus making zoning a widely used urban-planning technique. In a 1978 case, *Penn Central Transportation Company v. City of New York,* the court recognized protection of historical landmarks as a valid use of police power and denied the principle of "highest and best use of property." As these cases help demonstrate, the judicial system in the United States has played a fundamental role in defining the sphere of action of land use planners (Blaesser and Weinstein 1989; Levy 1997; Duerkesen and Roddewig 1994).

Figure 1. Constitutional Framework of Land Use Planning



Source: Peña 2002

In Mexico, checks and balances between the three branches of government were absent for many years; the executive branch had overwhelming power compared to the legislative and judicial branches. Rodríguez (1997) claims the lack of checks and balances among the branches of government indicates a lack of horizontal decentralization in government. Furthermore, there was no clear separation between the ruling Institutionalized Revolutionary Party, known as PRI, and the executive, legislative, and judicial branches of government. Consequently, laws were interpreted and applied in a discretionary way with the objective of maintaining the political status quo. As a result, a "clientelistic-discretional" decision model evolved whereby urban land decisions were made following political, rather than technical, influences (Azuela and Dahau 1993; Duhau 1998).

The situation has begun to change as more state governments and congressional seats have been captured by parties such as the National Action Party (in Spanish, PAN) and the Democratic Revolution Party (in Spanish, PRD). Checks and balances among the branches of government started to take root, particularly since PRI's loss of the executive branch to PAN candidate Vicente Fox in July 2000. Today, the tendency is to create a more institutionalized model of planning where a necessary condition is a credible judicial system. The judiciary has recently begun to exercise its function in land use disputes. For example, in the state of Baja California in a landmark 1996 decision, the Supreme Court ordered the eviction of nearly 150 residents, most of them American, from Punta Banda for occupying land that had been illegally confiscated from its original owners by the Secretaría de la Reforma Agraria (Agrarian Reform Agency), and then subleased or subdivided.[2]

The Role of the Federal Government

The role the federal government plays in land use decisions in both countries could not be more different. In the United States, the conservative political position is that the best government is the least government. Following the founding of the country, states and local governments were empowered by the 10th Amendment to make decisions about land use. Although the U.S. federal government does not have an explicit constitutional mandate to establish national urban policy, it plays an important indirect role in how cities have been shaped by actively promoting home ownership through the Federal Housing Administration (FHA), giving tax advantages to home owners, and investing in infrastructure such as the interstate highway system through the Federal-Aid Highway Act of 1956 (Levy 1997). The government also set federal standards such as the 1990 Clean Air Act and the 1972 Clean Water Act, the requirements of which may be enhanced, but not diminished, by states and municipalities. The federal government uses grants and highway money to reward states that comply and punish those that do not.

In Mexico, a federalist system is recognized on paper in Article 40 of its constitution, but the federal government has a strong influence on planning decisions. Unlike the United States, Article 26 of the Mexican Constitution gives power to the executive branch through the federal government to create and coordinate national planning following democratic principles. Article 73, Section XXIX-C gives power to the federal government to create laws to coordinate urban policy among the three levels of government. Furthermore, it is through this concept of national planning that general laws are developed to deal with specific issues. LGAH provides the guidelines and concepts for urban planning and land uses at the national level. The LGAH addresses four themes:

- Concurrency among the plans of the different levels of government for the organization and regulation of cities
- Basic norms and regulations of land use planning
- General principles for the establishment of open space and land use regulation
- The basis upon which the population will participate in the planning process

Thus, the role of the U.S. federal government is indirect, through expenditures on infrastructure and fiscal incentives, while the Mexican federal government proactively sets national mandates for states and municipalities.

Legally, local communities cannot enter into formal binational agreements because the power to enter into such international agreements is reserved by the federal governments in both countries (according to Article 89 section X of the Mexican Constitution and Article I, Section 10 and the 10th Amendment of the U.S. Constitution). This constitutional impediment fosters the role of the federal government in planning issues along the border and limits inter-local agreements.

Border planning by the federal governments in Mexico and the United States has focused on issues such as water and boundaries, which are addressed by the International Boundary and Water Commission (IBWC). The IBWC, under this name and its original title, the International Boundary Commission (IBC), has been operating for more than a century, applying the boundary and water treaties between the two countries. The function and priorities of IBWC have been adapted to the new circumstances and context of the bilateral relationship. One of the first projects IBWC carried out was the demarcation of the international boundary. The Convention of March 1, 1889, established IBC to apply the rules set forth in the 1884 Convention dealing with the location of the border. Those rules were modified by the Banco Convention of March 20, 1905, to retain the Rio Grande and the Colorado River as the international boundary. Under the water treaty signed in 1944, dam projects became another priority for IBWC, and the commission took the first steps to address sanitation issues on the border.[3]

In recent years, the U.S. section of IBWC[4] has pledged the incorporation of sustainable development and public participation as part of its mission statement, which "is to provide environmentally sensitive, timely, and fiscally responsible boundary, water, and environmental services along the United States and Mexico border region." The commission provides "these services in an atmosphere of binational cooperation and in a manner responsive to public concerns and our stakeholders."

Recently, there has been a shift in handling border issues from bilateral cooperation and coordination to binational co-management (Lara 2000) through the Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADBank). BECC and NADBank are the result of a side agreement forged during the NAFTA negotiations to deal with the negative environmental impacts of free trade. The role and function of BECC is to certify projects, which can then receive financing from NADBank, and to provide technical support to local municipalities and stakeholders. BECC supports water supply, wastewater treatment, solid waste, and other related projects along the U.S.-Mexican border. The mandate was expanded in 2003 to include projects related to air quality, public transportation, clean and efficient energy, municipal planning and development, and water management.

Mumme and Brown (2002), who also use the Rodríguez (1997) typology, are correct in their assessment that border planning has moved from a highly centralized model where federal governments had a great deal of power to a model of "administrative deconcentration." This allows the federal government to grant some administrative and planning function to a subunit (BECC, NADBank, and others) while at the same time maintain some degree of control through regulation and financial links.

The Role of the States

In Mexico, LGAH gives the states the authority to coordinate urban policy. That means LGAH addresses not only coordination among the three levels of government but also among states and municipalities. Article 115, Section VI of the constitution also discusses coordination among the different levels of government. According to Azuela (1989), the reforms made to Article 115 of the Mexican Constitution weaken the role of the states in urban planning matters and give the authority to regulate land uses directly to local governments.

The U.S. Constitution does not delegate powers to the federal government to legislate land uses, nor does it prohibit the states from using this power. Because of the 10th Amendment, states have the authority to legislate and develop statewide standards and guidelines for land uses and urban management policies within their jurisdictions. Two questions arise: Do states develop statewide land use plans? And, what has been the approach of states located along the U.S.-Mexican border?

Since the 1970s there have been efforts to pass statewide mandates and laws to deal with urban sprawl in places such as California, Florida, Oregon, Hawaii, Vermont, and Georgia (Kelly 1993). These efforts mainly focused on protecting environmentally sensitive ecosystems and reducing the fiscal burden of urban sprawl on local municipalities. According to Holcombe and Staley (2001), the "smart growth" movement has fostered strong intervention by the states in land use matters by imposing statewide mandates.

On the second question, the approach to statewide urban growth management strategies of U.S. border states varies. For example, California and Texas have taken different paths. California has been proactive in terms of growth management, and a Governor's Office of Planning and Research assists local governments in complying with state laws. Texas has played a weaker role, allowing cities like Houston to take a *laissez-faire* approach in land use decisions. Notably, lack of subdivision restrictions allows the rise of unplanned communities in border counties known as *colonias*.

In November 1998, Arizona voters rejected an initiative to set statewide growth management standards, instead approving Proposition 303, known as the "Growing Smarter Act," where state funds are used every year to buy or lease land for open space. Proposition 303 gives local communities the power to adopt their own growth management policies.

New Mexico uses a mixed approach. For example, Santa Fe, a city considered a strong advocate of urban growth management, imposes strict building codes to maintain the character of the community and city. Other communities, like Doña Ana County, have lax controls on subdivisions and a significant number of *colonias*. Innovative projects include the one approved by the 2002 state legislature to create a water bank and market mechanisms to allocate the scarce water resources of the lower Pecos River basin. This decision could have significant implications for land use issues.

Coordination of Border Initiatives

From above, inferences can be made about the difficulty of coordinating border initiatives. The large number of political jurisdictions and the different approaches to setting urban policy complicate the management of urban growth on the U.S.-Mexican border. The border extends for more than 3,000 kilometers (approximately 1,952 miles) from the Gulf of Mexico to the Pacific coast, and is shared by 10 states (four in the United States and six in Mexico) and 64 municipalities (39 in Mexico and 25 in the United States).

In Mexico, general laws such as LGAH allow some coordination among the border states. The watershed councils, or *consejos de cuenca,* in Mexico are an example of this interstate coordination. The watershed councils are coordinated by the Comisión Nacional del Agua (National Water Commission, CNA in Spanish). Some authors propose using this interstate planning model for managing the Rio Grande and Colorado Rivers "to serve the many users of hydrologic resources, to establish hydrologic infrastructure, and to preserve water resources" (Brown and Mumme 2000).

In the United States, where the federal government is limited in land use planning and there are no national laws such as the Mexican LGAH, coordination initiatives must come from states, local governments, and specific federal programs. Examples of interstate coordination are few, but one is the Western Governors' Association, whose mission calls for the advancement of the role of western states in the federal arena. Specific border issues, however, are neither an issue nor a priority. The Border XXI Program, when it existed, and the Border Governors' Conference are two examples of efforts to develop coordinated initiatives for border states in both countries. Unfortunately, neither program addresses urban planning or land use coordination issues *per se.*

The objective of the Border XXI Program was to promote sustainable development along the border through public participation, capacity building, decentralized environmental management, and interagency cooperation. The program included nine binational work groups to identify needs and programs in the areas of air, water, solid waste, pollution, contingency and emergency planning, cooperative enforcement and compliance, environmental information resources, natural resources, and environmental health. Note the lack of a land use planning or urban growth management focus.

The Border Governors' Conference focuses on economic development and promoting the welfare of both countries. There are also neighboring state commissions such as the Arizona-Mexico

Commission, whose mission is "to improve the economic well-being and quality of life for the citizens of the Arizona-Mexico region by promoting a strong, cooperative relationship with Mexico." An important goal of this commission is to develop indicators of well-being and quality of life to help assess the impact of NAFTA on the economies of Sonora and Arizona.

Texas and California have placed more attention on border issues because two halves of the biggest binational twin city pairs, San Diego, Calif.-Tijuana, B.C., and El Paso, Tex.-Ciudad Juárez, Chih., are located in these states. In California, the San Diego Association of Governments (SANDAG), through its Committee on Binational Regional Opportunities (COBRO) is proactive on border planning issues in the San Diego-Tijuana area. In Texas, the Rio Grande Council of Government (RGCOG) was created to promote intergovernmental cooperation. Unlike SANDAG, however, RGCOG does not have an entity resembling a border committee.

This brief analysis of state initiatives on land use coordination corroborates Herzog's (2000) assessment that land use policies are the least coordinated, in a binational sense, in the U.S.-Mexican border region.

The Role of the Municipalities

Although Mexico and the United States have explicitly adopted a federal and republican form of government, their practices have been quite different with respect to land use policies. A key difference is that local communities in the United States play a strong role in land use and urban growth management. In contrast, municipalities in Mexico have had a weaker role in managing urban growth. For many years, Mexican planning practice followed the clientelistic-discretional model (Azuela and Duhau 1993), although this has begun to change. Progress has been made by municipalities, mainly those governed by PAN. Ciudad Juárez now has the Municipal Institute of Planning and Research (IMIP), and the Municipal Planning Institute (IMPLAN) exists in Tijuana, as does a similar entity in León, Guanajuato. In addition, reforms to Article 115 increased the role of municipal planning through the Comité de

Planeación para el Desarrollo Municipal (Municipal Development Planning Committees, or COPLADEMUN in Spanish) (Rodríguez 1997).

Another important difference is that in Mexico, LGAH sets forth municipal planning standards under a one-size-fits-all approach. In contrast, municipal land use planning in the United States often is a custom-made or negotiated practice between market and community values—between the "growth machine" (Molotch 1976) and environmental advocates or coalitions. The way local officials are elected to city government is another key difference between the two systems. In the United States, city council members are generally elected directly by specific constituencies within a district or area, and they can be reelected; this system allows citizens to vote out a council member whose decision-making goes against their interests. In Mexico, council, *or cabildo*, members are elected as part of a party slate. As a result, the council reflects the proportion that each party obtained in the election and voting patterns are based on party lines and interests rather than constituencies or district base.

What are the advantages and disadvantages of one approach versus the other? The approach in the United States offers many opportunities for communities to experiment with different land use techniques adopted according to local goals such as promoting, curbing, or financing growth. Impact fees, urban boundary, building permit moratoria, and development agreements have been used to manage urban sprawl and ease the financial burden on local communities. There are also land use regulations to promote higher density and mixed-used development (Schiffman 1989).

Giving local communities the power to choose the appropriate land use regulations for themselves allows them to adopt policies according to their preferences and economic circumstances. The main disadvantage is that ecosystems do not necessarily follow political boundaries, so some coordination among communities is needed to prevent damage to the environment resulting from isolated decisions. The fundamental issues are who should control coordination and what the mechanisms should be. As explained in the previous section, one approach has been to pass statewide legislation. At the same time, the federal government's role has generally been limited to setting standards such as those of the Endangered Species Act, Clean Water Act, and Clean Air Act, which communities must meet to receive federal funds. In Mexico, the federal government assumed the role of coordinating and facilitating federal urban policy through LGAH. This would give BECC a niche to perform a facilitator role and overcome the legal restrictions of establishing inter-local agreements between border communities.

Rights and Administration in Mexico and the United States

Water Management Scheme

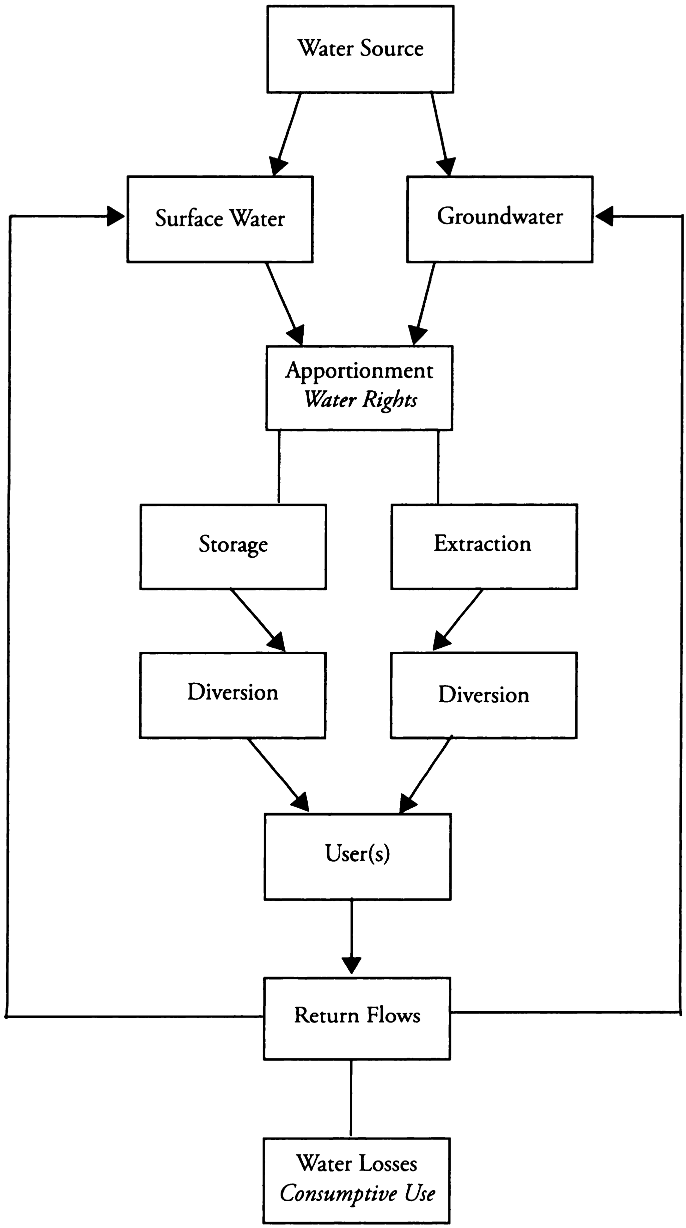
Figure 2 shows a conceptual framework based on the basic thermodynamic principle that matter is neither created nor destroyed. As Pearce and Turner (1990) point out, the environment becomes a supplier of services as well as a receptacle of waste in the sense that water taken out of the environment must be returned to the environment.

In the figure, it is assumed that the water cycle begins at a source that could be surface water or groundwater. Surface water flows in a defined channel, whereas groundwater can be stationary or follow a current. As needs arise, surface water can be captured, stored, and diverted to wherever it is used. On the other hand, groundwater has to be extracted or pumped from the ground and used on site or diverted through piping systems.

The core issue in water management is how the resource will be allocated among different users. The apportionment aspect of water shifts the discussion from the purely technical-engineering arena into the economic, social, and political context, where property rights play an important role. The property rights system determines how rationally and efficiently the resource is used.

When water has been used for domestic, agricultural, or industrial purposes, the quality of the water may be altered. Waste water, raw sewage, or water mixed with chemical substances can be hazardous to health. An important dimension of water regulation involves developing and implementing policies that ensure water

Figure 2. Water Management Scheme



Source: Authors

releases can meet certain standards that will not be harmful to humans or do irreparable damage to the environment. Finally, there is the issue of water lost to evaporation and evapotranspiration.

The Constitutional Role: Power Delegation

The constitution is the fundamental document that establishes the basic laws that regulate any society, and any law must derive from or be based on the constitution. The constitutions of Mexico and the United States address water rights and who has the legal power to regulate and legislate those rights differently.

The two countries could not be more different with regard to the powers that their constitutions assign to the federal governments. This reflects what Mumme (1982) refers to as "the dominant policy modes"—on the one hand a centralized political system and on the other hand a decentralized system that diffuses power. In fact, the U.S. Constitution makes only one reference to water issues, in Article I Section 8, whereas in Mexico Article 27 dedicates considerable time to water rights.

According to the U.S. Constitution, Congress shall have the power to make "Rules concerning Captures on Land and Water," thus turning over authority to legislate water issues to the legislative branch of government. Article 27 in the Mexican Constitution gives the executive and legislative branches that same power. The Mexican Constitution states that all land and waters within the national territory belong to the nation, which at all times has the right to regulate private property on behalf of the public interest. Furthermore, the federal executive can regulate the extraction and exploitation of underground water on behalf of the public interest. Historically, the executive has had more power, although this has changed recently and a true check-and-balance system is developing among the branches of government.

The judicial branch of government has a contrasting role. According to Goldfarb (1988), the common law system in the United States gives to the judicial branch an active role through case law; litigation plays an important role in defining water rights. In contrast, the Mexican judicial system, which is based on civil law, determines whether some laws or acts of government are constitutionally legal, thus assigning the Mexican judicial system a more passive role.

Power Distribution among Government Levels

Article 124 in the Mexican Constitution and the 10th Amendment of the U.S. Constitution are important starting points to understanding the role each level of government plays in water rights. Both constitutions share a basic principle or rule of power delegation: Rights not explicitly assigned to the federal government or denied to the states are reserved to the states or the people.

The U.S. Constitution in Article 1 Section 8 gives Congress the power to legislate the capture of water; however, it does not explicitly delegate to Congress the power to legislate water diversion and apportionment. Based on the 10th Amendment, the power to legislate those issues belongs to the states. There are, however, tracts of federal land where states must account for the fact that the federal government is a stakeholder in water issues, specifically in national parks, national forests, on Indian reservations, and the like. According to Goldfarb (1988), the U.S. Supreme Court has decided that "the federal government is presumed to have reserved enough unappropriated water (surface or ground) to accomplish the purposes..." This matter is particularly important in western states with semi-arid and arid climates where federal land holdings are substantially large.

The Mexican Constitution is more explicit about the role of the federal government in water issues. It grants a great deal of power to the federal government—more precisely to the executive—compared to the power delegated to the states. Article 27 paragraph 5 is specific about which watersheds are considered national waters and, consequently, fall within federal jurisdiction. The following criteria are used to determine what qualifies as national water:

- Ocean water, according to international law
- If the water stream flows into the sea
- If the water stream crosses two nations
- If the water stream crosses two or more states

- If the water stream serves as a boundary of the states or nations
- Underground, as determined by the law

Furthermore, the Mexican Constitution in the same article recognizes that the landholder can appropriate groundwater but the federal executive can regulate or ban the extraction whenever the public interest requires it. Other types of water not considered in the article are deemed an integral part of property, but if the water source or aquifer is located in two or more properties, the water is considered to be of public interest and subject to state law. Therefore, states have limited power on water policy and administration because most of the watershed ecosystems extend beyond the artificial political boundaries of the states.

The above discussion demonstrates that the Mexican Constitution grants a great deal of power to the federal government and very little to the states; in the United States it is the opposite.

Mexico chose to centralize administrative decisions within the federal government to avoid the cumbersome legal problem of letting states deal with water appropriation whenever the watershed is shared by two or more states. In other words, the Mexican system of water rights can be described with the analogy of the "benevolent dictator" that economists often used to describe a non-market method of rationally allocating resources. The United States, by granting power to the states to deal with water issues, has generated a great amount of conflict between states, especially in the dry west. Interstate conflicts over water rights in the United States have been solved through three methods: interstate compacts, congressional allocation, and litigation between states in the U.S. Supreme Court under the international rule of "equitable apportionment" (Goldfarb 1988).

Power Distribution and International Waters

The United States and Mexico have considerable hydrologic resources involving both groundwater and surface water, such as the Colorado River and the Río Bravo/Rio Grande. Thus, it is important to understand how two countries with completely different legal systems have been able to craft an institutional framework to manage water allocation between themselves.

A constitutional principle that both countries share is a ban that prevents states from entering into treaties with a foreign power or government, thus preventing a state on either side of the border from crafting a transborder treaty. Article I Section 10 of the U.S. Constitution states that "No State shall, without the consent of Congress...enter into any Agreement or Compact with another state, or with a foreign Power..." The Mexican Constitution in its Article 89-X sets forth that the President directs foreign policy and engages in international treaties that are then ratified by the Senate.

The Mexican Constitution is even more explicit about surface water and groundwater. Article 27 paragraph 5 considers rivers whose watersheds cross two nations or serve as an international limit to contain federal waters. Furthermore, the right to regulate use of underground water is reserved for the federal executive.

In contrast, the U.S. Constitution does not provide standards like Mexico's to determine the jurisdiction of the federal government on water. According to Goldfarb (1988), U.S. policy on international waters is made through treaties and uses "customary international law" to interpret them. The federal sphere of jurisdiction is bounded by what is agreed upon within international treaties; anything else becomes state jurisdiction.

The 1944 water treaty serves as a framework to determine the U.S. federal role and jurisdiction on water issues in the U.S.-Mexican border region. The main characteristic of the treaty is that it primarily deals with allocation of surface waters of the Río Bravo/Rio Grande, Colorado River, and Tijuana River. Section V of Article 24a gives IBWC authority over groundwater issues "to initiate and carry on investigations and develop plans for the works which are to be constructed or established in accordance with the provisions of this and other treaties or agreements in force between the two Governments dealing with boundaries and international waters." Finally, IBWC Minute 242, signed on August 30, 1973,[5] limits the pumping of groundwater within five miles of the Arizona-Sonora boundary and requires both countries to consult prior to undertaking any project involving surface water or groundwater.

Administration of Water Rights

The administration and management of water rights along the U.S.-Mexican border for efficiency and sustainability must address two substantially different property systems. The Ley de Aguas Nacionales (National Water Law), approved by the Mexican Congress in December 1992, is the regulatory instrument derived from Article 27 of the Mexican Constitution and sets the standards and procedures for distributing water rights. It also appoints CNA as the agency that administers the rights. In contrast, the U.S. system has neither a national comprehensive law nor a specific federal agency in charge of administering water rights; the administration of water rights falls to the state jurisdiction.

Article 27 of the Mexican Constitution states that "...property of land and waters within the boundaries of the national territory, originally belong to the Nation, which has the right to transfer its domain to individuals creating the private property." Furthermore, the National Water Law in Chapter II deals specifically with concessions and allocation. Article 20 establishes that the use and benefit of national waters by individuals or corporations will be made through concessions by CNA. Finally, the use and benefit can be revoked whenever the public interest requires it or when the concessionary fails to follow the rules.

In the United States, a water right is the same as any property and therefore is protected under the 5th Amendment (Goldfarb 1988). The holder of the right is entitled only to the "usufructuary right"—that is, the waterbody (lake, river, etc.) cannot be privately owned but is instead "owned by the state as trustee for its citizens" (Goldfarb 1988).

Table 1 presents the different types of water rights in the four border states on the U.S. side. The system of rights differentiates between surface water and groundwater.

Table 1. Water Rights Diversion in the U.S. Border States

	Surface	Groundwater
Absolute ownership		Texas
Reasonable use		Arizona
Correletive rights		California
Prior appropriation	Arizona New Mexico Texas (after 1913)	New Mexico
Riparian	California Texas	

Source: Authors

As Table 1 shows, different U.S. border states practice different water rights doctrines. Absolute ownership does not impose any constraints on diverting water. Some authors say that the owner with the "biggest pump wins." Prior appropriation operates under "first in time, first in right" as well as "use it or lose it," which means that to continue claiming the right the owner must have a beneficial use for the resource. Correlative rights mean that in times of shortage "fair and just proportion" among the users is applied. Reasonable use of groundwater is similar to absolute ownership and follows two rules: waste is prohibited, and water must be used on land overlying the aquifer and can be transported only if it does not affect other owners (Golfarb 1988; Mumme 1982; Harris, et al. 1990). Riparian rights are mainly applied to surface water and are widely used in the eastern United States where water is not as scarce as in western states, which rely more on groundwater. This is a significant issue. In order to have riparian rights, property must be adjacent to the stream or one of its tributaries.

A fundamental difference between the two property rights systems is the transfer of the right. In the United States, water is treated as a property and the right can be sold and purchased like any other commodity. However in Mexico, water rights from national waters are concessions. If the owner fails to comply with the terms of the concession, it can be revoked.[6] For example, Article 27d of the Mexican water law states that the concession can be terminated if rights are transferred in violation of the law. This presents a major problem in establishing alternative water policies such as a binational water bank at the U.S.-Mexican border.

Furthermore, the different laws and water rights systems of the border states make matters more complicated. Border states in the United States apply a combination of water rights to deal with surface water and groundwater. The two most widely used systems are inefficient in the sense that the water is not allocated to its highest and best use. "First in time, first in right" does not allocate water to the best use, nor does "use it or lose it" promote conservation or a rational use of the resource. This has caused some states to establish regulations that promote conservation rather than a more efficient allocation method involving the reasonable use doctrine or correlative rights.

It is important to emphasize that Article 3 of the 1944 treaty assigns some priorities among users of international waters. It reads, "In matters in which the Commission may be called upon to make provision for the joint use of international waters, the following order of preferences shall serve as a guide: 1) domestic and municipal uses, 2) agriculture and stock raising, 3) electric power, 4) other industrial uses, 5) navigation, 6) fishing and hunting and 7) any other beneficial uses which may be determined by the Commission."

Water Quality and Protection

Water quality and water pollution are areas where the federal governments in both countries have the most active role. The right of governments to regulate issues affecting water quality is based on police power. This refers to the rights of governments to impose regulations and laws to protect the safety, morals, public health, and welfare of its citizens. Regulation of water releases or uses can protect water quality, and thus, the public health and welfare of the people.

In the United States, environmental protection and conservation were in the forefront of the 1970s political agenda after several events, including the oil embargo in Arab countries and discoveries such as the toxic pollution at Love Canal, a former chemical landfill in Niagara Falls, N.Y., that became a 15-acre neighborhood (SUNY Buffalo 2001). Since then, the federal government has been active in passing legislation to protect the environment. A number of federal mandates directly or indirectly relate to water, including the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), the Wild and Scenic Rivers Act, and the Clean Water Act. A key characteristic of environmental policy in the United States is that the federal government sets environmental standards and state and local governments are free to implement policies and comply with the federal mandate. The U.S. Environmental Protection Agency (EPA) supervises compliance or non-compliance and provides technical and financial assistance to local governments (Goldfarb 1988).

In Mexico, two constitutional articles address water pollution prevention. The 1987 constitutional reforms to Article 27 incorporated concepts such as conservation, restoration, and ecological balance. Article 73-XXIX-G empowered Congress to pass legislation to coordinate policy at all levels of government to protect, conserve, restore, and balance the environment. This created the most comprehensive environmental law, called the Ley General del Equilibrio Ecológico y la Protección al Ambiente (General Law of Ecological Balance and Environmental Protection, in Spanish LGEEPA) (Gonzalez and Montelongo 1999). Environmental policy was put at the top, to the level of a state department, under the Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT).

With regard to environmental policy on the U.S.-Mexican border, IBWC Minute 261, titled "Recommendations for the Solution to the Border Sanitation Problems," undertaken in 1979, was the first formal agreement protecting the border environment.[7] In 1983, the Agreement on Cooperation for the Protection and Improvement of the Environment and Transboundary Problems, known as the La Paz Agreement, set the basis for the protection and preservation of the environment, as well as for cooperation among the different binational institutions. Since then, task forces have been established involving different departments and agencies on both sides of the border, such as EPA and SEMARNAT.

In 1990, Presidents George H. W. Bush and Carlos Salinas de Gortari met and made border environmental conditions a top priority. As a result, both countries agreed to develop a comprehensive plan, the Integrated Border Environmental Plan (IBEP). The purpose of the plan was to foster environmental coordination and cooperation between the two countries. The Border XXI Programs were the continuation of these cooperative efforts and attempts to promote and include public participation in the design stage of the plans. Another binational agency, BECC, was created to deal with the environmental effects on the border resulting from the economic integration of Mexico and the United States. BECC's mandate includes drinking water as well as sanitation.

In spite of efforts to address sanitation problems on the U.S.-Mexican border, water pollution continues to be a serious threat not only to the physical environment but to public health. According to Herzog (2000), environmental problems are linked to land use decisions. This means any environmental policy enacted on the border also must consider land use decisions.

Legal issues constrain the coordination of environmental policies and land use decisions. For example, both federal governments gave IBWC the legal authority to address sanitation problems related to water outflows that end up in rivers or the ocean. IBWC, however, does not have jurisdictional authority over land use decisions. In the United States, land use decisions are a local matter, according to the 5th and 10th Amendments. In Mexico, Article 115 gives local governments authority to regulate land uses; however, the constitution also allows the federal and state governments to have some input on the issue, as set forth in Article 73-XXIXC. BECC, in this regard, has an advantage and could play an important role, especially since its mandate has been expanded to offer technical assistance to communities on projects related to air quality, public transportation, municipal planning, and water management. A key difference between BECC and IBWC is that IBWC projects are a result of a treaty and therefore resources are allocated from the federal government. BECC projects have to be funded either through its operating budget, NADBank, or grants from EPA, SEMARNAT, or others.

Water Management and Policy Options on the U.S.-Mexican Border

Recent controversy over the water debt Mexico owes the United States has captured media attention. Under Article 4 of the 1944 water treaty, the United States is entitled to "one-third of the flow reaching the main channel of the Rio Grande (Río Bravo) from the Conchos, San Diego, San Rodrigo, Escondido and Salado Rivers and the Las Vacas Arroyo, provided that this third shall not be less, as an average amount in cycles of five consecutive years, than 350,000 acre-feet (431,721,000 cubic meters) annually." Due to severe drought, Mexico did not deliver the water in a timely fashion as the treaty required and the amount of water "debt" reached 1,541,268 acre-feet on June 22, 2002. According to IBWC, the "debt" as of September 2004 is about half (741,012 acre feet) of what it used to be in June 2002. The water debt has become an issue that makes the U.S.-Mexican relationship difficult. The issue became politicized when Mexican politicians saw the opportunity to win voters by adopting nationalistic defensive positions. Meanwhile, Texas politicians used the issue to win votes by arguing that Mexico was hoarding water.

Over the past three decades, economic growth led by the maquiladora industry went hand in hand with population growth in border municipalities. The population in border communities has increased rapidly since 1970, particularly in cities such as Tijuana, where the population more than quadrupled in 30 years from approximately 277,000 in 1970 to nearly 1.2 million in 2000. In Ciudad Juárez, the population tripled in 30 years from more than 407,000 in 1970 to more than 1.2 million in 2000.[8] This population growth has made it difficult for communities such as Ciudad Juárez to provide basic services like drinking water without also seriously depleting the source aquifer. This situation raises new cross-border issues because of the lack of an institutional framework for dealing with groundwater pumping (except for some restrictions imposed by IBWC Minute 242, as explained earlier). Also, El Paso and Ciudad Juárez have moved their attention to surface water as an alternative water supply source, creating fierce competition not only among different water uses, but also creating competition and litigation between states such as Texas and New Mexico.

Circumstances and context have changed from the time when the southwest United States was open to settlement and when Mexico and the United States signed the 1944 water treaty, which is the current institutional framework for water allocation between the two countries. An important question is, What policy alternatives exist that would make possible an institutional framework to allocate water in a more efficient and sustainable way? Three policy alternatives, advocated by different scholars, are evaluated in the remainder of this chapter. The first option is a null alternative of taking no action; the second option is to create binational watershed councils (Brown and Mumme 2000); the third option involves creating water banks, which are advocated by economists and have been approved as a pilot project by the New Mexico legislature to allocate waters from the Pecos River.

Evaluation Criteria

The evaluation criteria developed by Ostrom, et al. (1993) can be used to analyze the advantages and disadvantages of bilateral and binational approaches to environmental management on the U.S.-Mexican border. The institutional evaluation criteria developed by the authors is divided into two broad categories: overall performance criteria and intermediate performance criteria.

The overall performance criteria for evaluation of institutions include economic efficiency, equity, accountability, and adaptability. The intermediate performance criteria refer to the cost of service and include transformation costs and transaction costs (coordination, information, and strategic).

Economic Efficiency

Economic efficiency of water delivery and management is when regulation and policy in both countries could achieve an environmental balance to ensure the basic function of the environment as a "resource supplier" and "waste assimilator" (Pearce and Turner

1990). Thus, border institutions whose functions relate to resources management should be judged on how well they reach the ideal state of environmental equilibrium.

In evaluating the three policy alternatives, the null alternative of taking no action in either Mexico or the United States is assigned a low ranking because the probability that the environment can continue to be a resource supplier and waste assimilator is low. Furthermore, the western United States' property rights systems currently in use, such as prior appropriation and absolute rights, are wasteful. The first operates under "use it or lose it," and the second, "the biggest pump wins" (Goldfarb 1988); this means water is not put to its highest and best use. As a consequence, water-saving technologies and crops are discouraged. In Mexico, however, there exists a centralized management system that could easily make changes to water rights and allocation. The key problem is the lack of financial resources to improve not only irrigation ditches but the leaky and wasteful urban water delivery systems.

In theory, water banks would be a way to allocate the resource to its highest and best use through market mechanisms. The ultimate outcome of a water bank is that the market will price the water based on its marginal costs, and that those users who value the resource more will pay those willing to sell. For example, urban users purchase rights from agricultural users and this will encourage farmers to implement water-saving technologies because they could make money selling crops and water. According to the New Mexico Legislature, the water bank is "... a water management strategy that speeds up the temporary transfer of water from those willing to lease it to those willing to pay to use it" (New Mexico Legislature 2001).

Table 2. Economic Efficiency

Economic Efficiency	Null Alternative	Watershed Council	Water Banks
U.S.	Low	Medium	High
Mexico	Low	Medium	?

Source: Authors

In the United States, a water bank may be a good strategy to achieve economic efficiency because water rights are defined as property and can be transferable. However, Mexican water rights are defined as concessions and are not tradable, thus making the possibility of a water bank unlikely.

Watershed councils, according to Brown and Mumme (2000), are regional institutional mechanisms that manage water resources in Mexico, and they could be applied in a binational regional context. The key to understanding the economic efficiency of watershed councils is management coordination—instead of a fragmented coordination where the same watershed could have several managers each representing the interest of his constituency and overlooking the whole system, a council would be a mechanism where policy-making can happen in a more comprehensive and holistic way. In other words, economic efficiency of resource allocation can be achieved through an administrative regional institution that reduces transaction costs (in the form of coordination, information gathering, and sharing) as well as strategic costs.

Equity

Equity can be approached using the concepts of *pareto optimum* and *pareto superior,* which are used in economics to evaluate welfare policy. A *pareto optimum* is defined as a situation where the welfare of a water user cannot be improved without making other water users worse off. A *pareto superior* can be achieved when the welfare of the water user is improved in such a way that the marginal benefit is greater than the marginal costs of the affected party, and compensation could take place, thus transforming the situation into a positive sum game.

Under the null hypothesis, the United States scores low in the equity criterion using the *pareto optimum* and *pareto superior* concepts. Under the current water rights system that prevails in the Western states, the burden of scarcity or drought is not shared equitably. For example, under the prior appropriation system, priority is given to the senior appropriators under "first in time, first in right." When rationing is required, the first users to be shut down are the junior appropriators or later claimants (Goldfarb 1988). The pro-

Table 3. Equity

Equity	Null Alternative	Watershed Council	Water Banks
U.S.	Low	Medium	High
Mexico	Medium	Medium	High

Source: Authors

portional principle in Mexico is applied to manage scarcity during drought; that is, all water users share the drought burden equally in a way similar way to the riparian rights system. Although closer to a *pareto optimum* outcome, it is far from *pareto superior.*

The watershed council strategy is assigned a medium grade because equity will be approached in the same fashion as in Mexico, and users will share a proportional burden. It is unclear whether a watershed council would involve changes in the water right system or simply institutional changes among agencies (Brown and Mumme 2000).

Water banks will deliver the most equitable outcome, given that, theoretically, a *pareto superior* situation could be reached. For example, agricultural users willing to sell their water rights to urban dwellers implicitly are incurring an opportunity cost (farming); however, benefits (recreational amenities, nice landscaping, healthier communities) to urban dwellers outweigh the private costs (forgone income for the farmer) as well as the social costs (employment losses and multiplier effects) associated with discontinuing farming. If the price is set right, everyone, in theory, should be better off.

Accountability

Accountability requires a system where all users (agriculture, domestic, environment/ecosystem) have equal rights and claims to the resource and the administrator allocates those resources in the most transparent way. Table 4 shows the evaluation given to each alternative with regard to accountability.

Table 4. Accountability

Accountability	Null Alternative	Watershed Council	Water Banks
U.S.	Medium	High	?
Mexico	Low	High	?

Source: Authors

In the null alternative, the United States certainly has taken bigger steps in making policy decisions more transparent, as well as in incorporating democratic principles in its planning approach. In contrast, for many years Mexico lagged behind in accountability and policymaking by following a top-down model. Furthermore, the judicial system gives the United States a venue to challenge government actions. For example, IBWC is often sued by state water quality boards and environmentalists for violating EPA water outflow standards of treatment plants such as the binational wastewater treatment plant in San Diego.

Under the null alternative, water managers are often accountable only to their own constituencies, including water districts, federal governments (as in the case of IBWC) (Peña 2004), or urban dwellers (as in the case of water utilities boards). Since fish and native plants cannot speak for themselves, the ecosystem is often overlooked. The fragmented and clashing interests of water users are unified and made more transparent under the watershed alternative. This approach could help maintain healthier ecosystems, thus making it the best option for accountability.

Transparency or accountability issues are quite different from those in the political or public arena under a market situation. In a market where perfect competition exists, buyers and sellers are well-informed of prices and quantities available. Neither buyer nor seller can change the prices, and entry and exit into the market is free. Also, buyers and sellers are rational actors seeking to maximize the market's benefit. On the other hand, there are markets where a seller exercises great power (monopoly) and by controlling quantity can manipulate both prices and buyers. In summary, as Table 5 shows, transparency improves as the water market bears a closer resemblance to perfect competition. In this situation, Mexico is the country that shows room for improvement.

Adaptability

Adaptability (Table 5) is the institution's ability to transform its function to the changing context of the U.S.-Mexican relationship on border issues. The null alternative offers the best outcome for adapting and transforming to the changing context; the watershed council option is the least adaptable.

The null alternative is ranked higher for several reasons. Time is a good criterion for testing the flexibility of the present institutional arrangements for managing water. The Treaty of Guadalupe Hidalgo between the United States and Mexico in 1848 established the actual boundary between the two countries and the 1944 water treaty provided the current framework for allocating water between them. This combination of treaties has proven flexible enough and has allowed the two countries to work out their differences in a civilized and peaceful way (Peña 2004). The property rights system has avoided a massive rebellion of water users, although it has not prevented scarcity or environmental deterioration.

Watershed councils are ranked lowest because they will require a substantial institutional change at all levels of government—mostly in the United States. It will also be difficult to assess the degree of flexibility that this alternative offers. Furthermore, given the fact that several actors will be involved or considered, it will be difficult to reach consensus or change institutional culture (as Brown and Mumme [2000] recognize). Mexico has been practicing this option, so adopting this approach as a binational model would be relatively

Table 5. Adaptability

Adaptability	Null Alternative	Watershed Councils	Water Banks
U.S.	High	Low	Medium
Mexico	High	Low	Medium

Source: Authors

easy. In addition, the strong power that the Mexican federal government has over water issues, compared to the United States, may facilitate the operation of the councils.

A water bank or water market would operate under the assumption that any changes in water demand will cause a shift to supply those needs. For example, if water demand increases among domestic or urban users due to changes in the population income,[9] there will be a shift of supply from non-domestic to domestic water users. However, flexibility and adaptability depends on how well the market works to allocate water, as shown in Table 6.

Intermediate Performance

Intermediate performance criteria refer to the cost of service, including transformation costs and transaction costs (coordination, information, and strategic). According to Ostrom, et al. (1993) transformation costs are the costs involved in turning stakeholders' preferences and willingness to pay into concrete demand packages, a financing mechanism, monitoring, regulation, and enforcement. Transaction costs (Table 6) in a simple market exchange between a buyer and a seller are normally low.[10] However, in situations where the number of actors and the type increase, the transaction costs grow as well. From this discussion three types of transaction costs are identified: coordination costs,[11] information costs,[12] and strategic costs[13] (Ostrom, et al. 1993).

Transformation costs in this context are those involved in transforming the resource from its source (water) and allocating it among users (including domestic and agricultural, among others) who put it to a beneficial use. The transformation costs in the United States are extremely high due to the fact that the decentralized system

Table 6. Transformation Costs

Transformation Costs	Null Alternative	Watershed Councils	Water Banks
U.S.	High	High	Low
Mexico	Medium	High	Low

Source: Authors

allows for a greater number of entities (such as federal and state agencies, regional boards, and water districts) that provide fertile ground for a high amount of litigation between states, users, agencies, and others. In Mexico, the centralized system allows CNA to coordinate water allocation, thus significantly reducing transformation costs. The total budget of IBWC and its Mexican counterpart, Comisión Internacional de Límites y Aguas (CILA), could be used as a proxy of transformation costs to allocate water between Mexico and the United States, plus whatever BECC, EPA, SEMARNAT, and other agencies contribute.

The watershed council alternative would have the highest transformation costs because in addition to the aforementioned transformation costs are those of several new binational regional agencies in each watershed along the U.S.-Mexican border. This alternative could have lower transformation costs only if some agencies disappear. In that case, coordination costs would be lower; however, this alternative is highly unfeasible politically.

Water banks' or markets' transformation costs depend on the cost to gather information or the degree of power that some buyers or sellers will have. As has been stated, if information is scarce and powerful players could affect supply and demand, the transformation cost would be higher. In summary, the transformation costs depend on the degree of imperfection in the water market, which in theory could be very low.

Conclusion

This chapter, which focused on the institutional analysis of land use and water, may prompt the questions: What is the relationship between land use and water? And, what is the importance of the institutional framework for modeling purposes?

Herzog (2000) provides an excellent answer to the first question by stating that land use is the "glue" that puts together the built environment and the natural environment. In other words, public policy decisions regarding the way a society builds and organizes the urban environment will have an effect on natural resources. This implies that any policy regarding the management of natural resources, such as water, needs to go in tandem with urban policy.

Land use policy is, perhaps, the most widely used planning tool to shape the urban environment, so the effects of poor land use policy are likely to be reflected in the natural environment in the form of negative externalities.

The Paso del Norte region faces a dual problem concerning water—quantity and quality. This chapter demonstrated that the current institutional framework, to a great extent, is part of the problem but also can be part of the solution. For example, on one hand poor land use decisions have an effect on water quality, on the other hand an obsolete property rights system that discourages more efficient practices and allocation contributes to the problem of water scarcity.

El Paso and Ciudad Juárez taken together are one of the largest binational conurbations in the world with a population of nearly 2 million people. It is imperative to not only coordinate land use policy but also reform the institutional mechanisms that govern water rights and allocation. This chapter identified the legal constraints that interfered with land use coordination and discussed alternative institutional arrangements (binational watershed councils and water banks) to allocate resources in a more efficient and effective way to deal with water scarcity. It is the authors' intention that future discussions of models promoted by the Southwest Consortium for Environmental Research and Policy (SCERP) would take into consideration not only the technical aspects but also the institutional and policy aspects.

Regarding the second question of why institutional analysis is important from a modeling perspective in general and for the Border Plus Twenty Years (B+20) model in particular, an institutional analysis offers alternative scenarios that can be explored in the model. The institutional analysis brings the model into reality; that is, the modeling process moves from being a simple scientific curiosity of particular interest for researchers into a tool that can be helpful for public policy. Although, B+20 does not include water banks explicitly as a module, this does not mean the implications of implementing certain land use decisions or shifting property rights regimes cannot be explored. This can be accomplished by adjusting the parameters within the model to be able to explore alternative policies. The B+20 model offers ways to adjust levels of variables to explore the implications of changing certain policies, including, for example, increasing the price of water, paving roads, and connecting each household to the sewer system.

Endnotes

[1] "...[A] municipal corporation possesses and can exercise the following powers and no others: First, those granted in express words; second, those necessarily implied or necessarily incident to the powers expressly granted; third, those absolutely essential to the declared objects and purposes of the corporation—not simply convenient, but indispensable..." *Merriam v. Moody's Executors,* 25 Iowa 163, 170 (1868) in Black (1991).

[2] In 1996, Mexico's Supreme Court ruled in favor of the plaintiffs, arguing that the Agrarian Reform Secretary's confiscation of 100 hectares of land in 1973 to create Ejido Colonia Estebán Cantú was illegal. Since 1973, the land had been subdivided and leased by the *ejido* people to Americans, who built their homes. With the eviction order, many risk losing their investment and it is unclear whether they are entitled to compensation.

[3] The treaty of February 3, 1944, for the "Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande" distributed the waters in the international segment of the Rio Grande from Fort Quitman, Texas, to the Gulf of Mexico. This treaty also authorized the two countries to construct, operate, and maintain dams on the main channel of the Rio Grande. The 1944 treaty changed the name of the International Boundary Commission to the International Boundary and Water Commission (IBWC), and in Article 3, the two governments entrusted IBWC to give preferential attention to the solution of all border sanitation problems (IBWC No Date).

[4] IBWC has a Mexican section, the Comisión Internacional de Límites y Aguas (CILA).

[5] "Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River." Both the United States and Mexico approved the Minute on August 30, 1973. For a discussion of groundwater issues, see Mumme 1982 and 1988.

[6] A concession can be revoked if: 1) the term of the concession expires and it is not renewed; 2) the volume diverted exceeds the allotment; 3) fees are not paid; 4) the work's agreed-to terms have not been executed; 5) there is a transfer of rights in violation of the national water law; 6) the exploitation, use, benefit, or return flows are in violation; 7) the concession is not exploited during three years; 8) the public interest requires it; and 9) a court overturns or cancels the right.

[7] This minute, signed September 24, 1979, was the result of a request made to IBWC and CILA by Presidents Jimmy Carter and Lopez Portillo to deal with sanitation issues on the U.S.-Mexican border (see Bustamante 1999).

[8] Data come from Lorey 1993 and http://www.inegi.gob.mx/estadistica/espanol/economia/feconomia.html.

[9] Water, according to different studies, is price-inelastic but income-elastic. Thus, consumer consumption patterns change very little when the price of water is increased. However, the consumption patterns of the consumer change substantially when personal income increases.

[10] This idea is derived from the Coase theorem, which states that in the absence of transaction costs, resources would be allocated to the highest bidder.

[11] Coordination costs are the sum of the costs of the time, capital, lawyers, and personnel invested in monitoring and enforcing water rights.

[12] Ostrom, et al. (1993) define information costs as the sum of the costs of searching for and organizing information, and the costs of errors resulting from a lack of or an ineffective blend of knowledge about time and place variables and general scientific principles.

[13] Strategic costs are the increased transformation costs produced when individuals use asymmetric distribution of information, power, or other resources to obtain benefits at the cost of others (Ostrom, et al. 1993).

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Water Issues in the U.S.-Mexican Border Region

D. Rick Van Schoik, Amy Conner, and Elena Lelea

Abstract

International boundaries, including the border between the United States and Mexico, are conduits of intangible things such as capital, electricity, ideas, pollution, and diseases, the transport of which poses unique challenges to human health, environmental quality, and especially water supplies. Water is arguably the issue on which the border region must place its most careful focus. As population explodes in the border region the demand for clean water increases. Several issues are created by the intersection of water with energy, biodiversity, economics, security, and health. These issues are further exacerbated by the inaction of institutions currently working in the region.

The border environment and quality of life for border residents are in danger of deteriorating significantly if "business-as-usual" trends continue for population and economic growth. While technologies like desalination offer some short-term solutions, substantial incentives are necessary to promote conservation. Several options exist that could serve as springboards to other initiatives that save water in the U.S.-Mexican border region. One approach involves a forecasting and backcasting (proactive planning now

based upon predictions to avoid worst-case scenarios) tool for stakeholders that allows them to understand the human, natural, and fiscal consequences of economic growth and development in the region. The Southwest Consortium for Environmental Research and Policy's (SCERP) Border Plus Twenty Years (B+20) Project works to this end.

Factores del Agua en la Región Fronteriza México-Estados Unidos

D. Rick Van Schoik, Amy Conner, y Elena Lelea

Resumen

Los límites internacionales, incluyendo la frontera entre México y los Estados Unidos, son conductos de factores intangibles como el capital, la electricidad, las ideas, la contaminación, y las enfermedades. El transporte de muchos de estos significa retos únicos a la salud humana y a la calidad del medio ambiente y especialmente a los suministros del agua.

Es debatible que el agua es uno de los tópicos en los que la frontera debe destinar un enfoque más detallado. Mientras que la población se expande en la región fronteriza, la demanda de agua limpia se incrementa. Diversos factores son creados con la intersección del agua con la energía, biodiversidad, economía, seguridad, y la salud. Estos factores son exacerbados con la pasividad de las instituciones actualmente trabajando en la frontera.

El medio ambiente fronterizo y la calidad de vida para los residentes fronterizos están en peligro de deteriorarse significativamente si las tendencias continúan igual para el crecimiento de la población y para la economía. Mientras que las tecnologías como la desalinización ofrecen soluciones a corto plazo, son necesarios incentivos substanciales para promover la conservación. Existen diversas

opciones que podrían servir como trampolines para otras iniciativas que conservan el agua en la región fronteriza México-Estados Undios. Un de los planteamientos involucra una herramienta de pronóstico y de planeación en retrospección (planeación proactiva actual basada en predicciones para evadir el peor escenario posible) para las personas interesadas, que les permita comprender las consecuencias humanas, naturales y fiscales del crecimiento económico y del desarrollo en la región. El Proyecto Frontera Más Veinte Años (F+20) trabaja hacia esta finalidad.

INTRODUCTION

International boundaries, a prime example of which is the border between the United States and Mexico, are increasingly becoming conduits of intangible things such as capital, electricity, ideas, pollution, and diseases, the transport of which poses unique challenges to human health, environmental quality, and especially water supplies. Planning for a sustainable future requires that residents on each side of the U.S.-Mexican border consider the effects their choices will have on the other side of the political divide.

Water is arguably the issue on which the border region must place its most careful focus. Relations over this important resource have potentially serious implications for the bilateral relationship as a whole. Water is becoming such a major international issue that many foresee serious conflicts emerging from worsening tensions and disputes over it, as has happened on a smaller scale in the border region. For example, California, Arizona, Nevada, and Colorado have argued for years over Colorado River water allocations. Mexico as well continues to owe a water debt to the United States, which at times strains relations in the border community.

Groundwater issues have been especially problematic in the border region due to the involvement of different levels of government with conflicting perspectives on ownership. For example, jurisdiction over groundwater lying under the Paso del Norte region is owned by individual property owners in Texas, the state in New Mexico, and the federal government in Mexico (Lyndon B. Johnson School of Public Affairs 1999). In a state-to-state comparison, when matched against the other border states, Arizona has a relatively progressive approach because it considers the watershed an administrative unit for groundwater extraction. In California, groundwater rules are further complicated by a distinction between water in a stationary aquifer and groundwater that moves with river systems above it. Neither the United States nor Mexico knows enough about groundwater resources to justify their current pumping rates. The aquifers in the border region are nearly unknown in quantity, quality, dimension, and flows. Yet, many locations that have exhausted their surface supplies are turning to their limited, and probably overdrawn, reserves. Few are replacing them.

As population explodes in the border region the demand for clean water increases. This increased demand intensifies competition among water users, including the economy, communities, and the environment itself. Water availability projections for major sister-city pairs in the border region are not optimistic. For example, in a typical year San Diego County, Calif., imports 90% of its water while Tijuana, B.C., imports about 95%; by 2010 San Diego will consume about 87% of the water in this area while Tijuana will consume 13%—that is, if infrastructure keeps up with demand (Bradley and de la Fuente 2003). El Paso, Tex., and Ciudad Juárez, Chih., are likely to exhaust fresh water from the Hueco Bolson, the major source of supply for these two cities, by the mid-2020s (Boyle Engineering Corp. 1992). Agricultural use is relatively constant, measuring between 60% and more than 80% of surface waters while municipal withdrawals range from 10% to 30%, depending on location. Per capita use is higher in U.S. border cities than Mexican border cities. Likewise, information quality, institutional capacity, and budget size is better on the U.S. side.

As this chapter will demonstrate, several issues are created by the intersection of water with energy, biodiversity, economics, security, and health. These issues are further exacerbated by the inaction of institutions currently working in the region. However, several options do exist that could serve as springboards to other initiatives that save water in the U.S.-Mexican border region.

The Status Quo

Water is related to everything and everything is related to water. The hydrological cycle provides surface water, which is the lifeblood for all natural capital and over time replenishes groundwater. Water supply affects water quality parameters and water quality affects ecosystem health, how much water is readily available to humans, human health, and the vitality of the economy—all of which are interrelated.

Disturbing the hydrological cycle or any component of it disrupts almost all other water features. Drawing down an aquifer leaves populations more vulnerable to future demands, risks salination from nearby salty groundwater, and could cause the permanent loss of underground storage capacity. Thus, tapping surface water or groundwater sources on one side of the border affects the other, just as disposal of wastewater on one side affects the other.

Unfortunately, the workings of binational aquifers are not known or understood well enough to drawn them down; researchers have to determine how big they are, which way they flow, and the contaminants in or salinity of them. As well, the full dynamic of human response to drought and water shortages is not understood on either side of the border. Arguments already exist for the meteorological and climatic definition of normal and severe drought, but the economic, health, and social dimensions of lost water have yet to be pondered.

Energy

The border region lacks sufficient indigenous energy sources. Production of the energy needed depends on available water while the access, treatment, and distribution of water depends on energy. Thus, clean water depends on energy to generate it and energy depends on water to generate it. One of every seven watts of electricity used in California is dedicated to pumping or treating water (Rohy 2003). As water is mined deeper or farther away, that component increases in a region already starved for electricity. As the availability of both energy and water becomes more stressed, the sectors related to them become stressed as well.

Biodiversity

Many desert rivers around the world are literally biological lifelines. For example, in the vast 630,000 square kilometer Chihuahuan Desert, the transboundary Rio Grande/Río Bravo and its tributaries provide essential aquatic and riparian habitats, as well as supply water for municipal, agricultural, and industrial needs. In this arid region, fresh water is a critical resource for both aquatic and terrestrial species. Many of the highest priority terrestrial conservation sites in the Chihuahuan Desert overlap with freshwater priority sites. Some 450 endemic species and 700 migratory species are found in the border area, 31% of the species listed as threatened or endangered by the U.S. Department of the Interior are found in the borderlands, and the rates of endangerment are the highest for those species found along the international boundary (Van Schoik, et al. 2004a). Riparian woodlands are a keystone habitat, exerting powerful influence on the biodiversity of surrounding areas and serving as migration corridors for large mammals, songbirds, bats, and butterflies. The aquatic fauna that have evolved to live under the Rio Grande's variable flow conditions—from drought and low flow to large flood events—exhibit a high degree of endemism. As ground- and surface waters are depleted, little, if any, water remains for nature. Unknown billions of dollars are lost in biodiversity due to habitat destruction.

Economy

Significant economic costs for human populations accrue every year because of accelerated environmental degradation, particularly degradation of water. Nearly $1 billion in productivity is lost directly due to water contamination. This, in turn, leads to a probable loss of approximately $1 billion due to decreased recreational and leisure use of water bodies.

The border region also faces a severe environmental infrastructure deficit. The U.S. General Accounting Office (GAO) and others have estimated a shortfall of anywhere from $1.3 billion to $8.5 billion in water supply, wastewater, solid waste, and municipal infrastructure to treat wastes and protect the environment (Van Schoik 2002).

Those funds will be needed by 2030 to address the current shortfall and meet growing needs for water, sewage treatment, and landfill infrastructure.

Health

All the issues described above combine to negatively affect the single most important aspect of the border: The health of its citizens. Without regard for the political boundary, pollution and disease travel easily across it, causing sickness in border communities. Deficiencies in water treatment and delivery infrastructure perpetuate poor water quality, which contributes to increases in the number of waterborne and water-associated diseases. Diminished water supply also exacerbates health risks because pollutants and pathogens become concentrated in water bodies. Disease and pathology know no borders, yet political borders constrain the process of mitigating health risks and resolving the problem of ensuring a sustainable, healthy water supply for residents on both sides of the political boundary.

Although the demonstrated link between human exposure to environmental pollution and human health is a tenuous one, the suffering is real. Hepatitis A, a waterborne disease, causes many symptoms—diarrhea being one of the most serious and, in the border region, life-threatening. Incidence of Hepatitis A in the border region is 37.1 per 100,000, while nationwide in the United States it is 12.6 per 100,000 and in Mexico it is 50.1 per 100,000 (EPA 2000).

Binational Sustainability Institutions

In addition to the issues of the status quo, there are binational obstacles and barriers to sustainability created by institutions currently working on the border. Although well-conceived, in practice the groups cannot or will not take the actions necessary to begin providing remedies.

IBWC-CILA

In 1944, the Treaty Between the United States of America and Mexico Respecting the Utilization of the Colorado and Tijuana Rivers and the Rio Grande, commonly known as the 1944 water treaty, turned the International Boundary Commission into the International Boundary and Water Commission (IBWC) and established a formal procedure for sharing water resources in these three international watersheds. However, because the drafters of the treaty could not imagine current population growth and commensurate water demands, nor persistent and peaked drought cycles, the treaty and the commission, along with its Mexican counterpart the Comisión Internacional de Límites y Aguas (CILA), are thought of by critics and friends alike as anachronistic and unable to deal with today's problems. Recent successes—including a minute (the format under which IBWC-CILA drafts binational agreements) recognizing the ecological significance of the lower Colorado River delta and actions to protect it—juxtapose with failures to reconcile the often conflicting political primacy that exists at the local, state, national, and international levels.

In addition to the formal structure of IBWC-CILA detailed above, scholars of border water resource issues have suggested alternate means by which IBWC-CILA can address water resource management issues. Many advocate for some form of a border-wide science advisory council or board that would more aggressively bring academia-based research into the debate. IBWC-CILA has established a range of regional technical advisory groups that focus on specific regional challenges, but the prospect of the science advisory council or board has only recently been suggested to IBWC staff, with limited interest to date (Spener 2003).

BECC-NADBank

Pre-NAFTA negotiations ingeniously created an organization, the Border Environment Cooperation Commission (BECC), to help develop and certify projects as financially and environmentally sound and to ensure community involvement in their development. It then created and urged binational funding of a bank known as the

North American Development Bank (NADBank). Both were created as government-appointed boards with positions specified by the NAFTA side-agreement. The creation of BECC was truly unique as it promised—through public participation and transparency—to guard against the excesses of past development projects of the World Bank and other agencies that advanced economic development activities without adequate safeguards for the environment. This structure and intent for BECC and NADBank are notable, but the record of these institutions is mixed at best. Several years after BECC's creation, the lack of progress and performance prompted Congress to commission a study by GAO (GAO 1999), which strongly recommended that BECC develop a strategic plan.[1] But that has yet to happen. Additional uncertainty has recently become evident due to a reorganization effort advanced by the Bush Administration. In 2003, the BECC and NADBank boards intended to merge after the then-current performance review, thus threatening the public participation clauses, transparency, and regulatory and financial flexibility of the institutions.

BECC's inaction and NADBank's inability to act on some fundamental fronts threatens the health of people on the border, who risk being sickened by waterborne diseases. Funding for the Border Environmental Infrastructure Fund (BEIF) has slipped from the initial proposed level of $100 million to $50 million. BEIF is funded by the U.S. Environmental Protection Agency (EPA) to support grants from other institutions that can be combined with loans and guaranties to facilitate project financing through NADBank. This decrease in funding has constrained the ability of NADBank to make the critical investments in infrastructure that many border residents have demanded.

In addition to these funding problems, accountability of BECC and NADBank is also of concern to residents of the border and observers of border environmental policy. Performance accountability can be shown with surveys of environmental health before and after projects are completed. Without them, the true effectiveness of BECC and NADBank remain unknown, and opportunities to optimize investment may be missed. There can be little assurance that the millions of dollars invested in health in the region have had any effect because BECC has not performed these surveys among its proposed beneficiaries.

The Next Solutions

The myriad issues described herein create a particular challenge to meet the needs of an increasingly thirsty economy and populace. The move to bolster security activities and infrastructure makes the border less permeable to almost everything, including water. The continuing, if not widening, economic asymmetry means one side can continue to afford plentiful and clean water while the other may not. But there are several solutions specific to water that may provide some remedy to the situation.

Transboundary Environmental Impact Assessments

The trinational Commission for Environmental Cooperation (CEC) was formed to ensure that trade did not interfere with environmental enforcement within each NAFTA-signatory nation. One of the most useful tools CEC has at its disposal are Transboundary Environmental Impact Assessments (TEIAs), which are powerful mechanisms that can address negative environmental actions on one side of a political boundary that unfairly and adversely impact the other. TEIAs are moving ahead in Europe, the Baltic states, and Russia. With the knowledge gleaned from these assessments, minimization and mitigation of impacts can occur. The problem is, despite mandates to implement these assessments, little in this regard has occurred in the U.S.-Mexican border region, begging the question, Why? Some suggest that CEC has had a tacit agreement with U.S. and Mexican federal government officials who believe that the border is receiving enough attention from BECC, NADBank, and BEIF, and so further investment of time and resources is unwarranted (Vaughan 2003).

Aquifer Assessment

As the culmination of the three-day Border Institute VI conference, sponsored by the Southwest Consortium for Environmental Research and Policy (SCERP) in April 2004, participants developed policy recommendations to enhance the management and conservation of transboundary ecosystems. Chief among them was the recognition that water for nature must be sufficient and sustained. Rivers must no longer be seen as water supplies and must be valued for their own sake. Both the United States and Mexico should pass legislation recognizing international rivers, dedicating water to them, and allowing the purchase of water to maintain their flows—all the way to their mouths. The legislation should include consideration of drought and flood years, as well as long-term global climate change predictions.

Border Institute participants recommended that a binational watershed assessment for the entire Rio Grande/Río Bravo, from Colorado to the Gulf of Mexico, should be undertaken to determine how much water is needed to sustain life. It is also important to determine which stakeholders need to be at the table to make decisions about the river and plans for future conservation, which ongoing assessments can provide helpful information, and to elect a body to oversee the assessment, such as IBWC-CILA. The assessment should be divided into subbasin levels, and then the coordinating body can harmonize the data. In conjunction with or after the assessment is complete, stakeholders should identify key areas in need of protection. Several successful small watershed pilot projects exist along the border and they can be replicated for development in other areas of the region. Existing organizations on both sides of the border should work together to develop long-term, holistic visions for their watersheds. As well, a water budget should be developed for the border region and tribal input on it should be sought aggressively.

Water Trades

Permits to emit air pollution are currently being traded across the international border. An exchange of water pollution permits across the border could be conducted in the same way. Wastewater can be used for agriculture, treated water can be recharged into the ground instead of dumped into the ocean, and excess municipal flows can be diverted to nature's use in winter, at night, or during other off-peak times. If agricultural waters can be conserved through various practices on one side, they could be made available to the other.

For example, a Mexican farmer should be compensated for saving water (or perhaps temporarily fallowing) and "delivering" the saved water to a broker. The broker, in turn, could sell the water to a farmer in Texas or to a government agency restoring a habitat. In 2000, for example, agencies paid \$61 million for nearly 397 million cubic meters of water for habitat restoration. The possibilities of moving water across the border are many and wasted, as reclaimed water can be engineered to serve either side without topographical hindrances and associated costs.

The idea is not so far-fetched as some claim. Very recently, when the California and Arizona water managers met with the Secretary of the Interior's water official regarding the river, they realized that innovation and so called "breaking the rules" was necessary to avoid disaster for all concerned. They agreed that takes and returns to the river at different locations and times could indeed solve some current and future demand woes. As well, water transfers have become a popular research topic, with teams discerning the fluctuations in price, transaction costs, and the value of such trades to both countries.

SCERP recently completed a study that seriously explored an international water market with a bank-and-exchange philosophy and found that indeed there is the opportunity to match and trade across the border. By comparing a hypothetical market institution to current non-market allocations of water, the study reports the economic benefits and costs of an international water market—run by an agency tasked with monitoring, moving, pricing, and accounting for flows—along the reach of the Rio Grande from Elephant Butte in New Mexico to Fort Quitman in Texas.

SCERP appreciates all the challenges and transaction costs to such a trading scheme, but consortium researchers have worked on and seen a successful trade of air emission reduction credits across the international boundary. Such cooperative leanings could lead to trades of water, water pollution reduction credits, water-related habitat mitigation credits, and other water-associated assets, and maybe even end tensions between the national governments, among water managers and users, and ultimately lead to secure and sustainable water for all.

OUTLOOK

The border environment and quality of life for border residents are in danger of deteriorating significantly if "business-as-usual" trends continue for population and economic growth. The Border Plus Twenty Years (B+20) system dynamics model describes three scenarios for the future: business-as-usual, increasing and improving technologies and economic impacts, and changes in societal values. As expected, the business-as-usual picture is dismal. By 2020, with no dramatic changes in regional development, the border region will be one of greater traffic congestion, poorer water quality and the attendant human health effects, water shortages, increasing numbers of endangered and threatened habitats and species, hazardous and solid waste disposal crises, sewage infrastructure shortfalls, and contaminated beaches and oceans (Ganster, et al. 2000). More and larger transfers of water away from relatively unpopulated and agricultural watersheds to the more populated and urban ones are expected, and these transfers will cause ecosystems to suffer greatly, cause major declines in agricultural productivity and attendant social problems, and negatively impact the urban poor.

While technologies like desalination offer some short-term solutions, substantial incentives are necessary to promote conservation. Considerable research must also examine the complex interactions and outcomes of water transfers to ensure that the end results of these transfers are rational for the parties involved.

The best options for long-term sustainability are those hardest to achieve—changes in individual and corporate behavior. Residents in the arid border region must recognize and behave as if they live in a desert and begin to value water as a precious resource rather than a mere commodity. Many border residents do not perceive their water supply as dwindling, nor do they understand the effects of their water-intensive habits on local water availability. Discouraging the use of potable water for lawn irrigation and encouraging the use of drought-resistant vegetation for landscaping is an unpopular message for people who treasure their green lawns and lack an appreciation for landscaping with plants native to the desert region of the U.S. Southwest. Currently, water is simply priced too cheaply to promote conservation. To spark major changes in water use patterns, it must be priced to reflect the actual costs involved in generating needed supplies and its value as a life spring. Academia, in its role as educator and facilitator of sustainability science and research, is performing the task of instilling a water "culture" in the residents of the border region. Its message will be heard best when border residents begin to perceive water scarcity as a threat and change water use behavior.

Clearly, to make sense of the present and future stresses on the region, some sort of forecasting and backcasting (proactive current planning based upon predictions to avoid worst-case scenarios) tool is needed by stakeholders that allows them to understand the human, natural, and fiscal consequences of economic growth and development in the region. SCERP's B+20 Project works to this end. The purpose of the project is to create a systems modeling framework that provides an environment for imagining and exploring alternate futures for the border region and motivating prudent decision-making. This model will evaluate the interactions between human, environmental, and ecological systems. The prototype system will help stakeholders better understand changes in various environmental systems in response to population growth and industrial development. It will also account for the unique challenges associated with implementing binational environmental policy in the U.S.-Mexican border region.

ENDNOTE

[1] SCERP has developed a model that performs some of the same functions.

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I-5

Energy Issues in the U.S.-Mexican Binational Region: Focus on California-Baja California

Alan Sweedler, Margarito Quintero Núñez, and Kimberly Collins

Abstract

Energy is an indispensable lifeblood of the U.S.-Mexican border region and it is a key issue in the binational region's future. The energy sectors in the United States, Mexico, and Canada are undergoing changes that will affect how energy is produced, transmitted, distributed, and sold throughout North America. These changes will directly influence energy use and energy-related infrastructure in the U.S.-Mexican border region. This chapter focuses on national energy issues in the United States and Mexico, border-wide topics of concern, and the California-Baja California section on the border.

Population growth is the main force behind the increasing demand for energy services in the binational region. The expanding economy is another important factor. These factors have led to a greater demand for energy services in the border region than is expected for other areas of North America. To meet the expected demand in northern Mexico, new and upgraded interconnections of the transmission system with the United States will be needed. The

North American Free Trade Agreement (NAFTA) does provide new opportunities for private energy companies, particularly those in the electric power industry.

In addition to the increased need for power, there will be significant pressure on supplies of natural gas and associated infrastructure, such as high-pressure gas pipelines, distribution systems, and pumping stations. As prices for fossil fuels and electricity continue to rise, it is expected that solar energy (both thermal and electric) will also become more important in the border region than in the past.

A secure supply of reasonably priced energy with a minimal environmental impact will be needed for the U.S.-Mexican border region if it is to remain competitive in the global economy. Given the expected increase in population and living standards on the Mexican side of the border, it is difficult to see how power demand can be met without the construction of new generating facilities in the border region. However, if environmental degradation is to be avoided and quality of life standards improved, the type of generation will be important. Heavy reliance of fossil fuels, even natural gas, will inevitably degrade air quality, contribute to global climate change, and stress limited water supplies.

There are several ways to enhance crossborder cooperation in the energy field and provide the energy services needed for border residents in the future. But doing so will require effective cooperation and coordination between the privatized energy market players and the local and state agencies still responsible for regulating the energy sector in both the United States and Mexico.

Energy Issues in the U.S.-Mexican Binational Region:
Focus on California-Baja California

Temas de Energía en la Región Binacional México-Estados Unidos: Enfoque en Baja California-California

Alan Sweedler, Margarito Quintero Núñez, y Kimberly Collins

Resumen

La energía es un sustento indispensable de la región fronteriza México-Estados Unidos y es un factor calve en el futuro de la región binacional. Los sectores de energía en los Estados Unidos, México y Canadá se encuentran sufriendo cambios continuos que afectarán la producción, transmisión, distribución y venta de energía en Norteamérica. Estos cambios influenciarán directamente el uso de la energía y la infraestructura relacionada con la energía en la región fronteriza México-Estados Unidos. Este capítulo se enfoca en temas nacionales de energía en México y los Estados Unidos, en temas fronterizos de preocupación, y en la sección fronteriza de Baja California-California.

El crecimiento de la población es la fuerza principal detrás de la creciente demanda de energía en la región binacional. La expansión de la economía es otro factor importante. Estos factores han llevado a una gran demanda de servicios de energía en la región fronteriza que no se esperan en otras áreas de Norteamérica. Para poder satisfacer la demanda esperada en el norte de México, se requerirán interconexiones nuevas y actualizadas de los sistemas de transmisión con los Estados Unidos. El Tratado de Libre Comercio para América del Norte (TLCAN) proporciona oportunidades nuevas para compañías privadas de energía, particularmente aquéllas pertenecientes al sector industrial de energía.

Adicionalmente a la demanda incrementada de energía, habrá una presión significativa de recursos de gas natural e infraestructura relacionada, tales como conductos de gas de alta presión, sistemas de distribución y estaciones de bombeo. Mientras los precios altos de

combustible fósil y de electricidad siguen incrementándose, se espera que la energía solar (termal y eléctrica) se convierta más importante en la región fronteriza que en el pasado.

Si se pretende permanecer competitivo en la economía global será necesario un suministro seguro de energía a un precio razonable con un impacto ambiental mínimo para la región fronteriza de México-Estados Unidos. Debido al incremento esperado de la población así como a los estándares de vida en el lado mexicano de la frontera, es difícil ver como la demanda de energía se puede satisfacer sin la construcción de nuevas instalaciones generadoras en la región fronteriza. Sin embargo, si se desea evadir la degradación ambiental y beneficiar los estándares de la calidad de vida, el tipo de generación será importante. Una dependencia fuerte de combustible fósil, inclusive de gas natural, degradará indudablemente la calidad del aire, contribuirá al cambio climático global, y tensionará los suministros limitados de agua.

Existen diversas maneras de acrecentar la cooperación transfronteriza en el ámbito de la energía y proveer los servicios de energía necesitados en un futuro para los residentes de la frontera.

Para lograr esto se requerirá una cooperación y coordinación efectiva entre agencias locales y estatales aún responsables de regular el sector de energía en México y los Estados Unidos.

INTRODUCTION

Energy is an indispensable lifeblood of the U.S.-Mexican border region. It makes homes and businesses comfortable, moves people and goods, operates the machinery of industry, and powers the infrastructure that underpins the region's communities. This pervasive role makes energy a key issue in the border region's future. Energy choices made today will have significant effects on tomorrow's economy, environment, and quality of life. Without secure, reliable, and reasonably priced sources of energy, the border region cannot develop to its full potential.

The energy sectors in the United States, the four U.S. border states, Mexico, and Canada are undergoing major changes that will affect how energy is produced, transmitted, distributed, and sold throughout North America. These changes will directly influence energy use and energy-related infrastructure in the U.S.-Mexican border region.

Some of the important energy challenges confronting the binational region are:

- Meeting demand for electric services, which is expected to grow significantly over the next 10 years, in northern Mexico and the southwestern United States
- Meeting the rapidly increasing need for natural gas in the border region
- Understanding the complex array of different regulatory structures in the United States and those evolving in Mexico
- Developing crossborder infrastructure associated with natural gas and power transfers
- Creating the necessary administrative and regulatory mechanisms to plan and coordinate issues related to the energy sector in the binational region
- Developing environmentally sensitive and sustainable sources of energy for the region

This chapter discusses these issues and makes recommendations for improving crossborder collaboration to meet the future energy needs of the region. It will first focus on national energy issues in the United States and Mexico, then move on to border-wide topics of concern, and finally focus on the California-Baja California section on the border, where approximately 42% of the border population is currently located (Sweedler 2003). While many of the problems and opportunities facing the energy sector of this region are similar to other portions of the border, there are unique characteristics as well, which will be discussed.

Overview of the Region

To understand the energy sector in the border region it is important to examine the context within which energy services are used. The most important elements are the region's population and its expected growth, its economic activities, and the environmental impacts of energy production, transmission, and end use. Although this chapter is focused on the U.S.-Mexican border region, energy systems are integrated over much larger areas than just the border zone. In fact, today's energy markets are truly global, and a comprehensive analysis must recognize the global context of energy.

Although widely used, the term "border region" is not precisely defined. The La Paz Agreement between the United States and Mexico in 1983 defined the U.S.-Mexican border region as a zone stretching 100 kilometers (km) on either side of the international boundary. However, for the purpose of analyzing energy flows and related environmental issues such as air pollution, this definition is not particularly meaningful. Energy and transportation systems are not localized within a narrow region, and the cities in the border area all have important links to other regions throughout the United States, Mexico, and Canada.

Population growth is the main force behind the increasing demand for energy services in the border region. The region's population in 2000 was 11.9 million, and by the year 2020 it is projected to range between 15.9 million and 18.7 million (Peach and Williams 2004). Just in the California-Baja California region alone the projected population range for 2020 is between 5.9 million and 7.5 million.

In addition to population growth, the expanding economy—especially industrialization and the expected increase in the number of cars and trucks associated with increased U.S.-Mexican trade—is an important factor influencing the region's energy needs. Maquiladoras and other types of industrial facilities are major users of electricity and water, while the transportation sector depends on liquid fuels mostly in the form of gasoline and diesel fuel. Since natural gas is likely to be the fuel of choice for new power generation in the region, significant shortfalls of this versatile fuel can be expected unless measures are taken in the near future to meet projected demand. Details of population growth and economic trends are covered in other chapters in this volume and thus will not be covered here.

The United States and Mexican Energy Sectors

As noted above, the production, transmission, distribution, and use of energy in the U.S.-Mexican border region takes place within the framework of the larger energy markets of the southwestern United States, Mexico, and to some extent Canada. Power transmission grids and natural gas pipelines cross the North American continent and link the energy systems of the three North American countries. High-power transmission lines routinely transmit electricity generated in Canada or Mexico for use in the United States, and vice versa. Natural gas produced in Canada is transported to U.S. markets by transborder pipelines, and trade in natural gas has begun to take place between the United States and Mexico. To analyze the energy sector in the border region, it is therefore necessary to briefly discuss the larger North American energy context, focusing on the United States and Mexico.

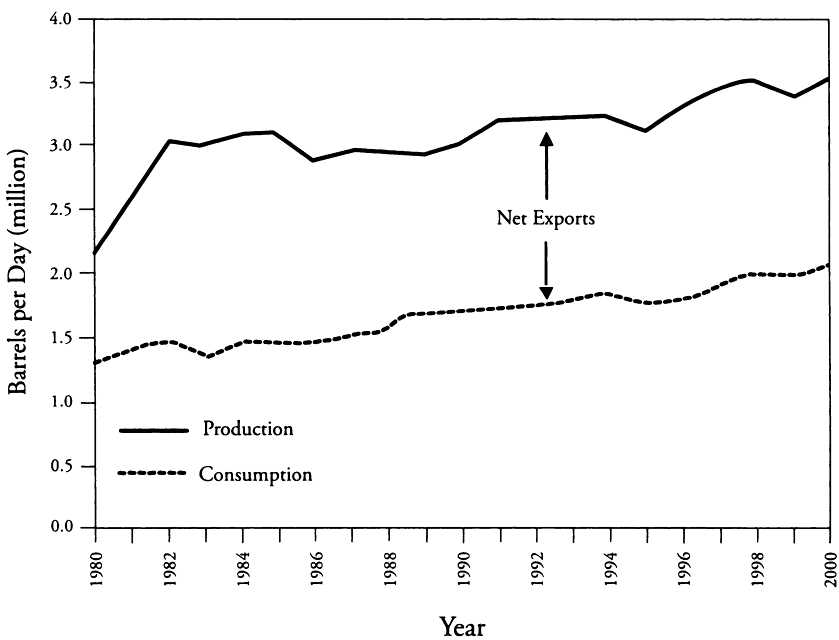
Energy Sources and Uses in the United States and Mexico

The structure of the energy sector and how energy is used in the United States and Mexico differ significantly. The United States uses a more broad spectrum of energy resources than Mexico, drawing on coal, oil, natural gas, nuclear, and hydropower, as well as a small amount of renewable resources. Mexico, by contrast, is heavily dependent on oil and natural gas, with the notable exception of geothermal resources in the state of Baja California.

Petroleum

The United States is the world's largest oil consumer, using 19.9 million barrels per day (bbl/d) in 1999 or 6.9 billion barrels per year (EIA 2001a). This is approximately one-quarter of oil consumption globally. In 2002, 11.4 million bbl/d were imported (57% of consumption), including 1.5 million bbl/d from Mexico (EIA 2004a). Mexico, by contrast, is self-sufficient in petroleum. It has the fourth largest proven crude oil reserves in the western hemisphere, totaling 20.7 billion barrels (Shields 2003). This estimate, lower than in previous years, was revised downward in September 2002 to meet new U.S. Securities and Exchange Commission (SEC) filing guidelines, which require "proven reserves" to be under commitment for exploration in the short term. In 2003, Mexico produced about 3.18 million bbl/d of oil (*Oil and Gas Journal* 2002), with net oil exports of roughly 1.664 million bbl/d (Pemex 2002). Mexico ranked as the world's fourth largest oil producer and ninth largest oil exporter in 2002, with nearly 1.5 million bbl/d bound for the United States. The value of Mexican oil exports increased from $10.4 billion in 2000 to an estimated $21.3 billion in 2003. Oil exports account for approximately one-third of government revenues (EIA 2004b; Pemex 2003). Mexico's petroleum production and consumption from 1980 to 2003 are shown in Figure 1.

Figure 1. Mexican Petroleum Production and Consumption from 1980 to 2003



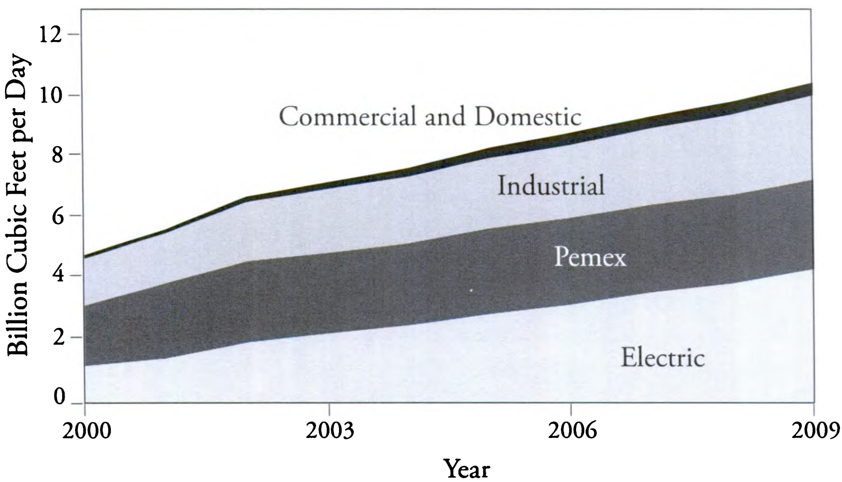
Source: U.S. Energy Information Agency 2003

Natural Gas

Mexico has proven natural gas reserves of 15.0 trillion cubic feet (Tcf), a figure that was also revised downward to meet SEC guidelines; 2002 production totaled nearly 1.33 Tcf (Secretaría de Energía 2004) and consumption nearly 1.51 Tcf (Pemex 2002). Mexico has not emphasized natural gas development and exploration until recently. Most of the gas now produced is "associated" gas that occurs as a co-product of oil production. Mexico is a small net importer of U.S. gas, a trend that is expected to continue in the coming decades. The tariff on Mexican imports of U.S. gas was eliminated in mid-1999, a move that will encourage continued and growing volumes of imports in the future.

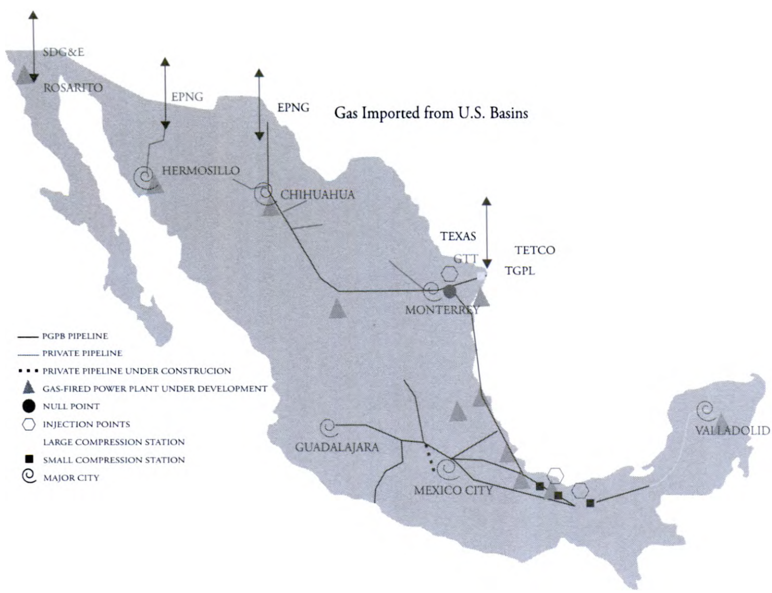
Natural gas is slated to play a more important role in the future as demand rises quickly, especially in the power sector and in the northern Mexican states. In response to anticipated demand growth, the state-run oil and gas monopoly Petróleos Mexicanos (Pemex) plans to increase U.S.-Mexican border infrastructure and capacity and to focus more on gas exploration activities. The Burgos field, located in northeastern Mexico, is expected to contain massive volumes of largely non-associated, recoverable natural gas resources. The Cantarell fields hold significant gas reserves in association with oil deposits, most of which is flared (emitted to the atmosphere). Pemex predicts that gas production will increase more than 50% from current levels by 2008. Pemex will invest almost twice as much capital in gas exploration and development activities in 2001 as it did in 2000. Figures 2 and 3 give the projected natural gas demand for Mexico and the major crossborder corridors. One can see that demand for natural gas in Mexico is expected to double in the next nine years.

Figure 2. Mexican Natural Gas Demand by Sector 2000–2009



Source: Pemex

Figure 3. Major U.S.-Mexican Gas Corridors



Source: El Paso Natural Gas Company

Mexico's growing reliance on natural gas is coinciding with historically high price levels for the fuel and growing demand in North America. The Mexican gas price was fixed to the Houston Ship Channel price in Texas in the early 1990s. As U.S. natural gas prices spiked in early 2001, Mexican President Vicente Fox came under pressure from Mexican industry and labor unions, which claimed that high prices were causing irreversible damage to businesses. In the wake of industrial plant closures, an agreement was reached whereby Pemex would sell natural gas to businesses at a fixed price of $4 per million British thermal units (Btu) for the next three years (compared to the U.S. Houston Ship Channel price, which reached more than $9 per million Btu in January 2001). Pemex would cover the difference when gas prices rose above $4 per million Btu but companies would continue to pay that price even if international prices drop below the $4 mark. The $4 per million Btu rate was retroactive to January 1, 2001. However, this arrangement excluded Baja California because natural gas in that region is purchased from the United States, not Pemex. Baja California remains subject to the price fluctuations of the U.S. market (EIA 2001). This illustrates the important point that Baja California is considered apart from the national energy markets by the Mexican authorities themselves, owing to the relatively isolated geography of Baja California relative to the rest of Mexico, as well as the growing reliance on U.S. natural gas in the state.

Natural gas consumption for the United States was 22.3 Tcf in 2003, nearly 15 times greater than Mexico's (*Natural Gas Monthly* 2003). Of this amount, 4.0 Tcf, or 18%, was imported; nearly 94% came from Canada (EIA 2004a). The availability and price of natural gas will be one of the most important energy issues in the border region during the next 20 years.

Electricity

Mexico has installed electric capacity of 42,300 megawatts (MW) and in 2002 generated 198.6 billion kilowatt-hours of electrical energy (CFE-CRE 2003). Oil-fired plants make up the largest share of electricity generation. Thermal (oil, gas, and coal) electricity generation in 2002 accounted for 80.1% of total generation, hydropower accounted for 12.4%, nuclear power for 4.8%, and geothermal and eolic for 2.7% (CFE 2003). By 2012, it is expected that natural gas will comprise a much larger portion of thermal production—approximately 63% (SE 2003). Mexico's industrial energy policy calls for conversion of many oil-fired power plants to natural gas by 2005. Most new power plants will be run on natural gas and all proposed plants in the northern Mexican border region are slated to use natural gas.

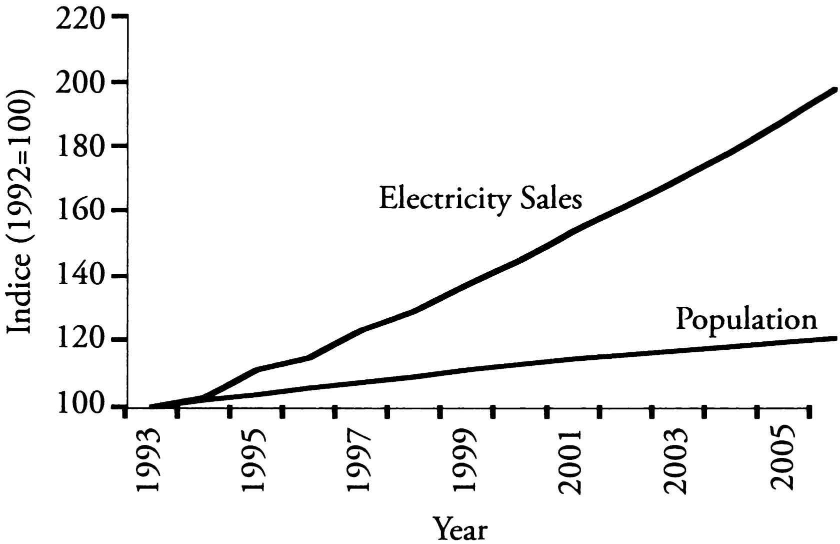
Mexico's electricity sector is at a crossroads. Although generation has increased rapidly over the past decade, supply is not expected to meet demand growth over the next two decades, especially in northern Mexico. Given current grid capacity constraints, shortages could result. It is expected that investments of approximately $50 billion will be needed over the next decade to meet projected electricity demand. Failure to make substantial investments in generation capacity and infrastructure could adversely affect the international competitiveness of key northern industrial regions. Although about 95% of Mexican households are electrified, there are still many thousands of rural towns without electricity (EIA 2001). Mexican electrical demand is plotted against population in Figure 4.

Structure of Energy Sectors in the United States and Mexico

The U.S. energy sector is, for the most part, owned and operated by private companies. Although in private hands, energy companies are regulated by state and federal agencies. The price of coal, oil, and natural gas is largely determined by market factors and relatively uniform prices exist across the United States. The price for electricity, however, has traditionally been established by state regulatory agencies and has not been determined directly by market forces until recently.

Some of the agencies responsible for regulating the energy industries in the United States are the Federal Energy Regulatory Commission (FERC), the U.S. Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), and state public utilities commissions. In California, the California Public Utilities Commission (CPUC) and the California Energy Commission are the principal agencies that oversee the energy sector. At the local level,

Figure 4. Mexican Electricity Demand Versus Population Growth



Source: Authors

city and county jurisdictions may have to grant approval for energy-related construction such as gas pipelines and power transmission lines.

In contrast to the way energy is handled in the United States, the production, distribution, and management of energy supplies in Mexico are, by and large, under the control of the federal government. The federal government also sets energy prices. The Secretaría de Energía (SE) is the key government ministry responsible for formulating energy policies. SE has direct oversight of the national electric utility (the Comisión Federal de Electricidad [CFE]), Pemex, the national energy conservation commission (Comisión Nacional Para el Ahorro de Energía [CONAE]), and several energy-related research institutes. A relatively new agency, the Comisión Reguladora de Energía (CRE), was established in 1993.

The power sector in Mexico is dominated by the state-controlled CFE. Like Pemex in the oil and gas industry, CFE has enjoyed a monopoly in the electric power sector for decades, although reforms instituted in 1992 allow independent power producers (IPPs) and cogenerators to sell power to CFE.

Deregulation of the energy sector is a contentious issue in Mexico. Mexican President Fox has made privatization of the sector a top priority, as private investment will be needed to meet the country's rapidly increasing demand for electricity and gas. However, his reform efforts to date have met strong resistance. Fox had planned to submit a reform bill for electricity privatization before the end of 2002, but thus far he has failed to muster support within the opposition-controlled Congress. The bill is expected to call for a change in the constitution to allow private generators to sell electricity in a wholesale market, create increased incentives for foreign companies to participate in developing new oil and gas fields, and establish a separate electricity regulatory body. Currently, only the state's power companies can distribute and sell electricity to the general public. Fox has pledged not to privatize CFE during his presidency.

IPPs are allowed to build and own power generation facilities; the power can be used at related industrial companies or sold under long-term contracts to CFE. As of July 2004, 20 IPP permits had been issued for a total investment of $6.313 billion (CRE 2004). The projects are expected to add more than 11,478 MW of capacity by 2004. Of the 20 IPP projects in progress, eight are in northern Mexico; most of these are either totally or partially dependent on natural gas imports from the United States. An additional eight projects in northern Mexico are in the bidding process. However, natural gas and electricity shortages in the United States are having a negative effect on IPP development in Mexico; uncertainty about import sources could explain the low level of interest in new projects offered by CFE (CFE 2002).

Subsidies paid to agricultural and residential electricity consumers and the lack of an open power market are blamed for escalating industrial electricity costs, which are now more than average international industrial electricity costs. Mexican industry warns that these costs will make Mexican industry internationally uncompetitive.

NAFTA and Energy

The treatment of the energy sector in the North American Free Trade Agreement (NAFTA) is perhaps most significant for what it lacks. Pursuant to the restriction in the Mexican Constitution that reserves for the Mexican federal government all ownership of Mexico's basic energy resources, NAFTA does not create significant new opportunities for private investment in oil, gas, refining, basic petrochemicals, or direct delivery of electricity. These activities remain controlled by Pemex and CFE. Nevertheless, NAFTA does provide new opportunities for private energy companies, particularly those in the electric power industry.

Under NAFTA, foreign companies can acquire, establish, and operate electric generation facilities in Mexico. Electricity generated at these facilities can be used at the site or sold to CFE. Moreover, the opening of the Mexican government procurement market will create opportunities for foreign companies to compete with Mexican entities for contracts to supply and service Pemex and CFE.

NAFTA reserves for the Mexican state goods, activities, and investments in the oil, gas, refining, basic petrochemicals, nuclear, and electricity sectors. Consistent with Mexico's move to greater privatization of industries and resources, however, NAFTA opens many downstream activities in the energy sector to greater private investment, both foreign and domestic. NAFTA also expands on Mexico's current Build-Lease-Transfer (BLT) program, which permits foreign companies to build an energy facility while leasing the site during construction, and then to transfer the plant back to the government shortly before commercial operation. With the full implementation of NAFTA, foreign companies will be able to own the plants and earn profits on sales of power back to CFE for the life of the facility. In addition, NAFTA's gas provisions potentially enable U.S. owners of gas-fired cogeneration facilities and other gas-fired facilities in Mexico to arrange for competitive gas supplies from U.S. gas companies.

NAFTA aims for more open markets in the energy sector, but it remains unclear whether those markets will provide sufficient returns to support increased investment. Remaining issues to be resolved are:

- The rates CFE will pay for electricity sold by the foreign-owned facilities
- The extent to which the Mexican government may regulate and modify the rates and terms of power sale agreements with CFE (deals will be limited or impossible if these arrangements fail to ensure a guaranteed payment stream to cover the debt service)
- The level of taxes that may be imposed on such operations in Mexico
- The role Pemex will play in importing gas for gas-fired electric power facilities

Genuinely open oil and gas markets are not created under NAFTA. The effect of the agreement's electricity provisions will depend greatly on how they are implemented. This will depend, in turn, on the extent to which the Mexican administration succeeds in bringing reform and a market-oriented spirit to Pemex and CFE.

The Energy Sector of the U.S.-Mexican Border Region

The four U.S. states and the six Mexican states that make up the border region confront some energy issues different from, but related to, the general energy situation in the whole of North America. Compared to other regions in the United States and Mexico, both the southwestern United States and northern Mexico are experiencing large population increases and high economic growth that are expected to continue for at least the next decade. These factors have led to a greater demand for energy services in the border region than is expected for other areas of North America. For example, demand for power in northern Mexico is expected to grow by 6.5% per year for the next 10 years, compared to 5.6% for the rest of the country (CFE 2002). To meet the expected demand in northern Mexico, new and upgraded interconnections of the transmission system with the United States will be needed.

In addition to the increased need for power, there will be significant pressure on supplies of natural gas and associated infrastructure, such as high-pressure gas pipelines, distribution systems, and pumping stations. Now more than ever, there is a close relationship between natural gas and power generation, since all of the new power plants in the border region are expected to be the high efficiency, combined-cycle design that requires natural gas for their primary fuel.

Like the rest of North America, the energy sector of the border region is primarily dependent on fossil fuels. The three main fossil fuels—petroleum, natural gas, and coal—account for the main sources of energy in the border region. Gasoline and diesel (derived from petroleum) are used as the main transportation fuels, and liquid petroleum gas (LPG) is used extensively in place of natural gas on the Mexican side of the border for cooking, heating, and industrial processes. Where available, natural gas is used for heating and industrial process heat. Current power production is dependent on oil, coal, and some natural gas in Mexico, whereas in the U.S. portion of the border region natural gas and nuclear energy make up the bulk of fuels used for power generation. As mentioned previously, this fuel mix will change during the next decade as natural gas replaces oil, coal, and nuclear as the most preferred fuel for power generation on both sides of the border.

Besides fossil fuels, renewable resources also play a role in the border region, especially geothermal energy and wind power, with the latter growing rapidly in Texas. The use of renewable resources is expected to grow substantially in California over the next two decades because the CPUC has stipulated that 20% of the state's energy must be generated using renewable sources by 2020. As prices for fossil fuels and electricity continue to rise, it is expected that solar energy (both thermal and electric) will also play a larger role in the border region than in the past.

Electric Energy in the Border Region

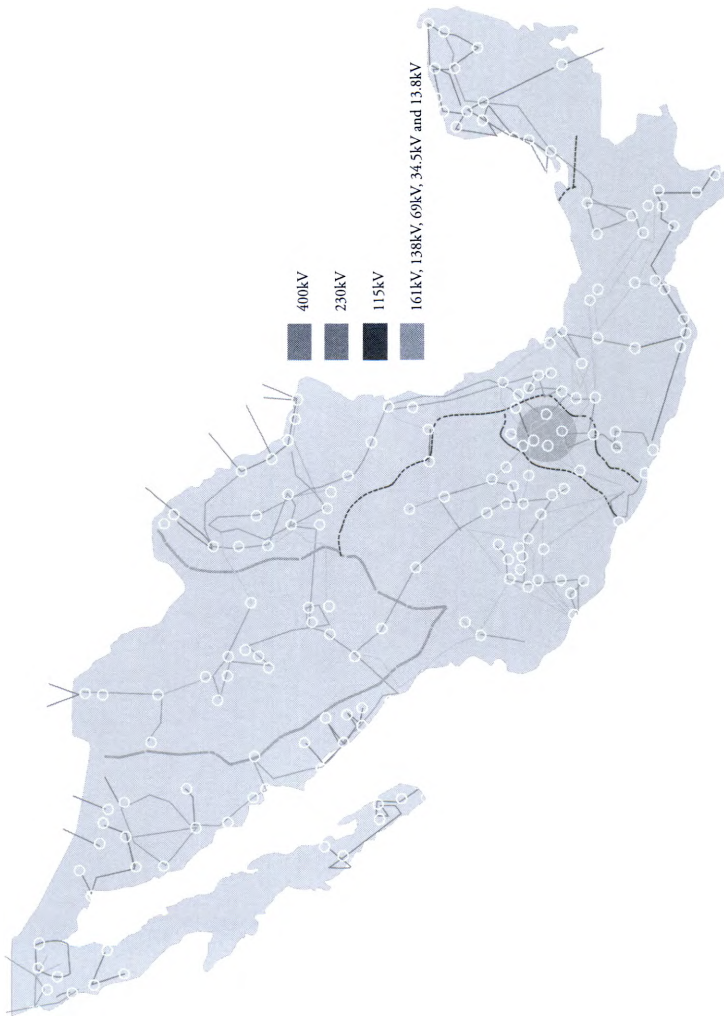
Figures 5 and 6 show the main electric transmission system of Mexico, as well as the crossborder connections. There are 12 transmission lines that cross the border—three in California, two in Arizona, and seven in Texas. Of these, only three are 230 kilovolts (kV); the others are 115 kV or less. The three high-voltage lines are located in the California-Baja California region. One important issue facing the border region is the need to increase the capacity of the crossborder transmission system by upgrading existing lines or developing new lines. Because this involves an international transfer of energy, FERC and DOE would have to be involved in addition to state and local agencies. In Mexico, CFE and SE would be the main entities involved, with possible input from the growing influence of state and municipal authorities.

Natural Gas

As previously noted, natural gas will become an important element in the fuel mix for the border region in years to come. The main reason is that natural gas is relatively clean-burning compared to coal or oil; it is also the best fuel for the new, efficient, gas turbine-steam generator (combined-cycle) power plants planned for construction in the border region. Because of this, creating, obtaining, and maintaining a secure and reasonably priced supply of natural gas will be one of the main challenges for the region.

The use of natural gas in the Mexican power sector will result in an unprecedented increase in the annual growth rate. It increased at 13.9% for the period 1993 to 2002 (SE 2003) and it is expected to remain at 12.1% for the period 2002 to 2011 (SE 2002), as shown in Figure 7. To increase domestic natural gas production, Mexico has introduced Multiple Service Contracts (MSCs). Under an MSC, foreign companies are paid for their services in developing natural gas reserves, but any gas produced remains the property of Pemex. To date, five of seven blocks have been awarded for a total estimated production increase of 440 million cubic feet per day (Mmcf/d).

Figure 5. Main Mexican Power Transmission Lines as of 1999



Source: CFE

Figure 6. Crossborder Power Transmission Lines in 1999

Source: CFE

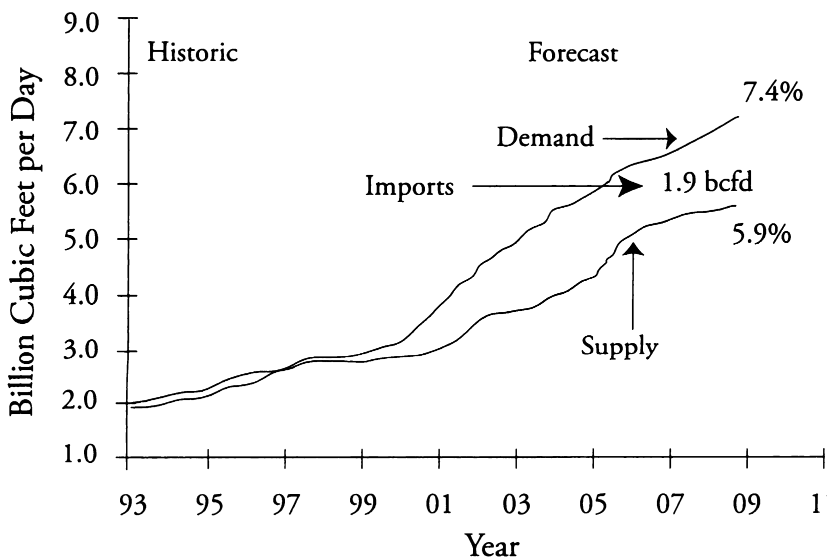
However, the two largest blocks did not receive any bids, demonstrating the lack of interest among large companies in the terms of the contracts.

In 1998, natural gas accounted for only 18% of total power generation in Mexico, but is expected to account for 58% by 2008 (CRE 2000), as seen in Figure 8. Much of that projected consumption for natural gas will take place in northern Mexico, as seen in Figure 9.

Geothermal Energy

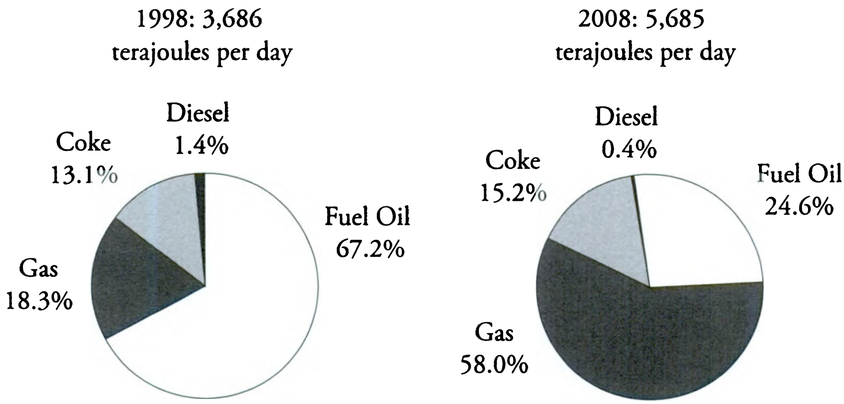
Geothermal sources of energy for power production are important in the border region, but only in the California-Baja California area, where there are significant geothermal resources in the Imperial-Mexicali Valley. These will be discussed later.

Figure 7. Historical and Projected Natural Gas Demand 1991–2008



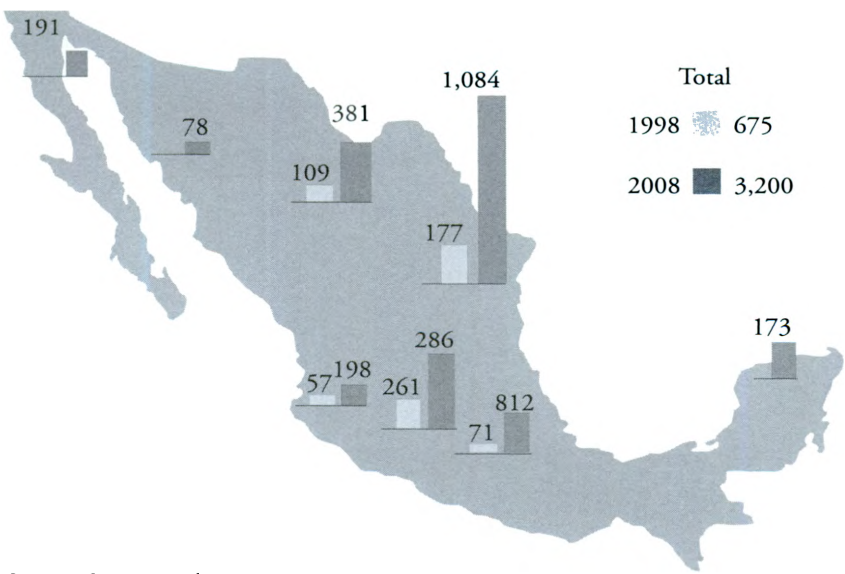
Source: Secretaría de Energía

Figure 8. Projected Evolution of Fossil Fuel Consumption in Electricity Generation



Source: CRE

Figure 9. Consumption of Natural Gas for the Generation of Electricity in Mexico



Source: Secretaría de Energía

California-Baja California Border Region

The California-Baja California portion of the U.S.-Mexican border region is an especially important section of the borderlands. In this western part of the border zone resides 42% of the total border population in the largest U.S. and Mexican twin cities—San Diego, Calif., and Tijuana, B.C. The energy issues here differ somewhat from other border regions because of the complex energy situation in California and the fact that Baja California is somewhat physically isolated from the rest of Mexico. Although the power grid of Baja California is not connected to the main Mexican transmission system, three of the largest crossborder connections are in this region (see Figure 6). The Mexican natural gas pipeline system also does not reach Baja California; any gas supplies will have to come across the border with California or Arizona, or possibly be imported in the form of liquefied natural gas (LNG).

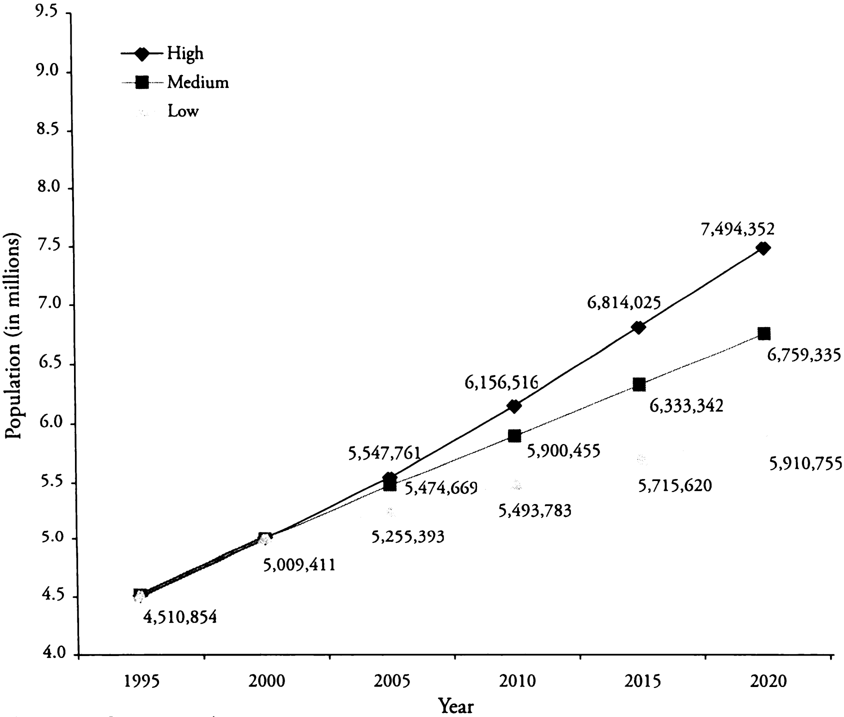
As is the case for the entire border region, population growth is the principal driving factor for projected increases in energy services. Figure 10 gives the expected population growth to 2020, at which time between 5.9 million and 7.5 million people are expected to reside in the region. Just the San Diego-Tijuana metropolitan region is expected to have 5.8 million people by 2020 (SCERP 2004).

In addition to population growth, the 867 maquiladora plants employing 215,186 people (SDE 2004) are major consumers of energy. Added to the growth of the industrial sector will be the large increase in cars and trucks as U.S.-Mexican trade increases. This, in turn, will lead to a greater demand for liquid fuels such as unleaded gasoline and diesel fuel.

Electric Power in Baja California

Demand for power in Baja California is expected to grow by 7.2% per year over the next decade, resulting in a doubling of demand by 2010 (CFE 2002). This translates into a need for more than 1,400 additional megawatts just to meet the needs of the Mexican population, leaving nothing for export to California. San Diego's power

Figure 10. California-Baja California Border Population, 1995–2020



Source: SCERP 2004

needs are also expected to grow, but by 2.11% per year through 2009 (SDG&E 2004). Although a lower growth rate, it is still considerable and begins from a higher base load.

Baja California's electrical energy infrastructure consists of power plant complexes near Tijuana and Mexicali. The current installed capacity is 4,000.5 MW. The location and fuels used are given in Table 1. The power grid is connected to San Diego via three 240 kV lines, one near Tijuana and the other two near Mexicali.

Table 1. Baja California Generating Facilities

Municipality	Site	Fuel	Capacity in MW
Tijuana	Turbogas	Diesel	210.0
Rosarito	Rosarito	Natural gas	1326.0
Mexicali	Cerro Prieto I-IV	Geothermal	720.0
	Termoeléctrica de Mexicali	Natural gas	600.0
	La Rosita	Natural gas	1060.0
	Turbogas	Diesel	62.0
Ensenada	Turbogas (Cipres)	Diesel	27.5
Total			4005.5

Source: Authors

Natural gas has become the main fuel used for power generation in Baja California and it powers the Rosarito and Mexicali facilities. From an air quality perspective, the main power plant supplying power to Tijuana—the 1,326-MW facility in Rosarito—is just 24 km from the border. It now uses natural gas as its primary fuel, although some generators still burn fuel oil. From an air quality perspective, it is important that the supply of natural gas, which is imported from the United States, be secure and reasonably priced. Although combustion of natural gas still results in significant atmospheric emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2), they emit less than coal- or oil-based plants for an equivalent amount of energy produced.

The only indigenous energy source used on a large scale in Baja California is geothermally generated electricity, located south of Mexicali at Cerro Prieto. Until a few years ago, power from Cerro Prieto was exported to Southern California under a contract with Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E). These exports peaked in 1987 and 1992, and accounted for 12% and 10%, respectively, of San Diego's electricity supply in those years (CFE 1993). Electric imports from Mexico to San Diego ended in 1996, as supply in Baja California has barely kept up with growing internal demand. However, beginning in July 2003 electricity exports totaling 1,130 MW from Intergen's recently completed La Rosita power plant and Sempra Energy's Termoelectrica de Mexicali plant began to flow into the United States (Cabrera 2003). These plants were built under the IPP scenario discussed earlier, mainly for the purpose of exporting power to California. For all of Mexico, the balance of trade in electricity is given in Table 2, where one can see the growing level of power imports from the United States beginning in 1995.

Table 2. Balance of Trade for Electricity (thousands of dollars)

Year	Exports	Imports
1980	104.0	615.0
1981	44.0	336.0
1982	8.0	9.0
1983	56.0	4.0
1984	90.0	5.0
1985	114.0	140.3
1986	1,461.0	100.7
1987	2,042.0	123.1
1988	1,996.0	170.9
1989	1,932.0	611.8
1990	1,946.0	575.1
1991	2,019.0	617.9
1992	2,041.0	989.5
1993	2,015.0	908.6
1994	1,970.0	1,140.2
1995	1,944.0	1,163.8
1996	1,288.4	1,387.5
1997	51.6	1,511.8
1998	77.0	1,510.0
1999	130.6	657.2
2000	202.7	1,080.8
2001	266.5	360.8
2002	343.5	475.8
2003	953.2	71.9

Source: Secretaría de Energía

Between 1996 and 1998, electric consumption increased 12.5% for the state of Baja California and 17.6% for Tijuana (CFE 2000). These large increases have put a significant strain on CFE's generating capacities in Baja California. By comparison, electric use in San Diego County increased by only 6.6% in the same two-year period (SDREO 2003). In Tijuana, the industrial and residential sectors are the major users of electricity. This is different from electric use patterns in San Diego, where the commercial and residential sectors consume more electricity than the industrial sector. The difference in electric energy use between Tijuana and San Diego reflects the fact that manufacturing and assembly activities form a larger part of the economy in Tijuana than they do in San Diego.

In Mexicali, residential electric consumption is more than twice Tijuana's, even though Mexicali's population is less than Tijuana's (CFE 2000). Mexicali has some of the highest temperatures in Mexico, with daily average outdoor temperatures well above 90°F in July and August. It also has an energy-inefficient housing infrastructure, mainly due to the poor shell characteristics of the housing stock and the low efficiency of the electric devices used for air conditioning. In fact, Mexicali has the highest per capita residential energy use in Mexico. The inefficient air conditioning sector in Mexicali is an obvious area where improvements could be made. Reduced air conditioning loads would result in a reduction in demand for electricity in Baja California. Several programs are under way to increase the energy efficiency of the housing stock and reduce air conditioning loads in Mexicali.

Although per capita electric use in Baja California is greater than the Mexican average, it is still much less than San Diego's. For Baja California as a whole, per capita electric use for 2000 was only 3,010 kilowatt-hours (kWh)—nearly half of San Diego's 6,333 kWh. For Tijuana, per capita electric use was only 2,362 kWh—nearly one-third of San Diego's. Mexicali, with 3,268 kWh per capita (CFE 2001), is the highest per capita consumer in Baja California.

Future Power Needs in Baja California

The process of estimating future energy needs and planning to meet those needs in Mexico is quite different from the process in California. There are no federal or state counterpart agencies in Mexico to the CPUC, the California Energy Commission, or the San Diego Association of Governments (SANDAG). Future electricity demand has traditionally been estimated by CFE, based more or less on historical growth patterns than on a detailed analysis of the different electricity-consuming sectors.

Estimates of future annual growth rates for power are in the range of 5% to 7% for Baja California for the next decade (CFE 2003). This means that between 910 MW and 1,400 MW of additional capacity will be needed by 2010. The completion of the two new power plants in Mexicali has added 1,560 MW of capacity. However, as most of this power is slated to be exported to California, it is unknown whether these new plants will be sufficient to meet Baja California's growing demand. Additional power plants proposed for the region are shown in Table 3. The total potential capacity of 430 MW will not be enough if actual demand follows CFE's projected demand.

Table 3. Proposed Power Plants in Baja California

Facility	Location	Output (MW)	Estimated Online Date	Technology	Fuel Type	Notes
La Jovita*	Costa Azul (15km North Ensenada)	280	2006	Combined cycle natural gas	Natural gas	CFE
El Carrizo	TKT	40-50	2007	Small hydro water	Water	CFE
El Retiro	Ensenada	60-100	2007	Small hydro water	Sea water	CFE

Source: Secretaría de Dessarrollo Económico, Estado de Baja California

Instead of increasing generating capacity within Baja California, expected demand might be met by purchasing more electricity from the North American power system and integrating Baja California more fully into the electric transmission system of the United States. As noted earlier, the Baja California power grid is isolated from the Mexican national system but connected to the California system at two points. This permits a limited amount of power transfers between the western North American system and Baja California. Whatever the ultimate fate of restructuring efforts in California and the west, there is little doubt that a regional market for power will develop in the western United States, and there is no reason why Baja California and northern Mexico will not be part of that power pool. Electric customers and energy brokers will be searching all over North America for the cheapest power available. It may prove cost-effective for CFE in Baja California to both buy and sell power within this large electric market. Large consumers of power in Baja California, such as industrial parks, may find it cheaper to purchase power from the United States rather than from CFE. Similarly, customers in San Diego may find it less costly to obtain power from CFE in Baja California or from independent power producers in Mexico instead of from local generators in the United States.

Baja California's Natural Gas Market

As noted above, Baja California has no direct access to the abundant natural gas resources of Mexico because of its location relative to those resources. There is, however, a growing recognition that natural gas would be an ideal fuel to meet the region's growing demand for industrial heat and electric generation and that the United States, and perhaps even Canada, can serve as sources of natural gas for Baja California if appropriate crossborder pipelines could be constructed.

Baja California's dependence on U.S. natural gas supplies can have drawbacks, however. The Mexican government is guaranteeing a price of $4 per therm, except for users in Baja California because that state's gas comes from the United States, not Pemex. Marcos Ramirez Silva, Pemex's director of gas and petrochemicals, has been quoted as saying, "We don't have any infrastructure there...

Nothing. Well, it's (Baja California) more like the United States. They should be burning fuel oil" (Lundquist 2001). Of course, if the price of U.S. natural gas falls below Mexico's price, Baja California could benefit.

The use of natural gas for power generation in Baja California is of particular importance to the San Diego-Tijuana region. Since the principal thermal power plant in the Baja California is just 24 km south of the border, supplying that plant and its planned additions with natural gas will improve air quality in the region while at the same time provide natural gas to industries and residents of Tijuana. Gas-fired electrical generation produces almost no sulfur oxides and is generally more efficient than an oil-fired plant because combined-cycle technology can be used.

For the first time in Baja California, natural gas is now available via pipelines crossing the border east of Calexico, Calif., and south of San Diego. As of May 1999, 70 industrial customers, 80 commercial businesses, and 10,308 residences had been connected to this distribution system. Contracts had already been signed for an additional 78 industrial customers, 127 commercial businesses, and 15,700 residences. In addition, a new pipeline is supplying natural gas to the new power plants at La Rosita, near Mexicali (Rivero 2002).

Plans to import LNG to the Baja California coast have run into significant opposition from local residents, state and local authorities, and even from some sections of the Mexican Congress. Out of six original proposals, there are currently only two projects in the advanced development stage. Shell International Gas Limited and Sempra Energy LNG Corp. have joined efforts to develop an onshore LNG terminal at Costa Azul between Rosarito and Ensenada. The $600 million project would provide 1 billion cubic feet per day (bcf/d) when completed in 2007 (Sempra Energy 2003). ChevronTexaco plans to construct an LNG regasification terminal eight miles off the coast of Baja California in the Coronado Islands. The $650 million project would deliver 1.4 bcf/d at full capacity, with operations projected to begin by the end of 2007 (ChevronTexaco 2003).

The experience of trying to site large LNG facilities on the Baja California coast highlights many of the energy-related issues of concern in the border region. On the one hand, most analyses of future natural gas demand in California and Baja California conclude that the region will experience shortfalls in this resource in the next 10 years. Because both San Diego and Baja California are located far from sources of natural gas in both countries and because pipeline transmission capacity is limited, importing LNG would appear to be an attractive source of supply.

On the other hand, critics have pointed out that these large facilities are inconsistent with the natural ecology of the peninsula's coast and near-shore environment. They also question the validity of demand forecasts that show large increases in natural gas needs, claiming that aggressive conservation and renewable energy resources can meet future demand. Critics also cite safety concerns in locating potentially dangerous plants near population centers.

An important argument, which has relevance for LNG plants and other large energy production facilities in Baja California, is that most of the gas will be used to satisfy the California market, with relatively little distribution in Baja California. Thus, in this view, Baja California assumes most of the negative environmental effects and potential safety risks with little benefit from increased supplies of natural gas.

Added to these issues is the question of national security, from both the U.S. and Mexican perspectives. From the U.S. perspective, becoming dependent on imported LNG from distant shores could result in a situation similar to what currently exists for imported petroleum. The United States now imports more than half of this vital resource (Department of Energy 2002), in many cases from unstable regions of the world, thus elevating oil supply to a question of national security. For those who advocate greater energy independence for the United States, importing LNG will only make matters worse.

For those in Mexico concerned about Mexican sovereignty, allowing the location of critical U.S. energy infrastructure facilities, such as LNG plants, in Mexico could raise questions about protecting those facilities from terrorist attacks. In this view, if the United States authorities do not believe that Mexico can provide adequate protection, they may intervene to secure the relevant facilities, which would clearly be a violation of national sovereignty. Although considered unlikely by most observers, this argument has been given prominence in the Mexican national press and in the Mexican Congress. To some extent it is a reaction to what is considered an aggressive American foreign policy to secure U.S. interests, especially where energy is concerned.

Regardless of one's view, it is important to understand the different perspectives and to understand that energy-related issues take place in a political and social context. In most cases, the types of energy systems that are finally constructed are the result of a complex interaction between resources, economics, politics, and local environmental considerations. This is even more true in a region between two very different nations.

Renewable Sources of Energy in Baja California

It was noted earlier that both San Diego and Baja California are heavily dependent for energy supplies on fossil fuels (petroleum products and natural gas) that originate far from the region. Not only does this represent an outflow of regional capital, but the burning of fossil fuels is a major source of air pollution. Therefore, it is of interest to examine the potential for development of indigenous and renewable sources of energy in the border area as a long-term replacement for fossil fuels.

Although Baja California has an impressive array of renewable energy resources, very few of these resources have been developed to produce significant amounts of energy. The main reasons for the lack of renewable energy development in Baja California are the same that plague renewable energy development elsewhere: Until recently, relatively low costs for oil and natural gas were coupled with relatively high initial capital costs for most renewable energy projects. These factors present an even larger impediment for the development of most renewable projects in Mexico because of the plentiful supply of oil and gas and the lack of capital. However, with the current upsurge in natural gas prices, the high prices of oil, and the shortage of power in California and the west, incentives to develop renewable energy resources continue to grow.

Renewable energy resources in Baja California consist of geothermal, microhydroelectric, biomass, wind, solar, and tidal. With the exception of geothermally generated electricity, none of these renewable resources has been significantly exploited to date.

Geothermal
Baja California is home to some of the largest geothermal reserves in Mexico. These considerable resources are located at Cerro Prieto in the Valley of Mexicali, about 30 km from the international border. An intriguing potential source of even greater geothermal energy than the Valley of Mexicali might be in the form of geopressurized deposits (high-temperature, high-pressure water located beneath the sea bed) located in the northern part of the Gulf of California. This region displays characteristics found nowhere else in the world for the development of marine geothermal resources. The initial geothermal potential has been estimated to be tens of times greater than that of Cerro Prieto.

Geothermal Binary Cycle
There is the potential to use heat from the residual brine that results from the operation of the geothermal fields at Cerro Prieto. The fields have an installed capacity of 720 MW and, when in full operation, produce approximately 12,000 tons of residual water per hour with a temperature range of 120°C to 135°C (Quintero N. 1988). This represents an important amount of useful energy for a binary cycle operation. Estimates suggest that as much as 246 MW of additional power could be produced in this fashion.

Microhydroelectric Power
An interesting renewable technology that could prove practical in Baja California is microhydroelectric power generation in the Mexicali Valley. This is based on capturing the energy in the flow of water from the extensive irrigation system that exists in the agriculture-intensive region surrounding the city of Mexicali. Estimates as high as 80 MW have been suggested for microhydroelectric generation.

Solar, Wind, and Biomass

Table 4 lists an estimate of renewable and alternative energy resources for Baja California. One can see that these sources of energy could play a significant role in the region's energy portfolio. Although the potential contribution to the region's energy mix from solar (thermal and electric), wind power, and biomass could be substantial, there are no studies that examine in a comprehensive fashion the potential of these resources. The authors of this chapter are in the process of completing such a study.

Table 4. Estimated Renewable and Alternative Energy Resources for Baja California

Energy Source	Potential
Geothermal	1,000 MW proven reserves (Mexicali)
Solar	3.3 kWh/m^2 to 6.9 kWh/m^2
Wind	100 watts/m^2 to 250 watts/m^2
Biomass	
Agricultural waste	3,600m^3 (Mexicali)
Solid urban waste	25 MW to 30 MW + heat
Seaweed	~75,000 Barrels of oil equivalent per year
Fuel wood	Negligible
Mycrohydroelectric	~80 MW (Mexicali)
	~20 MW (Tecate)
Tidal Power	~1,200 MW (Gulf of Cortez)

Source: Huacuz 1995

San Diego's Energy Sector

Overview

A comprehensive analysis of the energy sector in San Diego was recently carried out by a consortium of agencies led by the San Diego Regional Energy Office (SDREO) called "Energy 2030: The San Diego Regional Energy Plan" (SDREO 2003). The Regional Energy Strategy was adopted by SANDAG in December 2003 to form the energy component of the Regional Comprehensive Plan.

The main features of the energy sector in San Diego are the dominance of the transportation sector in terms of energy consumption, the high proportion of electricity imported from outside the region, and relatively high electricity and gasoline prices. Transportation accounts for more than 60% of end-use energy consumption in San Diego, followed by the residential, commercial, and industrial sectors. This energy consumption pattern reflects the structure of the San Diego economy—most San Diego residents commute to work in private automobiles with one or two occupants. Moreover, most of the rapid population growth during the last 10 years has occurred in the northern sections of the county, resulting in longer commutes from home to work.

Power Sector

San Diego is dependent on power imports from outside the region, which supplied more than half of summer peak demand in 2002. The commercial sector uses more electricity proportionally than the rest of the state, reflecting San Diego's concentration of high-tech businesses, tourist activities, and retail trade. This is important because these sectors are rapidly growing not only in San Diego but in Tijuana, although at the present time industrial use of power is still greater than commercial activities in Tijuana and Mexicali, compared to San Diego.

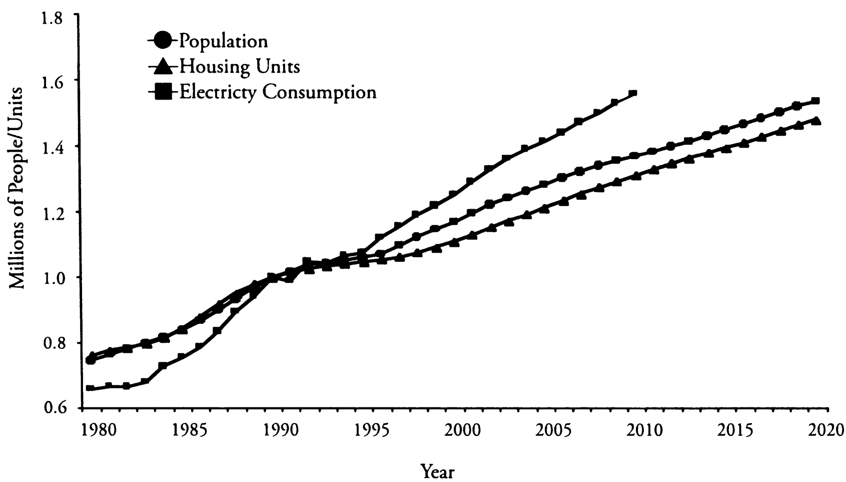
The major power-related infrastructure elements in San Diego consist of two large thermal power plants located in Carlsbad (Encina) and Chula Vista (South Bay), plus the San Onofre Nuclear Generating Station (SONGS) located just south of San Clemente, 20% of which is owned by SDG&E. All thermal power plants operating in the county use natural gas, and there are only two high-voltage (500 kV) transmission lines, one to the north and the other to the east, responsible for carrying all the imported power into the region.

Figure 11 gives historical and projected electricity demands compared to housing and population growth, indexed to 1990. The figure shows that demand for power has grown faster than population and housing since 1995, a trend that is expected to continue through 2020. The main reason for this is the large amounts of power consumed in office buildings, Web centers, and information-processing sectors, all of which play an important role in the San Diego economy.

To meet this projected demand for power, San Diego, indeed the entire binational region, has several choices:

- Increase in-region generation capability
- Increase electricity imports from outside the region
- Reduce demand
- Some combination of the above

Figure 11. Population, Housing, and Electric Use for San Diego County, 1980–2020



Source: California Energy Commission; SANDAG

For San Diego, new conventional power plants, distributed generation, and an increase in renewable energy generation offer three ways to increase in-region generation. In June 2004, two new large, combined-cycle power plants were approved by CPUC for San Diego. One, the Palomar Energy facility, which is to be constructed in Escondido, is slated to produce 546 MW when completed in late 2005. The other, a 550 MW facility owned by Calpine, is located on the border in Otay Mesa and is scheduled for completion in 2007. These two facilities and other smaller projects approved by the CPUC will add 1,236 MW of in-region generation by 2007.

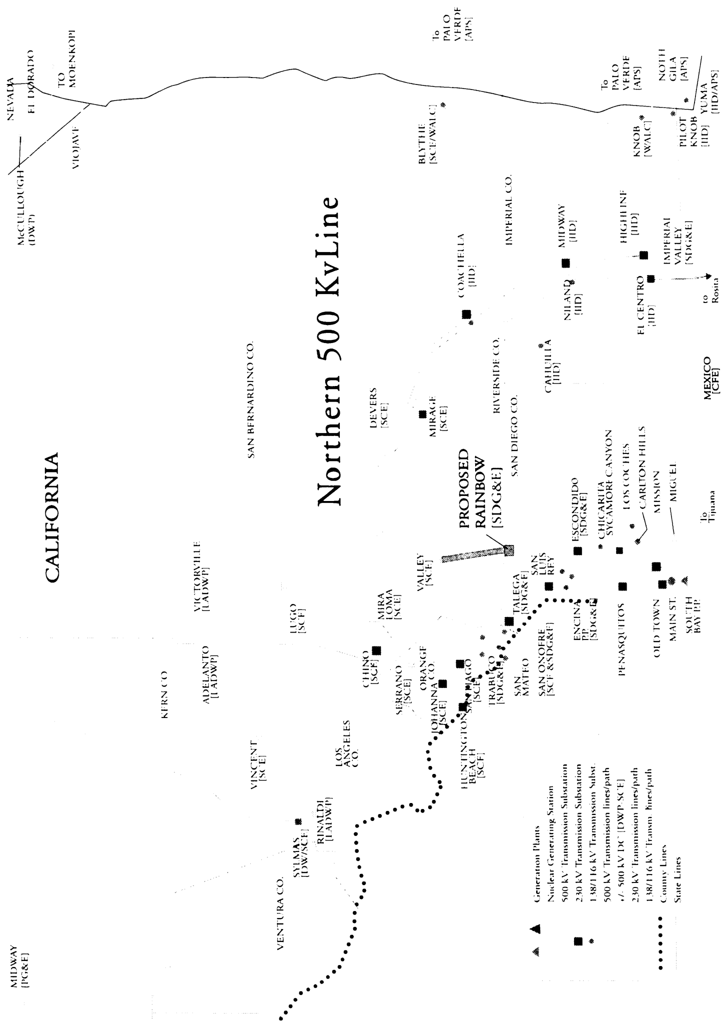
One of the interesting features of the Otay Mesa plant is the use of mobile offsets to comply with air emissions requirements. This means the plant owners will replace diesel buses with natural gas burning vehicles, thereby reducing mobile emissions in the region. This is the first time mobile offsets have been used to replace stationary emissions and it could represent a creative approach to reducing air pollution while increasing energy production. A natural extension of this concept would be to consider crossborder air emissions trading in regions such as San Diego-Tijuana, Imperial, Calif.-Mexicali, B.C., and El Paso, Tex.-Ciudad Juárez, Chih.

Importing more electricity into San Diego is currently difficult because of limited transmission capabilities into the region, as can be seen from Figure 12, which shows the grid system for San Diego.

There is a proposal to build a 500 kV connecting line that would allow more power to be brought into the region from the north. But, it has not yet been approved and there is considerable opposition to its construction.

Reducing energy demand is a tried and true approach that complements increasing energy supply. Any comprehensive energy plan for the binational region should have energy-reduction programs such as increasing energy efficiency in buildings, appliances, and lighting; economic incentives for installing energy-efficient devices; and tiered pricing structures that encourage lower energy consumption.

Figure 12. Electric Transmission for the San Diego Region



Source: Center for Energy Studies

Binational Energy Strategy Committee

Recognizing the need for better planning and coordination between California and Baja California in the energy sector, SANDAG, under its Borders Committee, established the Binational Energy Issues Group (BEIG) in 2000. BEIG serves as the only public forum that discusses energy issues of importance to the entire binational area. It serves as an information resource, a place where new projects can be vetted, and ensures better communication between and among stakeholders. Members of BEIG represent the major energy stakeholders from both sides of the border.

Challenges and Opportunities: Issues for Discussion

A secure supply of reasonably priced energy with a minimal environmental impact will be needed for the U.S.-Mexican border region if it is to remain competitive in the global economy. Given the high population growth expected over the next 10 years to 20 years, meeting increased demand for energy services will prove to be one of the most important challenges facing the binational region.

The large increase in energy demand projected over the next 20 years for the border region is not a forgone conclusion, however. It is clear that as a society develops and standards of living rise, per capita energy demand can actually decrease. This was the experience in many of the industrialized countries during the period from 1975 to 1998. Although total energy demand per capita may decrease as the economy becomes more efficient, there is also a trend that electric energy use appears to grow faster than the population. Therefore, unless vigorous and consistent power efficiency and conservation programs are put in place in the border region, residents are likely to realize the high growth rates discussed in this chapter.

Even with such a conservation program, given the expected increase in population and living standards on the Mexican side of the border, it is difficult to see how power demand can be met without the construction of new generating facilities in the region. However, if environmental degradation is to be avoided and quality of life standards improved, the type of generation will be important. Heavy reliance on fossil fuels, even natural gas, will inevitably degrade air quality and stress limited water supplies. Because transportation pollutes more than other sectors, plans to use fuels other than gasoline and diesel will ultimately pave the way for a cleaner environment than currently exists or is projected to exist in the next 20 years.

Meeting this challenge will require effective cooperation and coordination between the privatized energy market players and the local and state agencies still responsible for regulating the energy sector in both the United States and Mexico. Complicating the development of new methods of planning for future energy-related infrastructure is the lack of formal crossborder energy planning, coordination, and cooperation. The impediments to creating a healthy energy supply system in the binational region are not mainly technical or financial, but grow out of the absence of planning, forecasting, and coordination at the binational and regional level.

Some suggestions follow that would enhance crossborder cooperation in the energy field and provide the energy services needed for border residents.

1. Create a binational collaborative effort to examine the future energy needs of the binational region and surrounding areas. This group should have representatives from all the major stakeholders in the region, including energy services companies, major energy consumers, relevant local and state agencies, environmental groups, appropriate non-governmental organizations (NGOs), ratepayer advocates, and the general public. It is critical that broad representation from both sides of the border be present. An effort of this sort could be structured like the aforementioned Binational Energy Issues Group for the California-Baja California region. Another model is the Air Alliance for the El Paso-Ciudad Juárez region and the Binational Air Quality Alliance in the San Diego-Tijuana area.
2. Develop the necessary infrastructure to handle the increased use of natural gas in the border region, especially the western sections. A secure supply of natural gas for industry and power generation will go a long way toward meeting the energy needs of the binational region in a manner less harmful to the environment than fuels currently in use, such as oil and coal. One possible way to assist the transition to natural gas

in the California-Baja California region is to consider a gas exchange program between Mexico and the United States. Mexican natural gas could be imported to the United States via Texas and an equivalent amount of U.S. gas exported to Baja California by extending San Diego pipelines into Tijuana. This could reduce the burden on Mexico of having to use its foreign currency reserves to purchase U.S. natural gas. Other issues that need to be addressed are safety and security of supply.

3. Prepare and maintain a comprehensive energy database for the crossborder region. The region has no central database related to energy, and no entity is collecting or distributing such information.
4. Invest in renewable sources of energy. Although the crossborder region will likely remain dependent on non-renewable energy sources imported from outside the region for some time, more could be done to encourage and use existing renewable energy resources found on both sides of the border. The region has yet to fully use a combination of energy resources including solar, wind, geothermal, and biomass. Greater use of renewable sources of energy not only will reduce air pollution but could form the basis of a new high tech research, development, and manufacturing sector in the field of advanced energy technology.

The underlying logic of electric restructuring in the United States, the opening of the energy sector in Mexico to private investment, and the growing economic interdependence of the United States and Mexico will inevitable lead to greater crossborder trade in energy services between the two countries. This trade is likely to take place in the purchase and sale of electricity by private industries and local and state agencies responsible for supplying power that are located on either side of the border. In the open market for energy services emerging on both sides of the border, the final price to consumers will be the most important element in deciding where to purchase energy; the location of the energy source will become less relevant than it is today. Over time, the international border will become less of a barrier to energy flows—a consequence of the continued integration of the crossborder region.

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I-6

Using System Dynamics Models of the Environment to Teach Sustainability Science: The Border+20 Model as a Pedagogical Device

Edward Sadalla, Susan Ledlow, and Subhrajit Guhathakurta

ABSTRACT

The Southwest Consortium for Environmental Research and Policy (SCERP) system dynamics model was originally developed as a tool that would allow stakeholders to explore the future environmental and quality of life implications of policy decisions in the U.S.-Mexican border region. As the model took shape, it became apparent that it could also be useful in classroom settings to illustrate principles that apply to a wide variety of urban environments. This chapter argues that this model is uniquely suited for teaching concepts from the emerging field of sustainability science and for teaching systems thinking in relation to environmental issues. Use of the Border Plus Twenty Years (B+20) model fosters an appreciation of the widespread consequences of changing one part of a dynamic system and promotes an active learning approach to education that has been shown to enhance student involvement, interest, and retention of content.

The importance of introducing concepts concerning sustainability and human-environment interactions into educational curricula and the new field of sustainability science is herein discussed. Also reviewed are the educational problems that occur when the concept of sustainability is approached from the vantage point of a single academic discipline. System dynamics models are recommended as devices for teaching systems thinking about human-environment interactions. The pedagogical advantages of the B+20 model are also described using specific examples. Finally, the technical literature on the concepts of active learning and discovery learning is discussed, thus supporting the use of manipulable systems models in educational contexts.

La Enseñanza de la Ciencia Sustentable Utilizando Modelos de Sistemas de Dinámicas del Medio Ambiente: El Modelo Frontera+20 como un Mecanismo Pedagógico

Edward Sadalla, Susan Ledlow, y
Subhrajit Guhathakurta

Resumen

El modelo de sistema de dinámicas del Consorcio de Investigación y Política Ambiental del Suroeste (CIPAS), fue desarrollado originalmente para funcionar como una herramienta que permitiera a las personas interesadas explorar implicaciones futuras de decisiones de políticas del medio ambiente y de la calidad de vida en la región fronteriza México-Estados Unidos. Cuando se fue conformando el modelo, fue aparente que también podría ser útil en los salones de

clase para ilustrar principios aplicables a una amplia gama de ambientes urbanos. Este capítulo discute que este modelo es adecuado para la enseñanza de conceptos del área emergente de la ciencia sustentable así como para enseñar sistemas de pensamiento en relación a temas ambientales. El uso del modelo Frontera+20 (F+20) acoge una apreciación de las consecuencias extendidas de cambiar una parte de un sistema de dinámica y promueve un enfoque activo de enseñanza de la educación que ha demostrado realzar la participación de los estudiantes, su interés, y la retención del contenido.

La importancia de introducir conceptos relacionados con la sustentabilidad y las interacciones humano-ambientales en la curricula educativa así como la nueva área de ciencia sustentable son discutidas de aquí en adelante. De igual manera son revisados los problemas educativos que ocurren cuando el concepto de sustentabilidad es aplicado desde una posición ventajosa de una sola disciplina académica. Los modelos de sistema dinámicos son recomendados como mecanismos para la enseñanza de sistemas relacionados con interacciones humano-ambientales. Las ventajas pedagógicas del modelo F+20 son descritas a su vez utilizando ejemplos específicos. Finalmente, la literatura técnica de los conceptos de enseñanza activa y exploratoria es discutida apoyando el uso de modelos de sistemas de manipulación en un contexto educativo.

The Educational Problem

Given the trajectory of current environmental problems, there is a need for educated citizens who are aware of the dynamic relationships between elements in the environment, between human behavior and environmental systems, and between environmental systems and human quality of life. According to Peter Raven, chair of the American Association for the Advancement of Science board, "We must find new ways to provide for a human society that presently has outstripped the limits of global sustainability. New ways of thinking—an integrated multidimensional approach to the problems of global sustainability—have long been needed, and it is now up to us to decide whether the especially difficult challenges that we are facing today will jolt us into finding and accepting them" (Raven

2002). There are specific contributions science education can make to the development of a sustainable society. The National Research Council's study "Our Common Journey: A Transition Toward Sustainability" (NAS 1999) concludes that citizen education is a key component for societies moving in the direction of sustainability. The report stressed that advances in basic knowledge about environmental systems must be combined with the social capacity and the political will to turn this knowledge into action. Long-term sustainable development is primarily an applied problem rather than a theoretical one; if sustainability is to be achieved, new knowledge will have to be both generated and used for planning. Both citizens and decision-makers will need to be aware of long-term goals and the consequences of different courses of action.

The educational problem is how to foster such knowledge and new ways of thinking. Science education has traditionally focused on within-discipline problems and has not fostered the broad-based, multidisciplinary perspective required to make sound long-term decisions about environmental problems. One proposed remedy is the creation of a new scientific discipline and educational curriculum concerning the interaction between humans and the global environment.

Sustainability Science

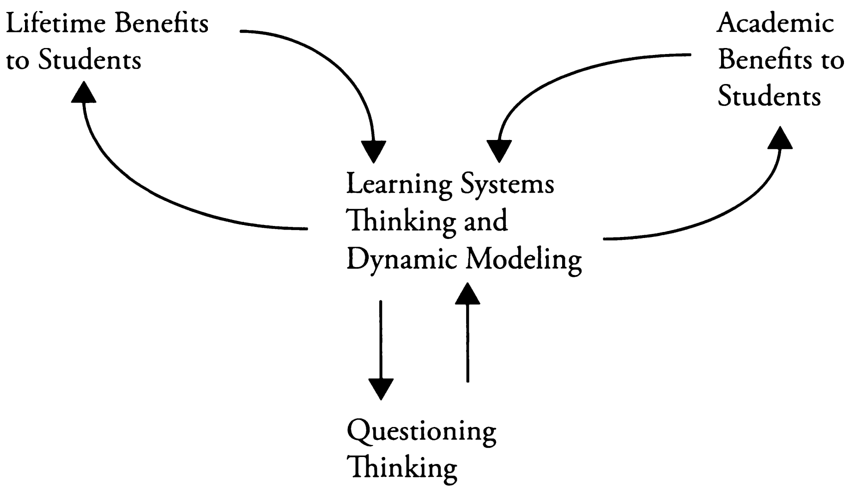
Recently, the U.S. National Academy of Sciences organized a group of professionals to examine the question of whether basic human needs over the next two generations could be met while sustaining the planet's life support systems (National Research Council, Board on Sustainable Development 1999). The report suggested that the achievement of sustainable human-environment interactions would require the development of a new intellectual discipline called sustainability science. This new field, discussed in a seminal article by Kates, et al. (2001) would use knowledge of industrial, social, and environmental processes to address applied questions about the sustainability of human-environment systems. As outlined by Kates, et al., sustainability science involves the use of scientific knowledge and methods in support of a transition to sustainable environments. It is responsive to concerns for environmental stability and human quality of life rather than to current scientific agendas. It is integrative across disciplines and based on concerns about specific places and specific human groups. Multidisciplinary skills will be required for this endeavor; practitioners will be required to combine information from diverse sources with the goal of balancing economic, environmental, and societal objectives (Milhicec, et al. 2003).

The field of sustainability science would break with the historical tradition of western science that has organized knowledge into discrete scientific fields or content disciplines. Traditional scientific disciplines, from anthropology to zoology, provide a conceptual structure for the organization of theory and research. Their disadvantage is that they do not necessarily match the way the world works, and they promote specialization in both knowledge and methods among their respective practitioners.

Over the past decade, the environmental movement and the accompanying interest in sustainable development have provided a major impetus for interaction among disciplines in social sciences, engineering, planning, construction, and environmental science. A number of international agreements, such as Agenda 21, the Rio Declaration on Environment and Development in 1992, the Earth Summit in 1995, and the World Summit on Sustainable Development at Johannesburg in 2002 pushed the cause of sustainable development across the world. Several nations followed with specific policy directives to implement an agenda for sustainable environments.

In response to problems of sustainability, natural and social scientists have begun to emphasize the importance of developing an integrated framework for modeling ecological and socioeconomic processes (Figure 1). Measuring and analyzing the dynamic interaction among economic, social, and environmental sustainability is critical because what gets measured can be managed, and possibly improved.

Figure 1. Pedagogical Implications of Systems Thinking and Dynamic Modeling



Source: Waters Foundation 2003

Sustainability science addresses applied issues of human-environment interactions. Although work in this area has been based on information gleaned from established scientific disciplines, the problems addressed underscore the limitations of such traditional scientific disciplines in dealing with the complex reality of social institutions interacting with natural phenomena. Core questions of sustainability science include:

- How are long-term trends in human population and consumption reshaping nature?
- Can scientifically meaningful limits or boundaries be defined that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation?
- What systems of incentive structures—including markets, rules, norms, and scientific information—can most effectively promote sustainable trajectories?

Answers to questions such as those posed above require models of interrelationships between complex systems and approaches that work backward from undesirable consequences to identify pathways that might avoid such outcomes. The problems of system complexity, complex interactions between system components, and long time lags between actions and their consequences make traditional methods of hypothesis testing problematic.

The type of education required is substantially different than the single-discipline and single-major approach that currently dominates higher education. Environmental problems are intrinsically multidisciplinary, and more importantly, are the result of the interrelationship between such diverse elements as economic variables, social variables, population growth, water use, air quality, and quality of life. The emerging discipline of sustainability science is based in part on the premise that systems thinking is necessary to understand the dynamic relationships that occur between environmental components.

Systems Thinking and the Nature of Dynamic Models

Across many diverse intellectual disciplines, system dynamics models are beginning to replace simple, one-way, causal chains as explanatory devices. Current thinking in the environmental sciences recognizes that simple cause-effect models do not allow students or researchers to grasp the complexity of the phenomena studied (Schellnhuber and Wenzel 1998). System dynamics models are based on the concept that modifying one component in a system has wide-ranging, and sometimes unforeseen, consequences that may in turn feed back and influence the component originally modified.

For example, during the past decade the harvesting of timber from forests in the Pacific northwest region of the United States has created jobs and supported economic development. Timber harvesting has, however, produced some unforeseen consequences. Logging has increased soil erosion during the rainy season, which has in turn increased the turbidity of water in rivers and streams. Because of increased water turbidity, salmon migrating upstream from the ocean have more difficulty mating and spawning. The soil runoff has thus reduced the harvest of salmon from rivers in this region and adversely affected the economic well-being of a network of employees and businesses that depend on the salmon harvest. Political pressure from the fishing industry is being brought to bear on the logging industry.

In the example above, timber, forest ecosystems, soil, salmon, economics, the social organizations involved in the lumber and fishing industries, and the quality of life of the residents of the region can be seen as part of a complex dynamic system. Understanding the impact of changing any part of the system requires the ability to model and think about the system as a whole.

What does the term "systems thinking" actually mean? As Forster and Cleveland discuss in Chapter I-1 of this volume, the phrase can refer to a set of tools—such as causal loop diagrams and simulation models—that help a student map and explore dynamic complexity. It can also mean a unique perspective on reality, a perspective that sharpens awareness of a whole system and of how the parts within that system interrelate. Finally, systems thinking can refer to a special vocabulary that expresses understanding of dynamic complexity. For example, systems thinkers may describe the world in terms of reinforcing and balancing processes, limits, delays, and patterns of behavior over time.

In this context, system dynamics models become important as pedagogical tools (Figure 1) that not only inform students about specific problem areas, but also teach a way of thinking about environmental issues in general.

Some type of model-building is central to understanding and the educational process. Everyone creates mental models of the world around them. With the advent of personal computers and graphical programming, more complex models of the phenomena in the surrounding world can be formally represented and displayed. As Heinz Pagels (1988) has noted, the system dynamics computer model is to the mind what the telescope and the microscope are to the eye. It is possible to model the macroscopic results of micro-phenomena, and vice versa. Possible futures of a dynamic process can be displayed. A key feature of system dynamics models is that such programs produce results that could not be predicted by the programmer.

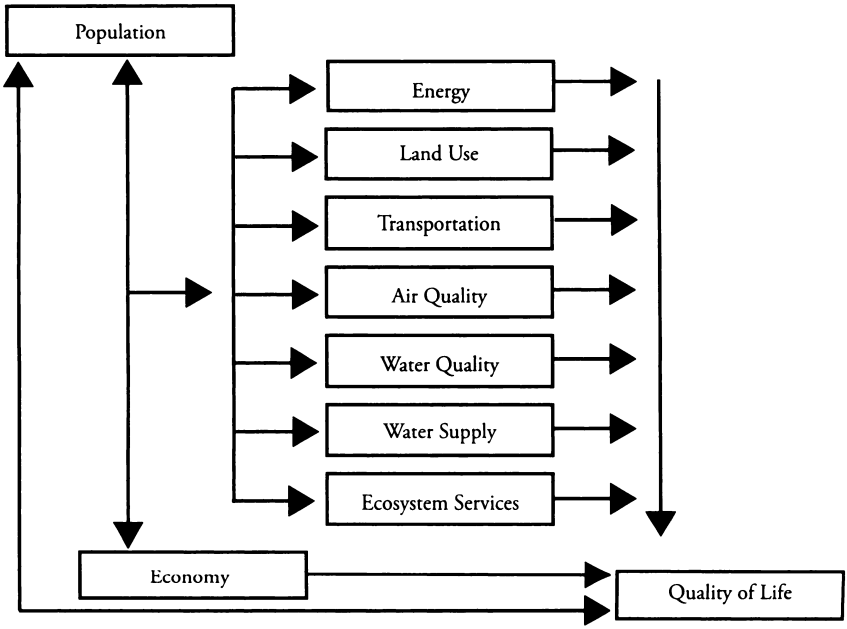
Manipulation of the models allows students to experience surprise and discovery—processes that engage their attention and facilitate long-term memory.

The system dynamics approach allows the student to manipulate and thereby explore the consequences and interrelationships between both hard (scientific/technical) and soft (social science/behavioral) variables. This combination of hard and soft variables and relationships is necessary to thoroughly understand any environmental system. Underpinning this approach is the assumption that policies related to migration, economy, air quality, or water supply have wide-ranging, long-term, and frequently surprising impacts on other environmental elements, as well as on human quality of life.

A useful aspect of system dynamics models is their ability to describe emergent phenomena that develop from micro-scale processes of individual behavior. Behavior in an urban environment is often derived from the interactions of many individual processes; simple aggregation of these micro-scale processes does not necessarily capture larger patterns of behavior. The products of interactive development may bear little resemblance to the original micro-scale patterns, and therefore require a synthetic approach to the study of the whole system.

For example, markets emerge from the dynamic interactions between consumers and producers and cannot be understood by examining one component in isolation. Similarly, urban phenomena such as traffic congestion, agglomeration of activities, and clustering of socioeconomic groups have to be seen in light of complex individual interactive processes (Nagel, Rassmussen, and Barrett 1996; Krugman 1996; Torrens 2000). The Border Plus Twenty Years (B+20) model (a computer-based system dynamics model of an urban environment) can be used to both foster systems thinking on the part of students and provide a novel and engaging way to teach key concepts in environmental sciences courses. The software tool represents the principal elements of an environmental system—such as population, economy, energy, air quality, water supply, land use/transportation, and quality of life sectors—and their interrelationships. A schema of the model is depicted in Figure 2.

Figure 2. SCERP System Dynamics Model



Source: Authors

Because the model captures the dynamics of any urban environmental system, it can be used as a pedagogical tool in a variety of environmental science courses. Although environmental attributes vary from region to region, the modeling framework attempts to capture underlying interrelationships common to all urban regions (such as relationships among population growth, economic development, transportation systems, air quality, and human health).

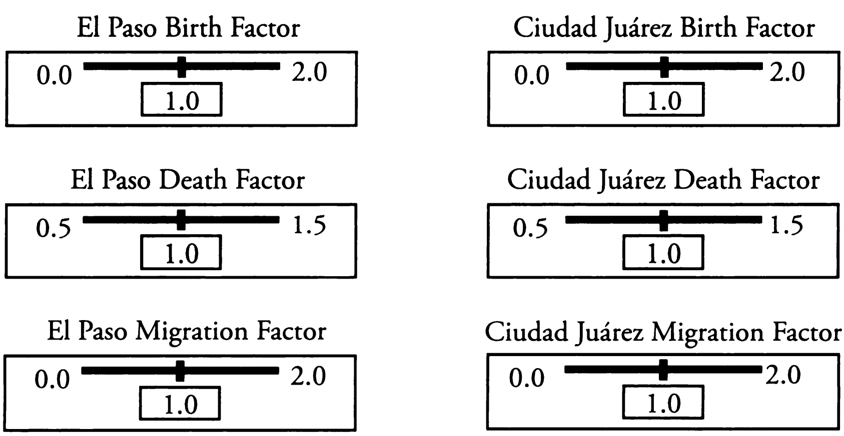
Decision-maker/stakeholder participation was gathered throughout the modeling process to ensure all potential users of the model have confidence in their ability to use it. The resultant user-friendly modeling environment also allows the user to change key system variables and observe the trends and consequences over different spans of time.

Manipulating the Model

One aspect of the model is the incorporation of "sliders" in each component of it. Sliders allow the user to manipulate particular parameters of one component of the system, then run the model and observe the consequences in other parts of the system. For example, Figure 3 depicts some of the sliders that can be manipulated in the demographic sector of the model.

Users can vary the birth rates, death rates, and migration rates in El Paso, Tex., and Ciudad Juárez, Chih., and observe the consequences of such variations on other demographic variables such as population size. More interestingly, the model will depict the impact of such variation on other components of the system. For example, increasing the size of the population in Ciudad Juárez will affect the air quality of both Ciudad Juárez and El Paso, and will have diverse impacts on water use, water availability, land use, and per capita income, as well as on quality of life variables such as health. Some of these consequences are capable of "feedbacks," that is, they may in turn affect birth rates, death rates, and migration rates.

Figure 3. Sliders in the Model Demographic Sector



Source: Authors

Through the manipulation of sliders, the model can also be used to teach the consequences of specific interventions. Consider the issues that surround environmental regulatory agencies. What are the trade-offs between environmental regulation and economic development? This general question can be explored by manipulating a slider in the economic sector that allows the user to adjust the level of "regulatory enforcement." The student can run the model for the base case, which assumes little regulatory enforcement. Questions such as the following may be explored: What happens to economic production? What happens to pollution per capita? What happens to pollution per dollar of gross domestic product (GDP)? What happens to air quality as the economy grows?

The impact of regulatory policies can be explored by moving the enforcement slider. With regulatory enforcement increased by 25% or 50%, the model can be run again to explore the impact of such manipulations on economic production, pollution, health, and health costs, among other sectors. This process leads students to general questions about goals. For example, should economic growth be sacrificed to achieve better air quality? What would be the anticipated total cost (including health costs) of improving air quality?

Pedagogical Rationale

Use of the model as a pedagogical tool exemplifies what is known about best practices in teaching and learning. In working with the model, students are automatically integrating knowledge from diverse areas and are actively engaged in posing problems and discovering their solutions.

Integrating Knowledge from Diverse Subject Areas

As discussed above, sustainability science involves knowledge from various scientific disciplines, including both the physical and social sciences. In current university settings, these disciplines are taught independently and students are rarely given the opportunity to integrate knowledge learned in different classrooms. The Boyer Commission on Educating Undergraduates in the Research

University (1998) notes that "[m]any students graduate having accumulated whatever number of courses is required, but still lacking a coherent body of knowledge or any inkling as to how one sort of information might relate to others."

Sustainability science requires conceptual frameworks that allow students to integrate previously learned material. Current research reviewed by the National Research Council and documented in the book *How People Learn* by Bransford, et al. (2000) indicates that to develop competence in an area of inquiry, students must have a deep foundation of factual knowledge, understand facts and ideas in the context of a conceptual framework, and organize knowledge in ways that facilitate retrieval and application.

The B+20 model lends itself perfectly to the integration of knowledge from different sources. The model draws upon knowledge gained in diverse disciplines and allows students to explore the relationship between economics, population, water use, air quality, land use, and quality of life variables. The model is itself a conceptual framework that promotes the ability to think systemically about environmental and quality of life variables.

Active v. Passive Learning

While evidence for the advantage of active engagement in learning continues to accrue, most college and university professors teach as they were taught—by the lecture method. While traditional lectures are an effective means of integrating information from diverse sources and for demonstrating disciplinary reasoning and habits of mind, they are not as effective for improving students' critical thinking or for promoting long-term retention of information. As Thorndike (1912) noted long ago, "The commonest error of the gifted scholar, inexperienced in teaching, is to expect pupils to know what they have been told. But telling is not teaching."

As a means of overcoming this limitation, a number of additional instructional strategies are currently being practiced and promoted in higher education. These include cooperative learning (Johnson, Johnson, and Smith 1991; Ledlow 2002; Millis and Cottell 1998), case teaching/Socratic dialogues (Christensen and Hansen 1987), classroom assessment techniques (Angelo and Cross 1993), writing across the curriculum/writing to learn (Bean 1996), and discovery or problem-based learning (Jonassen 2004; Starfield, Smith, and Bleloch 1994; Bruner 1960; Bruner 1966). These strategies fall under the general rubric of active learning. Bonwell and Eison (1991) note that while definitions of the term vary, most agree that when actively engaged, "students are involved in more than listening." The research literature indicates that when students are actively engaged in writing, discussing, and problem-solving, retention of information and critical understanding is enhanced (McKeachie, et al. 1986; Chickering and Gamson 1991; Boyer Commission 1998; Bransford, Brown, and Cocking 2000; Light 2001).

A representative study of the consequences of active learning methods was conducted by Felder, et al. (1998). In this project, a cohort of chemical engineering students took five courses taught by the same instructor in five consecutive semesters. Active and passive instructional techniques were systematically varied in an experimental design. Comparisons showed that students engaged in active learning classes outperformed students taught using traditional (passive) lecture methods. Experimental group students outperformed the comparison group on a number of measures, including content retention and graduation in chemical engineering; further, more of the graduates in this group chose to pursue advanced study in the field.

Most apropos of using the B+20 model in the classroom is discovery learning, originally discussed and advocated by Bruner (1960; 1966). Discovery learning is "an approach to instruction through which students interact with their environment by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments" (Ormrod 1995). Discovery learning requires the student to make decisions about what, how, and when something is to be learned. Instead of being told the content by the teacher, it is expected that the student will have to explore examples and from them discover the principles or concepts to be learned (Snelbecker 1974).

Bruner suggested that students are more likely to understand and retain information that they discover on their own. He also indicated that students engaged in discovery learning are likely to develop higher-order thinking skills:

> Mastery of the fundamental ideas of a field involves not only the grasping of general principles, but also the development of an attitude toward learning and inquiry, toward guessing and hunches, toward the possibility of solving problems on one's own ... For if we do nothing else we should somehow give to children (students) a respect for their own powers of thinking, for their power to generate good questions, to come up with interesting informed guesses ... to make ... study more rational, more amenable to the use of mind in the large rather than memorizing (Bruner 1960; 1966).

A focus on problem-solving also teaches scientific reasoning because "the natural as well as the social sciences always start from problems" (Popper 1999). A 1996 report to the National Science Foundation reviewing the state of undergraduate education in science, math, engineering, and technology concluded that:

> On the basis of all that we have heard and learned during this review process, we urgently wish for, and urge decisive action to achieve, an America in which: All students have access to supportive, excellent undergraduate education in science, mathematics, engineering and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry (George, et al. 1996).

The B+20 model is an ideal instrument for use in active learning and discovery learning contexts. Students literally discover concepts and outcomes by manipulating the model—programmers of the model do not themselves know the outcome of the program until it has run. Instructors may pose questions and ask students to try to answer them by manipulating sliders and then running the model. Alternatively, students may pose their own questions and run the model to answer them. Used in these ways, the model supports active engagement of the learner in the learning process and promotes the development of higher-order thinking skills (Bloom, et al. 1956).

Conclusion

The B+20 model represents a class of system dynamics models that are well-suited to teaching concepts related to sustainable development. This particular model is unique in that it includes environmental, demographic, economic, and quality of life components. Sustainable development means different things to different people, but the most frequently quoted definition is from the report "Our Common Future" (also known as the Brundtland Report): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The issue at hand is whether the present trajectory of human-environment interactions can be maintained for the foreseeable future.

It is becoming increasingly apparent that human actions are producing increasing impacts on the environmental conditions that support life on Earth. Major threats to Earth's environment, including global warming, ozone layer destruction, exhaustion of fisheries, erosion of agricultural land, loss of biodiversity, and air and water pollution have been documented. Unless the environmental consequences of human activity are understood and overcome, such changes could substantially decrease the quality of life for both present and future generations. Opportunities for mitigating environmental problems exist because the majority of current problems result from environmental policy, political decisions, and from patterns of human behavior such as overpopulation and overconsumption.

The magnitude of the problem is formidable. Raven (2002) suggests:

> ... the world has been converted in an instant of time from a wild natural one to one in which humans, one of an estimated 10 million or more species, are consuming, wasting, or diverting an estimated 45% of the total net biological productivity on land and using more than half

> of the renewable fresh water. The scale of changes in Earth's systems, well documented from the primary literature ... is so different from before that we cannot predict the future, much less chart a course of action, on the basis of what has happened in the past.

During the past several decades, much of the human impact on environmental systems has been related to the growth of the urban population. Within a few years, a majority of the world's people will, for the first time, be living in cities (Lash 2001). The world's urban population is currently growing at four times the rate of the rural population. Between 1990 and 2025, the number of people living in urban areas is projected to double to more than 5 billion; if it does, then nearly two-thirds of the world's population will be living in towns and cities.

The growth of urban areas has historically been associated with environmental degradation. Emissions from transportation systems and industrial sources degrade air quality. Farmland and open space is converted to factories, commercial, and residential use. As a result of obsolescence, industrial sites are abandoned or move, often leaving contaminated land in the urban core. Water quality is degraded through increased runoff volume, decreased infiltration, poor runoff quality, and increased discharge from point sources. The manner in which development or redevelopment takes place can significantly increase or decrease these impacts.

There is an emerging consensus that because environmental problems are the result of human behavior, education will play a key role in promoting sustainable environmental trajectories. Education should encourage thinking about the environment as a complex system, with humans as part of that system. Models such as the B+20 model can be used as pedagogical devices that facilitate the achievement of such educational goals.

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II-1

Overview of the Border+20 System Model Prototype: The Paso del Norte Region

Craig B. Forster

ABSTRACT

Chapter I-1 outlines how a systems thinking approach can be used to map the interactions among social, political, environmental, and economic aspects of communities at the U.S.-Mexican border. In Section II, members of the Border Plus Twenty Years (B+20) team explain how the system dynamics modeling approach is used to explore alternate futures for the Paso del Norte binational community. This particular chapter provides a background context for the Paso del Norte community and outlines how various aspects of that community are linked in the system model.

Many important political boundaries cut Paso del Norte and complicate planning and management for urban growth and natural resource use. Its cities share a binational air basin and aquifer system. Its economies are integrated and have largely risen and fallen together with the economic fortunes of the United States. The history of migration and settlement in Paso del Norte has led to a distinctive border community culture that reflects more than a century of contact and diffusion between people from the Spanish-Mexican

North and Anglo-American Southwest. As a consequence of sharing natural and urban environments, Paso del Norte communities also share an interrelated human health context.

It is generally assumed that improving quality of life in Paso del Norte is best done through binational collaboration that leads to an increasingly integrated community context. Unfortunately, developing the collaborative networks in a binational context is difficult, time consuming, and not always successful. Adopting a systems thinking perspective to attain the goal of improved quality of life requires an attempt to identify the feedbacks, tradeoffs, and lags in the overall urban ecosystem that might lead to unintended consequences of the policy decisions designed to mitigate the challenging situations.

Visión General del Prototipo de Modelo de Sistema Frontera+20: Región Paso del Norte

Craig B. Foster

Resumen

El Capítulo I-1 delimita como un enfoque de sistema de pensamiento puede ser utilizado para trazar las interacciones entre los aspectos sociales, políticos, ambientales y económicos de las comunidades de la frontera México-Estados Unidos. En la Sección II, los miembros del grupo de trabajo del Proyecto Frontera Más Veinte Años (F+20), explican cómo el enfoque del modelado de sistema de dinámicas es utilizado para explorar alternativas para el futuro de la comunidad binacional del Paso del Norte. Este capítulo proporciona

un antecedente para la comunidad del Paso Norte y delimita cómo diversos aspectos de esa comunidad están interrelacionados en el sistema de modelo.

Muchos límites políticos importantes cortan el Paso del Norte y complican la planeación y administración para el crecimiento urbano y el uso de recursos naturales. Sus ciudades comparten una cuenca binacional de aire y un sistema acuífero, sus economías están integradas y han crecido formando parte de la fortuna de los Estados Unidos. La historia de la migración y acuerdo en el Paso del Norte ha llevado a una cultura comunitaria de la frontera particular que refleja más de un siglo de contacto y difusión entre las personas españolas-mexicanas del norte y anglo-americanas del suroeste. Como consecuencia de compartir ambientes naturales y urbanos, las comunidades del Paso del Norte también comparten un contexto de salud humana interrelacionado.

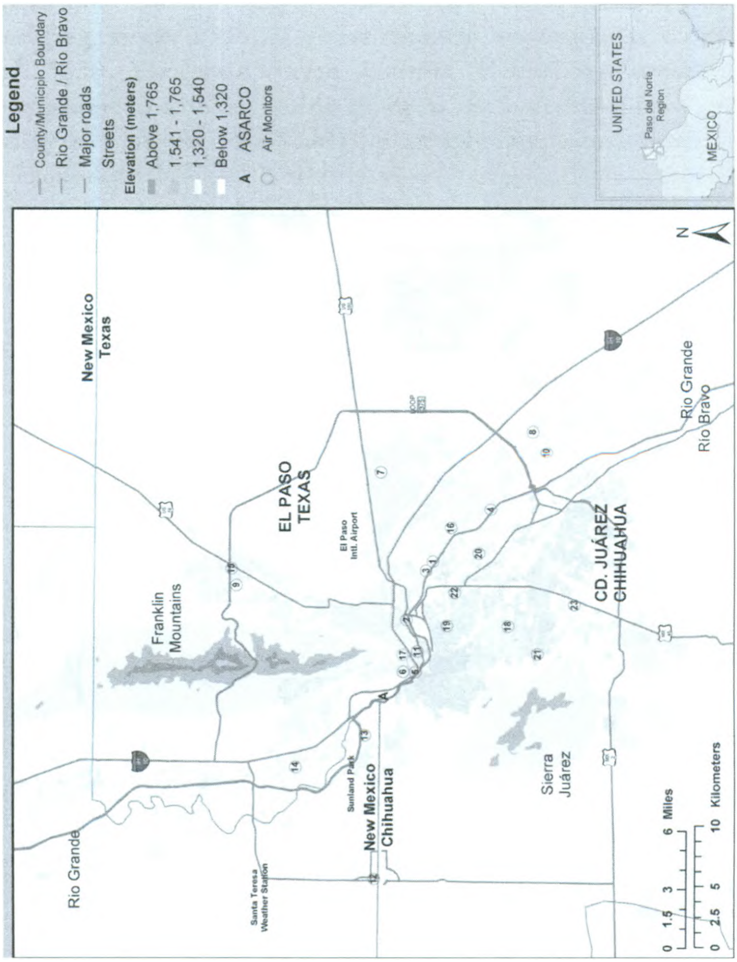
Se asume generalmente que se mejora la calidad de vida en el Paso del Norte a través de una colaboración binacional que lleva a un contexto comunitario integrado. Desafortunadamente, desarrollar las redes de colaboración en un contexto binacional es difícil, toma tiempo y no siempre es exitoso.

Adoptar una perspectiva de sistemas de pensamiento para lograr el objetivo de mejorar la calidad de vida requiere intentar identificar las retroalimentaciones, equilibrios, y retrasos en los ecosistemas urbanos generales que pueden llevar a consecuencias no intencionadas de las decisiones de política diseñadas para mitigar los retos.

Overview of the Paso del Norte Region

Paso del Norte sits at 3,760 feet above sea level in a wide basin bounded by steep mountains that rise more than 7,000 feet above sea level (Figure 1). It is this geography that led to the naming of the area; Paso del Norte means "the pass of the north" in Spanish. In past centuries, this pass through the southward extension of the Rocky Mountains attracted Spaniards traveling between Mexico City to Santa Fe. For more than 1,000 years Paso del Norte has been an important crossroads for trade as people travel through the region.

Figure 1. The Paso del Norte Region



Source: Rincón, et al. 2005

Situated in a high desert environment traversed by the Rio Grande, El Paso, Tex., (located in the middle of Paso del Norte) has average temperatures of 63°F with average highs of 96°F in July and average lows of 29°F in January. Mean annual precipitation is 8.8 inches (climateZONE.com 2004). Winds exceeding 50 miles per hour are not uncommon. These winds create dust storms yet also clear the region of air pollutants emitted by the urban community.

Many important political boundaries cut Paso del Norte and complicate planning and management for urban growth and natural resource use. Signed in 1848, the Treaty of Guadalupe Hidalgo fixed the U.S.-Mexican border at the Rio Grande and created today's Paso del Norte border community. Judged one of the largest urban border communities in the world (its population was 1.9 million in 2000), the Paso del Norte communities are intertwined economically, socially, and culturally in ways that reflect the historical evolution of the region. At the same time, however, the binational community exhibits the greatest border economic disparity in the world by juxtaposing a highly developed United States beside a developing Mexico (Stoddard 2001). The international border has led to a shared community context within multiple local, regional, and national jurisdictions that affect quality of life in this binational community. Key issues affected by the multiple jurisdictions include water supply and quality, air quality, and human health. The arid environment, multiple overlapping jurisdictions, and rapid population growth of Paso del Norte have led the U.S. Department of the Interior (2004) to identify this area as a region with substantial potential for future water conflicts.

Shared Air Basin and Watershed

This community shares a binational air basin bounded by mountains and collects the combined emissions from the border communities. This airshed is at the same time impacted, managed, and monitored by the different institutional and legal systems of the United States and Mexico. The free movement of airborne pollutants across state and national borders means that one city cannot control emissions within its borders because of pollution traveling from the other cities. For example, studies have shown that pollutant emissions from Ciudad Juárez, Chih., contribute to heightened concentrations of criteria air pollutants in El Paso that, in turn, contribute to levels of nonattainment on the U.S. side that can lead to federal sanctions (Texas Environmental Profiles 2004). As a consequence, the U.S. Environmental Protection Agency (EPA) has classified the El Paso region as one of "serious," rather than the higher level, "severe," nonattainment. This reclassification enables EPA to impose less-onerous sanctions and penalties than would otherwise be possible. Another proposed, but yet unapproved, solution is to allow El Paso companies to help meet clean air obligations by investing in emissions-reduction strategies in Ciudad Juárez.

Surface water contained in the Paso del Norte region of the Rio Grande/Río Bravo system is administered by the U.S. Bureau of Reclamation, the State of New Mexico, the State of Texas, the Comisión Nacional del Agua (CNA), and the International Boundary and Water Commission (IBWC). IBWC is the binational agency that oversees surface water resources on the border between Mexico and the United States and administers treaties between the two nations. The joint U.S.-Mexico Rio Grande Project agreement dictates that 60,000 acre-feet per year of water must be delivered to Mexico, except in drought years, when the delivery would be reduced according to a predetermined formula (Stoddard 2001). Although Mexico is interested in obtaining greater river flow by renegotiating the water delivery treaty, almost all agree this is an unlikely outcome (Ganster 2005).

The binational aquifer system, comprising the Hueco and Mesilla aquifers that underlie the border, forms a critical source of potable groundwater that underlies three state boundaries (New Mexico, Texas, and Chihuahua). Groundwater in the U.S. section of Paso del Norte is administered by the State of New Mexico and individual landowners in Texas. In Mexico, groundwater is administered by the federal government. Managing the binational groundwater resource is complicated because U.S. states lack the power to engage in international negotiations with Mexico. Thus, the potable groundwater resource is highly prone to overexploitation as water suppliers on each side of the border attempt to capture as much water as possible as quickly as possible, which in turn inevitably leads to tension and conflict.

Economy

For more than a century, the integrated economies of El Paso and Ciudad Juárez have largely risen and fallen together with the economic fortunes of the United States. For example, the depression of the 1920s slowed both economies, but then military personnel stationed at Fort Bliss during World War II helped spur the economies of both El Paso and Ciudad Juárez in the early 1940s. Increasing industrialization of Ciudad Juárez was sparked by Mexico's Border Industrialization Program, which in 1967 led to the first significant maquiladora in Ciudad Juárez. Maquiladoras (sometimes referred to as maquilas) are factories operated by non-Mexican companies in Mexico that take goods and raw materials from the United States and other countries, assemble the final product in Mexico, and then ship the product back to its point of origin, paying duties only on the value added to the product while in Mexico. Between 1990 and 2000, maquiladoras in the border region more than doubled from 1,683 to 3,562 (Bloom 2000). During the same period, the number of people employed in the maquiladoras grew from 418,306 to 1,055,343. Most of this growth occurred between 1995 and 2000 (Bloom 2000). Despite a significant reduction in maquiladora-related trade between the United States and Mexico (approximately a 30% decline in production between 2000 and early 2002), in 2001 the maquila-related exports to Mexico were $46 billion while maquila-related imports from Mexico were $64 billion, according to the U.S. Government Accountability Office.

Growth in the maquila industry in Ciudad Juárez has led to growth in the service-oriented and maquiladora-related economies of El Paso (Cañas and Coronado 2002). Some of the economic growth in El Paso is offset by the 1994 signing of the North American Free Trade Agreement (NAFTA), which is blamed for the subsequent loss of manufacturing jobs in the traditional apparel industry of El Paso. In addition to being directly affected by the maquila industry, the economic health of El Paso also depends on the ability of Ciudad Juárez residents to cross the border, shop, and thus help support the retail economy of El Paso. For example, the devaluation of Mexico's peso in 1994 (reducing buying power of Ciudad Juárez residents) led to significant declines in retail sales in

El Paso (Cañas and Coronado 2002). More recently, the 2000–2002 downturn in the U.S. economy caused reduced demand for maquila products, thus leading to a significant loss of maquila jobs, which in turn caused decreased retail sales in El Paso. Timmons (1990) reports that one El Paso resident stated, "El Paso and Ciudad Juárez are Siamese twins joined together at the cash register. They are welded together, and you cannot do anything in El Paso that does not affect Juárez."

Unfortunately, the conditions that stimulate economic growth at the border have yielded lower per capita incomes and higher unemployment rates in El Paso when compared to elsewhere in the United States. Although per capita incomes in Ciudad Juárez are much greater than in the interior of Mexico, minimum wage rates are approximately 10% of that of El Paso (Peach and Williams 2000). At the same time, rapid population growth with inadequate infrastructure development (for example, water supply and wastewater systems) leads to unhealthful conditions and a poor quality of life for many Paso del Norte residents.

Cultural Context

The history of migration and settlement in Paso del Norte has led to a distinctive border community culture that reflects more than a century of contact and diffusion between people from the Spanish-Mexican North and Anglo-American Southwest. The Spanish town of Paso del Norte was settled on the south side of the Rio Grande/Río Bravo in 1659, 78 years after the first Spanish priests and soldiers traveled through the area. In the 1680s, the community was joined by Pueblo Indians aligned with Spanish settlers driven from the north. El Paso City was founded on the north side of the river by Spaniard Ponce de Leon in 1827. Americans from the north began moving to El Paso in the 1840s. Since that time, the town of Paso del Norte has become Ciudad Juárez, and the El Paso suburb of Sunland Park, N.M., has grown to the north and west of El Paso. Northward migration of Mexican nationals that began in the 1880s was reinforced by the 22-year-long Bracero Program (which started in 1942) and has continued to the present day through the recent and rapid expansion of the maquiladora industry in Ciudad Juárez.

In 1960, the cities of El Paso and Ciudad Juárez had an equal population of approximately 276,000 in each city. Since that time, however, more rapid growth through migration and natural causes resulted in the population of Ciudad Juárez doubling El Paso's and reaching 1.2 million. This ratio of populations is projected to continue through 2020, when the combined population of El Paso and Ciudad Juárez is expected to rise to about 3.6 million (Peach and Williams 2000). The northward migration of Spanish-speaking people has caused the El Paso population with Spanish-speaking origins to rise from 70% in 1990 to 78% in 2000. The other residents of El Paso are largely of English-speaking origins.

Although considerable intermingling of cultures has occurred, there remain distinct differences in the way those of Spanish-speaking and English-speaking origins approach life in the binational community. For example, Stoddard (1984) suggests that many of the elite from Ciudad Juárez are educated in U.S. schools, speak English well, and understand the principles and practices underlying the U.S. social and economic systems. These elites look to the United States as a source of values, ideas, and economic benefits from border trade and traffic. Meanwhile, influential El Pasoans of English-speaking origin may retain Spanish-speaking housemaids that influence some of their household context. Stoddard (1984) notes that the influential El Pasoans likely do not look to Mexico for new ideas and have internalized little Mexican culture.

Human Health

As a consequence of sharing natural and urban environments, the Paso del Norte communities also share an interrelated human health context. For example, residents in the shared watershed and air basin have the potential to contract waterborne disease or succumb to air quality-related respiratory complications that might be derived from the crossborder travel of contaminants or people, or might be a consequence of living conditions at the border.

The incidence of waterborne disease such as dysentery, hepatitis, and tuberculosis is greatest in *colonias,* which are unincorporated and largely unregulated settlements found on both sides of the border that lack essential services such as water, sewers, electricity, paved roads, and safe and sanitary housing. The poor sanitary conditions of *colonias* are important contributors to the incidence of waterborne disease in El Paso County, which is higher than the national average. Because a water supply infrastructure is generally lacking or minimal, *colonia* residents often transport and store their own water, thus increasing the likelihood of contamination. The lack of adequate wastewater disposal systems also increases the likelihood of waterborne diseases spreading. Although it is clear that reducing the number of households lacking potable water and sewer systems will help reduce the incidence of waterborne disease, data are insufficient to quantitatively link the incidence of waterborne disease to the number of households lacking water and sewer infrastructure.

Airborne pollutants emitted from the cities of Paso del Norte, including significant contributions associated with border crossing congestion, mix with emissions from surrounding non-urban land and circulate within a complex, transborder air basin. The presence of air quality conditions that exceed regulatory thresholds imply a potential for heightened incidence of respiratory disease, including asthma. In the United States, El Paso is classified as a nonattainment area for particulate matter, carbon monoxide, and ozone. Pollutant levels in Ciudad Juárez are no less than those of El Paso (Emerson, et al. 1998; Li, et al. 2001). Nonattainment conditions continue to the present day in Paso del Norte, although air pollutant levels have been declining since the 1980s (Rincón and Emerson 2000). Although it is clear that increased emissions of criteria air pollutants will lead to less-healthy conditions, direct relationships are lacking between emission rates, pollutant concentrations, and the incidence of respiratory disease in Paso del Norte.

Because the community is an important migrant destination and crossroads for human travel, Crespin and Kallishman (1991) recommend that Ciudad Juárez, El Paso, and Las Cruces, N.M. (located 38 miles north of El Paso) be viewed as a single epidemiological unit when accounting for the transmission of communicable disease. Yet, language and cultural differences combined with different national approaches to immunization, vaccination, regular health care, and reporting practices complicate the ability to prevent the resurgence of vaccine-preventable diseases and other infectious conditions

(Brandon 1996). In addition, a complex pattern of health service usage and pharmaceutical purchase has evolved, with residents of one country accessing the resources of the other country depending upon relative availability, quality, and cost of the resource.

Efforts to Build Collaborative Binational Cooperation

It is generally assumed that improved quality of life in Paso del Norte is best effected through binational collaboration that leads to an increasingly integrated community context. Unfortunately, developing the collaborative networks in a binational context is difficult, time consuming, and not always successful. The past 125 years have seen a series of formal and informal collaborative initiatives emerge at both local and border-wide scales that have helped shape the Paso del Norte community. Some initiatives have been sustained while others have emerged only to disappear over time. Most initiatives strive, with reasonable success, to involve representatives of federal, state, and local governments from both the United States and Mexico. Principle areas of collaborative action include:

- Public health (e.g., Pan American Health Organization, U.S.-Mexico Border Health Commission, and Border 2012 Environmental Health Work Group)
- Water resources management (e.g., IBWC and the Paso del Norte Water Task Force)
- Urban planning (El Paso Metropolitan Planning Organization shares planning personnel with Ciudad Juárez's Instituto Municipal de Investigacion y Planeacion [IMIP])
- Environmental and natural resource management (e.g., La Paz Agreement, Border XXI Program, and Border 2012 Program)
- Air quality (e.g., Paso del Norte Air Quality Task Force and the local International Joint Advisory Committee on Air Quality Improvement)

Additional collaborative efforts to work on economic and environmental issues are embodied in NAFTA. Effective in 1994, NAFTA brought together 360 million consumers from the United States, Mexico, and Canada in a $6 trillion market. As a consequence, trade tariffs between Mexico and the United States have been eliminated to enable the free flow of goods and capital. Yet, while goods and services move freely across the border, human migration across the border is restricted (Sadowski-Smith 2002). NAFTA was implemented with environmental side agreements intended to address the environmental consequences of increased border trade and development. These agreements led to the creation of the North American Commission for Environmental Cooperation (CEC), the Border Environment Cooperation Commission (BECC), and the North American Development Bank (NADBank). CEC works to alleviate regional environmental concerns, help prevent potential trade and environmental conflicts, and promote environmental law enforcement. BECC and NADBank were created to provide environmental infrastructure along the U.S.-Mexican border.

Overview of the Paso del Norte System Model

System Story

Explaining the prototype system model for Paso del Norte is best approached by first outlining the narrative, or story, that underlies the model. This narrative is founded on the historical overview provided in the previous section, combined with anticipated scenarios for demographic, economic, and environmental futures.

Local economic opportunity in Paso del Norte, driven by international opportunities for trade and traffic across the U.S.-Mexican border, is the fundamental source of change in the binational community. Although present since the border was established, border-driven economic activity has grown rapidly in recent decades through the establishment of maquiladoras, which take advantage of tariff elimination and wage rate differentials between the two nations. Economic growth, combined with population growth, has yielded concomitant growth in commercial and industrial jobs in both El Paso and Ciudad Juárez.

People have been drawn to the intertwined community of Ciudad Juárez and El Paso by attractive opportunities for employment. This attraction is enhanced because some are also leaving their traditional homes in Mexico to escape dwindling agricultural opportunities, resource damage due to population growth, and political strife. Once in Paso del Norte, births within the relatively young population yield a high population growth rate. Each year, however, a portion of the growing population leaves the area to work and live elsewhere.

Population growth in Paso del Norte places increasing demands on local natural resources, including land, air, and water. Although following different patterns and rates of urban growth, both El Paso and Ciudad Juárez are consuming desert land and some former agricultural land. Both communities are emitting particulates and other air pollutants into the common air basin. On occasion, pollutant concentrations of ozone, carbon monoxide, and particulates exceed levels deemed unhealthful by both nations. The principal contributors to the particulate concentrations represented in the system model include the following: growing transportation emissions associated with the urban sprawl of El Paso, the rapidly increasing population in Ciudad Juárez, residential and industrial emissions, emissions from brick kilns supporting new home construction in Ciudad Juárez, particulates generated by traffic on unpaved roads, border crossing congestion, and the natural dust storms that often bring high concentrations of particulates into the community from the surrounding territory. The higher population density and greater intensity of urban emissions in Ciudad Juárez suggests that more people there are exposed to unhealthful, urban-derived air quality conditions than in El Paso.

Increasing urban water demand has caused declines in water levels and water quality in local aquifers. Methods for meeting the increasing water demand include conversion of Rio Grande water from agricultural to urban use, water recycling, desalination of brackish groundwater, aquifer recharge by reinjecting treated wastewater, water conservation, and water imports from other areas. El Paso is already experimenting with desalination and expects to have an operational, high-capacity desalination facility within the next two years. Meanwhile, lagging construction and maintenance of water supply and sewer infrastructure in the *colonias* of El Paso County and Ciudad Juárez increase the likelihood of unhealthful living conditions. Developing collaborative, community-based approaches to resolving water-related issues is complicated by the need to deal with the overlapping national and state jurisdictions that administer water rights in the region.

A principal goal of the Border Plus Twenty Years (B+20) Program is to obtain insight about ways to improve quality of life for residents of Paso del Norte. Although cause and effect relationships can be identified between human health and the lack of sewer connections (or elevated air pollutant emissions), insufficient data are available to develop quantitative relationships between the incidence of disease and the number of sewer connections or magnitude of air pollutant emissions. For example, it is logical to expect that reducing particulate emissions from brick kilns and unpaved roads will reduce negative health consequences in both Ciudad Juárez and El Paso. Elsewhere, health researchers have identified direct quantitative relationships between contaminant concentrations and incidence of upper respiratory disease or asthma. However, the quantitative relationships needed to link emissions rates and contaminant concentrations in a modeling context are currently lacking. There is a similar lack in researchers' ability to link quantitatively the number of households without sewer connections to the incidence of waterborne disease. These quantitative relationships are lacking, in part, because insufficient surveillance data have been collected to characterize the complex interrelationships among emissions rates, contaminant concentrations, and disease. At the same time, it seems that public health agencies are focused more on reducing the incidence of health problems (such as diabetes, obesity, and drug use) that are less directly linked to the environmental conditions emphasized in the B+20 project.

Adopting a systems thinking perspective requires an attempt to identify the feedbacks, tradeoffs, and lags in the overall urban ecosystem that might lead to unintended consequences of the policy decisions designed to mitigate the situations previously outlined. For example, how might the combined effects of transferring agricultural land and water to urban uses negatively impact the agricultural economy, urban economy, or water quality? Might attempts to reduce urban sprawl through compact urban development in El Paso and Sunland Park lead to greater exposure to unhealthful air quality, but reduce total water use? If funding is limited, should efforts to reduce particulate emissions be implemented instead of increasing the number of households connected to sewer systems? When evaluating the net health benefit, might the funds needed to pave roads, reduce automobile emissions, or increase the number of households with sewers be better spent in Ciudad Juárez than in El Paso?

Instigating change requires both funding and political will. At present it does not appear that community managers are evaluating the interagency tradeoffs that might be associated with deciding whether or not to invest in air pollution control versus water supply development. As water use outstrips water availability, investments are being made in the water supply strategies needed to supply the growing population. How will water managers maintain the level of funding required to keep up with the growing demand for water? Perhaps higher tax rates, water use fees, or federal subsidies will be required. Meanwhile, air quality strategies are afforded different priorities, draw on different funding sources, and are being designed and implemented by different agencies and people. The array of different policymaking, regulatory, and funding environments associated with water supply, air quality, public health, and urban planning inhibits communication between decision-makers from each arena. Thus, each decision-making and policymaking group in the air and water management arenas is proceeding along its own path to finding solutions within its media, but with active binational cooperation within each. This relatively independent approach to problem solving leads the B+20 team to ask: What interaction and interventions should occur between arenas that might lead to reduced overall costs and optimal solutions?

Questions to be Addressed

The B+20 project team has grappled extensively with attempting to define the systemic questions needed to configure the system model for useful explorations of alternate future scenarios in Paso del Norte. Input into this process has been provided by Paso del Norte stakeholders and decision-makers, SCERP managers and researchers, and others studying or living in the U.S.-Mexican border region. Although a broad range of questions were considered, two principal questions were ultimately identified by D. Rick Van Schoik, Managing Director of the Southwest Consortium for Environmental Research and Policy (SCERP):

1. Given the various state and national water management agencies involved in supplying water from common sources to urban communities and agriculturalists, what changes in agency policies and approaches might be made to increase the likelihood of achieving water sustainability and satisfactory quality of life for border residents?
2. Given transborder disparities in minimum wages and household income, what policies might be affected to increase the likelihood of providing a healthy economy and satisfactory quality of life for border residents?

These questions have led to the prototype Paso del Norte system model. The model represents:

- Population growth in El Paso and Ciudad Juárez
- Migration of Mexican nationals toward the border
- Variations in the local maquiladora economy in response to changes in the U.S. national economy
- Land use policies and urban growth processes
- Variations in water availability and quality in response to climate variability and water use
- Conservation alternatives
- Water supply infrastructure alternatives
- The dynamics of surface water rivers, reservoirs, and groundwater aquifers

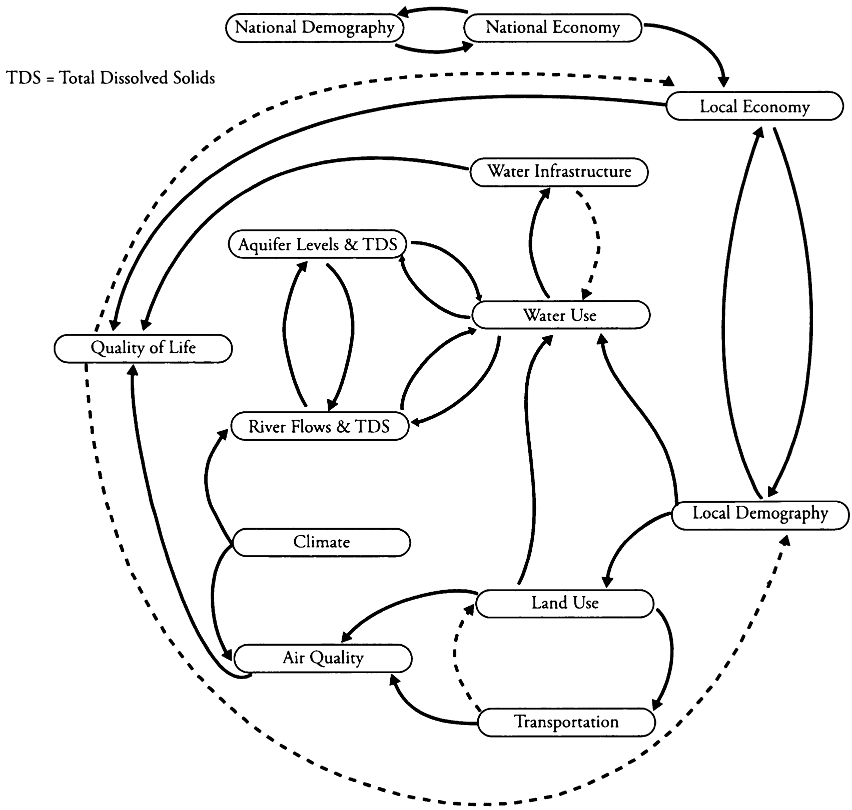
Idealized Map of the Paso del Norte System Model

Subsequent chapters in this section outline how different aspects of the Paso del Norte system—demography, economy, land use, transportation, air quality, transportation, water use, water availability, and quality of life—are incorporated in the system model. Figure 2 shows how the various sectors interact with one another in the model. Although the Paso del Norte system model continues to evolve, the following descriptions outline the model structure and operation at an earlier point during its development when all the key elements are incorporated and the system was operational.

Figure 2 shows the various sectors, or model components, incorporated into the Paso del Norte system model. It is important to note that most sectors contain internal relationships that represent the operation of binational processes that lead to transborder transfers of people, water, air pollutants, money, or goods. For example, the national demography sector accounts for population growth in both the United States and Mexico while accounting for the migration of Mexican nationals to the United States. Similarly, the local demography sector accounts for natural population growth in both El Paso and Ciudad Juárez while accounting for migration between each community and between the communities and the national populations. Analogous relationships are implemented for the national and local economy sectors. In addition, the river, aquifer, and air quality sectors account for the transfer of water and air between the United States and Mexico. Transportation, land use, and water and wastewater infrastructure operations and development in El Paso and Ciudad Juárez are assumed to operate quasi-independently on each side of the border.

The links indicated with solid arrows in Figure 2 are represented in the model at the stage of development described here. The links indicated with dashed arrows, and other model features not shown, are being incorporated to varying degrees in the current version of the evolving system model. As outlined in the system story, the economies of the United States and Mexico vary in response to changes in national and global economic conditions and population growth. The national-level economic variations are transmitted to

Figure 2. Schematic Map of the Links between Sectors of the Prototype Paso del Norte System Model



Note: Links shown with solid arrows are incorporated in the operational model while dashed links illustrate features being considered in ongoing model development.
Source: Author

the local economies of El Paso and Ciudad Juárez. The local economies, however, have a negligible impact on the national economies. Population growth in El Paso and Ciudad Juárez cause increased demand for potable water, sewage infrastructure, and urban land. Growth in urban land leads to road building in the transportation sector that in turn causes increased transportation-related particulate emissions that accompany increased emissions from stationary sources such as factories, brick kilns, ports of entry, and residential waste burning.

A complex interaction exists between the surface water, groundwater, agricultural, and urban elements of the hydrologic system. For example, a portion of the water extracted from the Rio Grande and groundwater aquifers for urban uses is returned to the aquifer system, after treatment, through aquifer recharge. The remainder of the water used is returned to the river after treatment. Thus, aquifer water levels, river flows, and water chemistry (represented in the model by tracking the concentration of total dissolved solids [TDS] concentrations) depend upon a variety of water management decisions that might include water conservation, water recycling, conversion of agricultural water for urban use, desalination of brackish aquifer water, water treatment technologies, and aquifer recharge strategies. Climate is represented in the model as an external, variable factor that causes changes in upstream river flows and river water chemistry in addition to affecting the windy conditions that control dilution of airborne pollutants in the air basin. The quality of life sector represents the ways changes in the local economy, water and wastewater infrastructure development, and air quality might affect the lives of Paso del Norte residents.

It is important to note that the prototype model structure shown in Figure 2 contains few mechanisms for feedback or interaction between groups of sectors. Several feedback mechanisms are indicated when the links represented by dashed arrows are considered. Dashed links include feedback between land use and transportation where traffic is induced by road building to reach sprawling suburbs (Emmi 2003). A similar positive feedback loop is anticipated to occur in cases where improved water supply infrastructure leads to increased per capita water consumption. Although discussed at length by the B+20 team, it is difficult to assess how feedback from the quality of life sector might affect other sectors. For example, the team concludes that the unhealthy living conditions of workers likely exert only a weak influence on the health of the local economy. Similarly, unhealthy living conditions that lead to small increases in the death rate likely have little impact on local population growth rates. Furthermore, few people will likely be dissuaded from migrating to Paso del Norte, nor induced to leave, if economic conditions are advantageous but living conditions are poor. The economic attraction of employment opportunities in Ciudad Juárez are explicitly incorporated in computing migration of Mexican nationals to Paso del Norte.

Even if the dashed links shown in Figure 2 are incorporated in the model, the model structure fails to provide the mechanisms needed to evaluate tradeoffs and links between the various sectors (water supply, air quality, urban planning, and environmental health). Adding a public finance sector (which is under development) that accounts for how funds are generated and spent in public works and services will improve the ability of the model to represent links and tradeoffs between sectors. Because financial issues are often key factors in decision-making, additional links and model elements that help compare the costs of alternative policies will increase the ability to explore how decisions made in one arena might affect people through impacts in another arena. For example, adding the differential costs of delivering potable and recycled water to urban, agricultural, and industrial customers will also help improve the assessment of alternative policies. The B+20 team suspects that working to increase collaboration between decision-makers and policymakers in the various sectors, in addition to increased collaboration between countries, will enhance on-the-ground interaction and feedback that can be represented in the model. Additional stakeholder engagement is needed, however, to map out, characterize, and influence the possible links. Future stakeholder engagement processes should be designed to assess the barriers to communication that likely exist between decision-makers and policymakers in the arenas of water supply, air quality, urban planning, and public health.

Model Application

As configured at the time of publication, the Paso del Norte system model is operational and embodies the features outlined in this and subsequent chapters of this monograph. The user interface is readily accessible to those who receive limited training with the model concepts and model operation. The potential value of using the model to explore tradeoffs in the binational Paso del Norte urban ecosystem has been demonstrated to several stakeholder groups, including water managers, public health workers, air quality managers, city mangers, and urban planners, among others. As a result, the model is ready for use in a stakeholder engagement process designed to help the model developers tune it to stakeholder interests and improve the representation of feedback and links between model sectors.

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II-2

Modeling the Impact of Environment on Quality of Life

Subhrajit Guhathakurta and Edward Sadalla

Abstract

This chapter explains the structure of the quality of life sector as included in the first phase of the Border Plus Twenty Years (B+20) model. The quality of life sector is an "output" indicator based on the parameters supplied by other sectors of the same model. This component uses indicators, or measures, that represent environmental impact in the respective sectors, as provided by the other sectors, and builds on them to develop more direct indicators related to quality of life issues.

The contributions to quality of life, especially from the water and air sectors of the current model, are described. The contribution of water supply to the quality of life sector is straightforward. As the gap between demand and supply for water increases, there is a corresponding decrease in perceived quality of life in the region. Alternatively, a decrease in the demand-supply gap for water improves quality of life perception.

The general method of epidemiological impact assessment used in the study of air quality is in accordance with the concept of population attributable risk (Rothman and Greenland 1998). The attributable cases are computed in a four-step process. The monetary saving

to society for each 5 microgram per cubic meter (μg/m³) drop in annual PM_{10} (particulate matter with an aerodynamic diameter of 10 microns or less) concentration from an initial value of 50 μg/m³ varies from $37 billion to $48 billion, in 1995 constant dollars, for the four health effects described. The most significant savings are derived from reduced premature mortality. This formulation is only an example that calculates the monetary values related to premature mortality followed by the reduced incidence of chronic bronchitis. The savings from fewer hospital admissions for cardiac arrest and respiratory disorders are an order of magnitude lower than two health effects discussed. Regardless, the monetary savings are substantial, suggesting that remedial measures for reducing PM_{10} concentrations have enormous benefits.

Modelado del Impacto Ambiental en la Calidad de Vida

Subhrajit Guhathakurta y Edward Sadalla

Resumen

Esta sección explica la estructura del sector de la calidad de vida como es incluido en la primera fase del Modelo Frontera Más Veinte Años (F+20). El sector de la calidad de vida es indicador de salida de información basado en los parámetros proveidos por otros sectores del mismo modelo. Este componente usa indicadores, o medidas, que representan impactos ambientales en los sectores respectivos, como son proporcionados por los otros sectores, y construye sobre ellos para desarrollar indicadores más directos relacionados a los temas de la calidad de vida.

Las contribuciones a la calidad de vida, especialmente desde los sectores de agua y aire del modelo actual, son descritas. La contribución de suministro de agua al sector de calidad de vida es

directa. Mientras la distancia entre la demanda y el suministro de agua se incrementa, existe una reducción correspondiente en la calidad de vida de la región. Alternativamente, una reducción en la distancia de demanda-suministro de agua mejora la percepción de la calidad de vida.

El método general de evaluación del impacto epidemiológico utilizado en el estudio de la calidad de aire, está en acuerdo con el concepto de riesgo atribuible de la población (Rothman y Greenland 1998). Los casos atribuibles son computados en un proceso de cuatro fases. El ahorro monetario de la sociedad por cada cinqo microgramos por metros cúbicos ($\mu g/m^3$) caen en concentraciones de PM_{10} anuales de un valor inicial de 50 $\mu g/m^3$ varía de \$37 billones a \$48 billones, en dólares constantes de 1995, para los cuatro efectos de salud descritos. Los ahorros más significativos son derivados de la mortalidad prematura. Esta formulación es sólo un ejemplo que calcula los valores monetarios relacionados a la mortalidad prematura seguida de la incidencia reducida de bronquitis crónica. Los ahorros por menos admisiones a hospitales por ataques cardiacos y problemas respiratorios son un orden de magnitud más baja que los dos efectos de la salud discutidos. De cualquier manera, los ahorros monetarios son substanciales, sugiriendo que medidas remediales para reducir concentraciones de PM_{10} tienen beneficios enormes.

INTRODUCTION

The Border Plus Twenty Years (B+20) model includes seven sectors that are linked with appropriate positive and negative feedback loops. The principle drivers of the B+20 model are the population (demographic) and economy sectors. These two sectors provide important information for determining the impact of urban growth on the border environment. In addition to demographics and economy, there are five generic environmental sectors: air quality, water quality and availability, land use, transportation, and overall quality of life. Many of these generic sectors have further sectoral divisions according to spatial detail (i.e., national and local contexts in two countries and two urban areas). Additional sectors, such as the public finance sector, are also planned in future versions of the model.

The model currently includes a detailed water availability sector that examines groundwater and surface water flows in the El Paso, Tex.-Ciudad Juárez, Chih., region. The air quality sector is based on emissions from factories, vehicles, roads, and homes in the same region. The land use sector simulates the conversion of drylands and irrigated lands to urban uses as induced by growth pressures. Most of the model sectors are developed with two interrelated spatial units—El Paso and Ciudad Juárez. This section explains the structure of the quality of life sector as included in the first phase of the B+20 model.

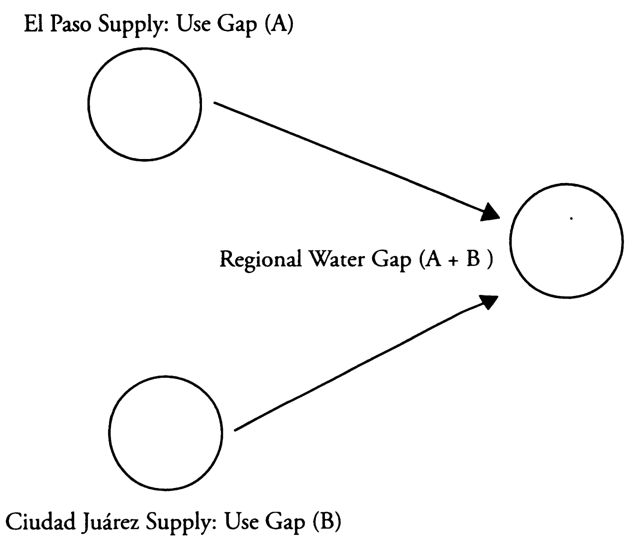
The quality of life sector in the model is an "output" indicator based on the parameters supplied by other sectors of the same model. The definition of quality of life in this case is limited to only those aspects being modeled within the B+20 model structure. In the next phase of model development, feedbacks from the quality of life sector to other model sectors, such as demographics and economy, will be examined. The conceptual framework, as developed earlier, is an ideal model that the current form of B+20 has not achieved. For example, although economic disparities have been identified as a significant component of quality of life, such disparities have not yet been modeled as part of the economy. Similarly, transportation access and modes of transportation do not figure in the current version of the model although their impact has been discussed in the conceptual framework. Future versions of the B+20 model will strive to include these and other important components of quality of life.

As indicated earlier, the quality of life model component uses the "hooks"— indicators, or measures, that represent environmental impact in the respective sectors—provided by the other sectors and builds on them to develop more direct indicators related to quality of life issues. The output measures used in the quality of life sector were not developed in isolation but in consultation with the entire group responsible for developing the B+20 model structure. The contributions to quality of life, especially from the water and air sectors of the current model, are described below.

WATER SUPPLY

The contribution of water supply to the quality of life sector is straightforward. The key element in this case is the availability of water for various uses in the El Paso-Ciudad Juárez region in relation to demand and demand growth. The water supply parameters with respect to both surface flows and groundwater flows have been modeled for this region. However, water quality issues do not feature in the current model. Therefore, current quality of life indicators from the water supply component of the model include only one parameter, which is well-defined in the model. This parameter is the supply-use gap for both El Paso and Ciudad Juárez. As the gap between demand and supply for water increases, there is a corresponding decrease in perceived quality of life in the region. Alternatively, a decrease in the demand-supply gap for water improves quality of life perception. An aggregate indicator is included here to estimate the total effect of this gap for both El Paso and Ciudad Juárez urban areas. The schematic of this component is provided in Figure 1.

Figure 1. Quality of Life Measure for Water Use



Source: Authors

A related component to water availability is water infrastructure. The availability of municipal water is directly related to improved water quality, given that municipalities have the responsibility to provide for consumption water that has been treated. Therefore, a good indicator of water quality for the region is the percentage of households connected to municipal water supply. The data in this regard are vastly different for the two sides of the border. While only 1% of the households in El Paso have no plumbing, nearly 20% of Ciudad Juárez households lack piped water inside their homes. In Ciudad Juárez, availability of piped water inside homes is directly related to socioeconomic status of the households (Peña forthcoming). According to 2000 census figures, the bottom quartile of the population is 25% less likely to have piped water in their homes than the top quartile (Table 1). In contrast, the relationship between household income and plumbing is small in El Paso and can be ignored for the purpose of developing the B+20 model (Table 2). Figure 2 represents the impact on health of income and availability of piped water in households.

Table 1. Access to Sewer and Piped Water Inside Homes in Ciudad Juárez by Household Income, 2000

Households	Lowest–$2,550	$2,550.10–$4,343.00	$4,343.01–$8,163.25	$8,163.26–Highest
Percentage of households with sewer connections	79.3	85.7	89.4	94.2
Percentage of households with water connections	67.2	74.1	81.7	91.0

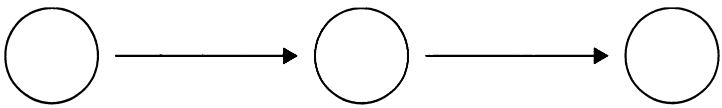
Note: All currency in 2000 current pesos.
Source: Adapted from Peña forthcoming

Table 2. Households Without Plumbing Facilities in El Paso by Poverty and Tenure Status, 2000

	Households below Poverty	Households above Poverty
Owners	2.10%	0.80%
Renters	2.10%	0.90%

Source: Authors' calculations based on U.S. Bureau of the Census 2000.

Figure 2. Estimating the Health Impacts of Water Infrastructure



Per Capita Income in Ciudad Juárez (from economy sector)

Availability of Piped Water in Ciudad Juárez (calculated from Peña 2002)

Incidence of Gastrointestinal Disease (calculated from Sadalla, et al. 2000)

Source: Authors

Water Contaminants

Contaminants in drinking water contribute to human ingestion of numerous chemicals that have acute and chronic health impacts. In addition, microbiological contaminants are often present in untreated water. Common chemical contaminants in the water supply include heavy metals (such as lead), fertilizers, pesticides, aromatic hydrocarbons, and organohalogens, among others. Microbiological contaminants include *cryptosporidium, Giardia lamblia, Legionella,* and total coliforms (including fecal coliform and *E. coli*). The treatment agents used in filtration systems also cause myriad health problems in some individuals. A wide variety of health hazards are associated with chemical contaminants ranging from skin and eye irritation to cancer. Microbial contaminants mostly cause gastrointestinal illnesses, although other more serious hazards such as Legionnaire's Disease are also attributed to them. A detailed list of such health effects and the recommended thresholds of such contaminants are available at the U.S. Environmental Protection Agency (EPA) website http://www.epa.gov/safewater/mcl.html#mcls.

An important measure of water quality and filtration effectiveness is turbidity. Turbidity contributes to the cloudiness of water and is mostly caused by soil runoffs. Higher turbidity levels are associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria. According to EPA's guidelines, turbidity should not be allowed to go above 5 nephelometric turbidity units (NTU). Water filtration systems are required to ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, new EPA guidelines for turbidity require that it never exceed 1 NTU, and 0.3 NTU in 95% of daily samples in any month.

Table 3. Approximate Particle Counts for Turbidity Levels

Turbidity	Approximate Particle Counts/10 ml
5.0	200,000
1.0	60,000
0.5	10,000
0.1	200

Source: Authors

Although turbidity is generally considered harmless, it may be an indicator of harmful water constituents. It is also aesthetically unpleasant and likely to cause color, odor, and taste problems. The major concern about turbidity is that it interferes with the disinfection process. Turbidity can harbor or carry pathogens and can interfere with disinfection by taking up or using the disinfectant intended for the pathogens in the water. The pathogens, which are not killed, can result in several waterborne diseases, as discussed earlier.

The current structure of the B+20 model does not address turbidity directly, but it does provide a measure of total dissolved solids (TDS) in water. Although there is a general relationship between particle counts and turbidity, a firm correlation does not exist. Measurement of turbidity is affected by the optical property of water. The current method of choice for measuring turbidity is the nephelometric turbidimeter, which measures the intensity of light scattered at 90 degrees to the path of incident light. This and other methods of measuring turbidity, however, do not provide an easy way to estimate the weight or concentration of suspended matter (TDS) in water samples. The size, shape, and refractive index of the particulates affect the light-scattering property of the suspension. Hence, similar concentrations of particulates in different water samples can register very different turbidity measures due to other factors such as luminosity of the particulate matter or the shape of the particles.

As explained above, estimating TDS within the model structure does not provide a clear picture of its effect on human health. Given that TDS is not accurately reflected in turbidity measures and that turbidity does not directly affect health but creates conditions for microbial substances to persist, similar levels of TDS or turbidity can have a wide range of health effects. Studies conducted on water distribution systems have shown conflicting findings with respect to turbidity and its relation to concentrations of microorganisms. Several studies reported increasing concentrations of microorganisms with increases in turbidity (Haas, et al. 1983; Geshko, et al. 1983). However, these studies also show that this relationship is non-linear. Other studies suggest that turbidities do not affect either coliform or "plate-count" organisms (Reilly and Kippin 1983). Hence, the B+20 models of the health impacts of total dissolved solids are largely speculative and for illustrative purposes only.

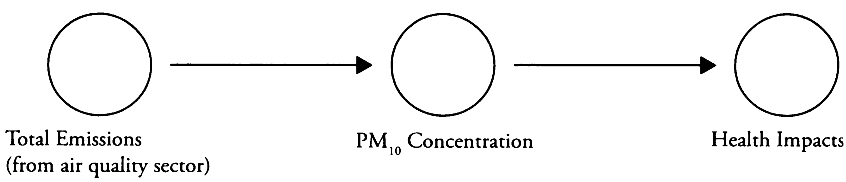
Air Quality

Air quality in the B+20 model is currently represented by a single measure—emissions. A number of sources of emissions are in the air quality model, including households, roads, manufacturing plants, and vehicles (especially those made to wait at border checkpoints). As a first step to modeling air quality impacts on quality of life, the amounts of particulates, especially annual average concentrations of particulate matter larger than 10 microns in diameter (PM_{10}), are estimated from total emissions. The PM_{10} concentrations are then evaluated with respect to their effects on health based on a number of epidemiological studies. Figure 3 is a simplified schematic of the link from emissions to quality of life.

Although many studies show that particulates affect everyone, some groups are more sensitive to particulate pollution than others (HEI 2000). For example, the elderly and children with a history of respiratory conditions are more susceptible, according to several studies. In addition, the health effects of particulates are strongly linked to particle size. Small particles, such as those from fossil fuel combustion, are likely to be most dangerous because they can be inhaled deeply into the lungs, settling in areas where the body's natural clearance mechanisms cannot remove them. The constituents in small particulates also tend to be more chemically active and may be acidic as well, therefore causing more damage.

Numerous studies associate particulate pollution with acute changes in lung function and respiratory illness, which results in increased hospital admissions for respiratory disease and heart disease, school and job absences because of respiratory infections, or aggravation of chronic conditions such as asthma and bronchitis (Kunzli, et al. 2000; Brunekreef 1997; Dockery, et al. 1993; Prescott, et al. 1998). But the more demonstrative and sometimes controversial evidence comes from a number of recent epidemiological studies (WHO 2000; Laden, et al. 2000). Many of these studies

Figure 3. The Procedure for Estimating Health Impacts of Emissions



Source: Authors

have linked short-term increases in particulate levels, such as those that occur during pollution episodes, with immediate (within 24 hours) increases in mortality. This pollution-induced spike in the death rate ranges from 2% to 8% for every increase of 50 micrograms per cubic meter (μg/m^3) in particulate levels. These basic findings have been replicated on several continents in cities as widely divergent as Athens, São Paulo, Beijing, and Philadelphia. During major pollution events, such as those involving a 200 μg increase in particulate levels, an expert panel at the World Health Organization (WHO) estimated that daily mortality rates could increase as much as 20%. These estimates should be viewed with caution, however, because some of those who die during a pollution episode were already sick, and the pollution may have hastened death by only a few days.

Health effects of particulates are not restricted to occasional episodes when pollutant levels are particularly high. Numerous studies suggest that health effects can occur at particulate levels that are at or below the levels permitted under national and international air quality standards. In fact, according to WHO and other organizations, no evidence so far shows a threshold below which particle pollution does not induce some adverse health effects, especially for the more susceptible populations. Airborne particulates are likely to be found in some amounts everywhere, but their effects on human health varies from individual to individual. There are several factors that can help determine the extent of these health effects. Among those factors are:

- Length of exposure (how long the person breathed the particulates)
- Type and toxicity
- Concentration (amount of particulates in the breathing zone)
- Size of particulates (which affects how deep within the respiratory system the matter can go and how long the dust remains in the air)
- Activity level and breathing rate
- Age and overall health

Given the wide variation in heath impacts, any aggregate statistic projecting the likely impact of particulate pollution is bound to be for illustration purposes only. What is certain, based on numerous studies, is that increased particulate pollution increases the risks of respiratory diseases and also increases mortality.

While air pollution consists of a mix of different pollutants, epidemiological studies are often based on measurements of a single "indicator pollutant" that is representative of air pollution's impact on health. Current epidemiological data regard PM_{10} concentrations as an "indicator pollutant" with respect to air pollution. PM_{10} consists of particulate matter with an aerodynamic diameter of 10 micrometers or less. The harmful effects of PM_{10} on health have been traced to eight partly overlapping outcomes in a WHO study (Kunzli, et al. 1999). The relative risk estimates and the confidence intervals for those risks are provided in Table 4.

Method of Estimating Air Pollution-Related Health Cases

Relative risk (RR) is the most common measure used to report results in epidemiological studies. Relative risk is the ratio of the risk of having a health impairment due to the effects of a hazard to the risk of having the same health impairment without being exposed to the hazard. If the exposed and the unexposed have the same risk, then RR = 1. When RR is greater than 1, then the impact of the hazard on health is regarded as positive. For example, an RR of 1.43 would indicate a 43% higher risk of health impairment when exposed versus when not exposed.

The general method of epidemiological impact assessment used in this study is in accordance with the concept of population attributable risk (Rothman and Greenland 1998). The attributable cases are computed in a four-step process described below.

Table 4. Relative Risks on Health per 10 μg/m^3 Increase of PM_{10} Concentration

Health Outcomes	Relative Risks	+ Confidence Interval	Percent Increase in Outcome for 10 μg/m^3 Increase in PM_{10}
Long term mortality (adults >= 30 years)	1.043	1.026–1.061	4.30%
Respiratory hospital admissions (all ages)	1.0131	1.001–1.025	1.30%
Cardiovascular hospital admissions (all ages)	1.0125	1.007–1.019	1.25%
Chronic bronchitis incidence (adults >= 25 years)	1.098	1.009–1.194	9.80%
Bronchitis (children < 15 years)	1.306	1.135–1.502	30.60%
Restricted activity days (adults >= 20 years)[a]	1.094	1.079–1.109	9.40%
Asthmatics: asthma attacks (children < 15 years)[b]	1.044	1.027–1.062	4.40%
Asthmatics: asthma attacks (>= 15 years)[b]	1.039	1.019–1.059	3.90%

Notes:
a) Restricted activity days: total person-days per year
b) Asthma Attacks: total person days with asthma attacks per year
Source: Kunzli, et al. 1999.

Step 1

The baseline population frequency (P_0) is derived from the observed frequency of the outcome in the population. The baseline population frequency is defined as the proportion of the relevant population that would experience the outcome, assuming a baseline air pollution level B (Krzyzanowski 1997).

$$P_0 = \frac{P_e}{1+[(RR-1)(E-B)/10]}$$

where,

P_e = observed prevalence/incidence of outcome in populations

P_0= baseline population frequency

E = observed population exposure level

B = baseline exposure level (set at 7.5 μg/m³)

RR = relative risk

Step 2

Baseline increments of the outcome per 1 million population is calculated assuming a linear additive effect of air pollution above the lowest effect level.

$$D_{10} = 1000000 \text{ x } F_P \text{ x } P_0 \text{ x } (RR-1)$$

where,

D_{10} = number of additional cases (per million) per 10 μg/m³ increment of PM_{10} annual mean concentration

F_p = fraction of the total population relevant to the defined outcome (for example, children or elderly)

P_0 = baseline population frequency (calculated in Step 1)

Step 3

The number of cases, N_c, attributable to the air pollution for a given population group P_c is computed:

$$N_c = \frac{D_{10} \text{ x } P_e}{1000000} \text{ x } [(X_c - B)/10]$$

where,
N_c = number of cases attributable to air pollution for a given population category c of exposure
P_c = population in category c of exposure
X_c = the average exposure in category c
B = baseline exposure level (assume 7.5 μg/m^3)

Step 4
The overall number of cases per year is computed by adding all N_c.

$$\sum_{i}^{c} N_c$$

Assigning Monetary Values for Health Effects

Although uncertainties exist in determining the economic value of health effects, several studies have attempted to put a monetary value on health and mortality to examine benefits and costs of public policy. Ideally, two sets of values are included in the economic valuation studies: the out-of-pocket expenses, such as medical costs and loss in income, and the less tangible effects on well-being, such as pain, discomfort, and emotional costs. The valuation of full impacts are conducted by estimating a "maximum willingness to pay" to prevent the health effect. Although there is no standard approach for conducting willingness to pay (WTP) studies, such studies usually contain three elements.

First, a hypothetical or real scenario is described. The description is often detailed and includes information on the expected effects of actions and/or the likely course of events should some actions not be taken. For example, the scenario might contain an estimate of increase in annual mortality risk that would be expected to result from worsening air quality. The scenario is constructed to enable the respondent to place a value on various courses of action or inaction. Second, the mechanism for eliciting the value choice is presented, and that can take several forms including open-ended questions ("What is the most you would pay for X?"), bidding games ("Would you pay $5? How about $10? or $15?"), or referendum formats

("The government is considering X, which would raise your annual tax bill by $Y. How would you vote?"). Finally, WTP surveys elicit information about the socioeconomic characteristics of the respondents as well as their attitudes and behaviors in specific arenas. These characteristics would form possible explanatory variables when examining the data on WTP. The use of WTP valuations have been controversial, given that values are inferred from hypothetical scenarios rather than actual market behavior. However, these studies have been useful in settling lawsuits that deal with estimating the damage from environmental degradation, such as with the Exxon Valdez oil spill in Alaska. Many regard WTP surveys as the only method available for estimating monetary compensation of large environmental losses (Portney 1994).

As can be expected, WTP is more difficult to determine than the direct costs of illness (COI). Extensive use of WTP in health care is a recent phenomenon (Diener, O'Brien, and Gafni 1998; Johannesson, Johansson, and Jonsson 1992; Onwujekwe, et al. 2001). While its use in cost-benefit analyses is sometimes controversial because trade-offs are not included explicitly, recent studies have attempted to provide evidence about demand at non-zero prices (Diener, O'Brien, and Gafni 1998). Even in this context, use of WTP is limited because there is no guarantee that households will behave as indicated in the interviews. Table 5 provides some estimates of the monetary effects of health impairments based on a review of literature and the type of estimate. WTP estimates were available for some but not all health impacts. When WTP was not available, COI information was used. These COI estimates were adjusted upward by a factor of two to correspond with WTP estimates, given that WTP for any health effect is usually greater than COI (Ostro and Chestnut 1998; Empire State Electric Energy Research Corporation Staff 1995). Empire State Electric Energy Research Corporation Staff (1995) has estimated that the total social WTP/COI ratios range from 1.3 to 2.4. Based on these results, a factor of two was selected for COI adjustment purposes in this study to align WTP and COI estimates.

WTP estimates for the various health risks included were calculated in two steps. First, the high, central, and low estimates for a 10-4 change in risk for working-age adults as calculated in Ostro

Table 5. Selected Monetary Values for Health Effects

Health Effect	Estimate per Incident (1995 $)			Type of Estimate
	Low	Medium	High	
Premature mortality	$2,100,000	$3,600,000	$7,300,000	WTP
Selected probability weights	33.00%	50.00%	17.00%	
Adult chronic bronchitis	$150,000	$220,000	$390,000	WTP
Respiratory hospital admission	$7,000	$14,000	$21,000	Adjusted COI
Cardiac hospital admission	$7,500	$15,000	$22,500	Adjusted COI
Emergency room visit	$260	$520	$780	Adjusted COI
Child acute bronchitis	$165	$330	$495	Adjusted COI
Restricted activity day	$31	$62	$93	WTP and Adjusted COI
Asthma symptom day	$13	$37	$60	WTP
Acute respiratory symptom day	$6	$12	$17	WTP
Selected probability weights for all morbidity effects	33.30%	33.40%	33.30%	

Source: Ostro and Chestnut 1998

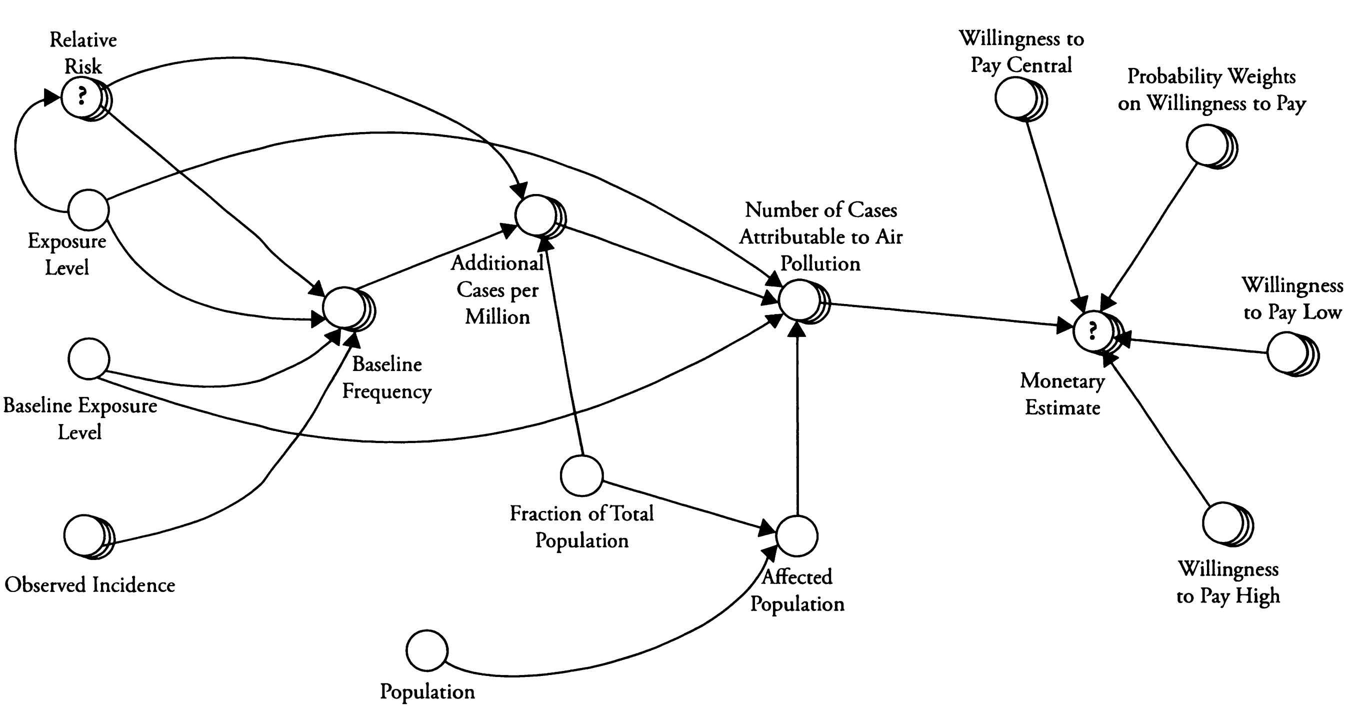
and Chestnut (1998) were applied to the population at risk. These estimates have been adjusted according to the distribution of mortality and morbidity in the population. For example, assuming 85% of the pollution-related mortality occurs in the population age group 65 and over, WTP for reducing mortality for this age group is 25% lower than working-age adults. The high, central, and low weights attempt to capture this non-linear distribution of pollution-related mortality in the population. Second, the weights are applied to the WTP values and aggregated across all the affected population to arrive at the total social cost of avoiding pollution-related health impacts.

A System Dynamics Formulation of Estimating the Value of Health Risks

Figure 4 shows the links established for estimating health risks and incidence of health effects of PM_{10}, based on the formulas shown previously. Monetary impacts of four pollution-related health effects have also been included in this model. The included health effects are long-term mortality, respiratory hospital admissions, cardiac hospital admissions, and chronic bronchitis incidence. The external links in this model include exposure level in terms of annual average PM_{10} concentration (determined in the air quality sector of the overall B+20 model) and population (estimated in the demographic sector). To run the model, a number of user inputs need to be provided. The observed incidence of the four health effects mentioned above in the population being studied are necessary inputs. In addition, the fraction of the total population that would suffer from pollution exposure also has to be estimated and provided. The exogenous variables in the model allow for detailed specification of affected population by spatial and age categories. However, for the purposes of this study, aggregate population information is used with limited spatial variation.

The model was tested with data based on a hypothetical scenario. Table 6 shows the monetary impacts of each 5 $\mu g/m^3$ change in annual average PM_{10} concentration from an initial level of 50 $\mu g/m^3$ under this scenario. This model run is based on a population of 1 million, 66% of which is affected by PM_{10}-related pollution. The

Figure 4. A System Dynamics Formulation of Health Costs of Air Pollution



Source: Probability weights and willingness to pay estimates are derived from Ostro and Chestnut 1998 baseline incidence of premature mortality, respiratory hospital admissions, cardiac hospital admissions, and chronic bronchitis incidence used in this scenario were 3%, 6%, 7.5%, and 15%, respectively. The results seem to be robust and as expected. The monetary saving to society for each 5 μg/m³ drop in annual PM_{10} concentration from an initial value of 50 μg/m³ varies from $37 billion to $48 billion for all four health effects in 1995 constant dollars. The most significant savings are derived from reduced premature mortality. This formulation is only an example that calculates the monetary values related to premature mortality followed by the reduced incidence of chronic bronchitis. The savings from fewer hospital admissions for cardiac arrest and respiratory disorders are an order of magnitude lower than the other two health effects previously discussed. Regardless, the monetary savings are substantial, suggesting that remedial measures for reducing PM_{10} concentrations have enormous benefits, if it is assumed that the costs of implementing such measures are typically far smaller.

A number of caveats should be kept in mind when interpreting the values provided in Table 5. WTP estimates are derived from studies in the United States and may not be applicable in the context of Mexico. Cultural differences in valuing various aspects of quality of life are well known. In addition, the COI estimates will

Table 6. Monetary Savings for Each 5 μg/m³ Change in PM_{10} Concentration (1995$billions)

PM_{10}	Monetary Savings for Each 5 μg/m³ Change in PM_{10} Concentration (1995 $billions)				
	Premature Mortality	Respiratory Hospital Admissions	Cardiac Hospital Admissions	Chronic Bronchitis Incidence	Total Social Benefit
50–45	$28.00	$0.13	$0.18	$8.70	$37.10
45–40	$30.50	$0.13	$0.17	$10.40	$41.20
40–35	$32.50	$0.12	$0.16	$12.40	$45.10
35–30	$33.40	$0.11	$0.15	$14.40	$48.10

Source: Authors' calculations based on the model be different in the Mexican context given vast differentials in income and expenses between Mexico and the United States. Another potentially problematic aspect of the values provided in Table 5 is the differences in the level of tolerance for pollution and ill health. Hospital admissions would not increase nearly as much as the numbers derived from the U.S. context indicate if alternative health care measures are taken and if a fraction of the population feels compelled to function under symptoms of ill health. This increased tolerance is quite probable in the absence of social safety nets that allow downtime for recovery.

Closing the Loop

The B+20 model captures several other quality of life attributes of Paso del Norte border populations, but the overall picture is far from complete. The perception of quality of life has multiple dimensions that vary across populations and among individuals. The focus in this effort has been to capture the immediate quality of life impacts of environmental concerns modeled within the B+20 structure. The critical environmental components were air and water pollution and water availability. However, other necessary sectors were also modeled to estimate changes in the environmental components. These other sectors included demographic and economic processes, which are the significant drivers of other sectors in the model. In addition, transportation and land use components have also been included, given their close relationship with air pollution and water availability. Within the quality of life sector, the following measures have also been incorporated, based on other sectors of the model:

- Ratio of unpaved to paved roads
- The gap between the demand for and supply of roads in the area
- Per capita income
- Employment levels
- Change in irrigated land area

A number of other quality of life indicators are planned for future versions of the B+20 model, including educational levels, crime, traffic congestion, and open space availability. A critical component for implementing many of the quality of life elements discussed is a model sector dealing with public finance. Development of such a sector is progressing and was scheduled for completion in 2004. The additional quality of life components previously mentioned will be accomplished in conjunction with the public finance sector and were also expected to be completed by 2004.

Another important remaining task in this endeavor is "closing the loop" from quality of life impacts to other sectors of the model. Because quality of life indicators provide a measure of human well-being, they should also determine human behavior. That is, individuals are expected to act in a manner that would improve their perceived quality of life. For example, labor would tend to move from a job-scarce to a job-rich area, which is in fact happening as migrants from the interior of Mexico seek employment from maquiladoras located at the border. Similarly, there would be an expected capitalization in the market values of land that has better infrastructure and is subjected to less pollution. At the same time, urban redevelopment pressures will be brought to bear on policymakers combating increased disease, crime, and social dysfunction. In the context of the B+20 model, a clear connection exists among health impacts, labor productivity, employment, and population growth. These relationships will be examined further and incorporated into the B+20 structure in the next version of the model.

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II-3

Modeling the Demographic Characteristics of the Paso del Norte Region

James Peach

Abstract

Demographic change in the border region, an overview of which is provided in this chapter, is affected profoundly by national demographic and economic trends in the United States and Mexico. The population growth rates of the two nations were far different in the 19th century than the 20th century, and even during the 20th century population growth rates in the two nations have been highly variable from decade to decade. Projections of the two nations' populations over the next 50 years illustrate clearly that demographic trends are closely related. Within both nations there has been a century-long tendency for the population of the border states to increase as a proportion of the total population.

Projection accuracy is not necessarily the most important aspect of the Border Plus Twenty Years (B+20) model. The model emphasizes relationships among sectors and feedback effects so that policymakers can examine different long-run scenarios and policy options. Nevertheless, the benchmark population projections from the B+20 model are well within the range of other published projections. The projections at the national level for both Mexico and the

United States closely approximate the medium projections of the United Nations. Similar comparisons are made for both El Paso, Tex., and Ciudad Juárez, Chih.

Modelado de las Características Demográficas de la Región Paso del Norte

James Peach

Resumen

El cambio demográfico en la región fronteriza, como se discute de manera general en este capítulo, es afectado profundamente por las tendencias demográficas y económicas nacionales en México y los Estados Unidos. Los índices de crecimiento de la población de las dos naciones eran más diferentes en el siglo 19 que en el siglo 20, y aún durante el siglo 20 los índices de crecimiento de la población en las dos naciones han variado de década a década. Las proyecciones de las poblaciones de las dos naciones para los próximos 50 años ilustran claramente que las tendencias demográficas están muy relacionadas. Dentro de ambas naciones ha habido durante un siglo una tendencia en los estados fronterizos de incremento de su población como proporción total de la población.

La exactitud de la proyección no es necesariamente el aspecto más importante del modelo Frontera Más 20 Años (F+20). El modelo enfatiza relaciones entre sectores y efectos de retroalimentación para que los responsables de elaborar políticas puedan examinar diferentes escenarios de larga duración y opciones de política. No obstante, las proyecciones de referencia de la población del modelo F+20 están bien dentro del rango de otras proyecciones publicadas. Las proyecciones a nivel nacional para ambos, México y los Estados

Unidos se aproximan a las proyecciones medianas de los Estados Unidos. Comparaciones similares se han llevado a cabo para ambos El Paso y Ciudad Juárez.

Demographic Background: The National and State Context

Demographic change in the border region is affected profoundly by national demographic and economic trends in the United States and Mexico. The population growth rates of the two nations were far different in the 19th century than the 20th century. Mexico's population increased from 5.7 million in 1800 to 13.6 million in 1900—or by roughly 2.4 times—while the U.S. population increased from 5.3 million in 1800 to 75.9 million in 1900—or about 14 times. The U.S. population then increased to approximately 281.4 million in 2000. During the same time period, Mexico's population increased from 13.6 million to nearly 100 million. In terms of absolute numbers, the increase in the U.S. population was more than double the increase in Mexico. In relative terms, Mexico's population increased at about twice the rate of the U.S. population[1].

Even during the 20th century, population growth rates in the two nations have been highly variable from decade to decade (Figure 1). In the United States, the highest population growth rates are associated with the pre-Depression era and baby-boom years following World War II. In Mexico, population growth rates increased in each decade from the 1920s to the 1970s, following the tragic loss of population during the Mexican Revolution from 1911 to 1920. By the mid-1970s, Mexico's birth rate began to fall dramatically; this fact is reflected in lower population growth rates in Mexico during the 1980s and 1990s compared to earlier decades.

Projections of the two nations' populations over the next 50 years illustrate clearly that demographic trends are closely related. United Nations population projections indicate a range of 293 million to 419 million for the United States in the year 2050. Differences in the projections for the two nations depend mainly upon differing migration assumptions. That is, the low figure for Mexico and the high figure for the United States are both based on significant migration from Mexico to the United States. In many respects, the demographic characteristics of the two populations complement each other and provide numerous possibilities for mutual cooperation. The U.S. labor force is aging rapidly and (without substantial immigration) will almost certainly grow slowly. Mexico's population, with a lower median age (22.0 in Mexico versus 35.3 in the United States), will add nearly 1 million relatively young workers per year to its labor force. As a result, Mexico faces a serious job-creation challenge over the next two or three decades. While demographic interaction between the two nations will be influenced powerfully by national economic conditions and immigration policies, it is difficult to imagine that the demographic futures of the two nations are not inherently intermingled.

Within both nations there has been a century-long tendency for the population of the border states to increase as a proportion of the total population. In the United States, the four border states (California, Arizona, New Mexico, and Texas) accounted for only one out of 18 U.S. residents in 1900. By 2000, more than one in five (21.9%) U.S. residents lived in a border state and the combined population of the border states had reached 61.6 million. In Mexico, the pattern is similar. In 1900 only one Mexican in 10 lived in a border state (Baja California, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas), while by 2000 that figure had reached one in six. Given these trends, it should not be surprising that in most decades of the 20th century the populations of the border states were growing more rapidly than the populations of their respective nations. Another important feature of border state population growth rates is that they have been highly variable from state to state and decade to decade. There is little reason to suggest that these trends will end in the next decade or two.

Demographic Background: El Paso and Ciudad Juárez

The El Paso, Tex.-Ciudad Juárez, Chih., metropolitan area is the second largest urban region on the U.S.-Mexican border—surpassed in population size only by the San Diego, Calif.-Tijuana, B.C., urban area. The region ranked second in population size in 1940, the starting point for this analysis, and ranked second along the border, according to the 2000 censuses of Mexico and the United States. This brief demographic history of the region begins in 1940 because it was during this decade that that the rapid growth of the border began. Prior to 1940, the border region as a whole was sparsely populated.

In 1940, the El Paso population was two-and-a-half times as large as Ciudad Juárez, which had a population of 55,024 (Table 1). Between 1940 and 1950 the region's population grew to 326,000, an increase of 76.9%. This growth rate was more than five times the growth rate of the U.S. population and more than double the population growth rate of Mexico. However, this growth rate was not unique along the border.

Table 1. Population Growth in the El Paso-Ciudad Juárez Region: 1940–2000

Year	El Paso	Percent Change	Ciudad Juárez	Percent Change	Total	Percent Change
1940	131,067	n/a	55,024	n/a	186,091	n/a
1950	197,968	48.8	131,308	138.6	329,276	76.9
1960	314,070	61.1	276,995	111.0	591,065	79.5
1970	359,291	14.4	424,135	53.1	783,426	32.5
1980	479,899	33.6	567,365	33.8	1,047,264	33.7
1990	591,610	23.3	798,499	40.7	1,390,109	32.7
2000	679,622	14.9	1,218,817	52.6	1,898,439	36.6

Source: Author

The region's growth rate peaked during the 1950s (79.5%). By 1960, the population of Ciudad Juárez was rapidly approaching the size of El Paso, although El Paso remained the larger of the two cities until the 1970 censuses. The 1960-to-1970 population growth rate for the two cities was less than half the growth rate of the previous decade, while El Paso's growth rate was only about one-fourth of the previous decade. By 1980, the population of the two cities reached 1 million for the first time. El Paso's growth rate during the 1970s was more than double that of the previous decade, while the growth rate of Ciudad Juárez declined substantially.

By 1990, the population of Ciudad Juárez was more than 200,000 larger than El Paso. Growth rates for both cities remained substantially higher than the corresponding national figures. During the 1990s, El Paso's population growth rate declined to 14.98%, not much higher than the U.S. population's growth rate of 13.15%. During the same decade, however, the Ciudad Juárez population growth rate increased substantially to 52.6%. By 2000, the population of the region was slightly more than 10 times its 1940 figure.

In general, population growth rates for both cities over the last 60 years have been high relative to their respective nations, but also highly variable. This pattern of high but highly variable growth rates is found in other border twin cities as well. In the context of building a simulation model of the border region over the next two decades, it is important to remember the historical pattern of variation in growth rates. In short, there is no *a priori* reason to expect constant growth rates during the coming decades.

Historically, both cities have had a relatively young population. As recently as 1970 the median age in Ciudad Juárez was 16.8 years and 46.1% of the population was under the age of 15. The median age in El Paso was 22.7 years, compared to the U.S. figure of 28.0 years. As in both nations, the populations of the two cities have been aging. By the census of 2000, the median age in Ciudad Juárez (23.0 years) was slightly higher than the corresponding figure for Mexico as a whole (22.0 years). The El Paso population, with a median age of 30.0 years in 2000, has not been aging as rapidly as the United States as a whole, which had a median age of 35.3 years in 2000. Nevertheless, both El Paso and Ciudad Juárez will have considerable demographic momentum over the next decade or two.[2]

The rapid growth of the border population has been attributed to many factors. These include the Mexican Revolution (1910–1920), U.S. prohibition (1919–1932), the beginning (in 1942) and end (1964) of the Bracero Program, the maquiladora program (starting in 1965), U.S.-Mexican wage differentials, the North American Free Trade Agreement (NAFTA), Mexico's various economic crises, and other factors. In all likelihood these and other issues have contributed to border region population growth, but some skepticism of these allegations is appropriate. Some of these phenomena occurred after, not before, the highest regional population growth rates. Further, the absence of these events is rarely suggested as a reason for a slowdown in border population growth rates. Finally, all of these factors operate only through migration and ignore the importance of fertility and mortality.

Methods of Population Projection

There are five basic types of population projection methods and literally hundreds of variations of these techniques. The five basic categories include:

- Purely subjective
- Naïve models
- Econometric models
- Cohort-component models
- Hybrid models

Purely subjective population projections consist of statements such as: "I think the population of Ciudad Juárez will be 7 million in the year 2025" or "Everyone knows that the population of Ciudad Juárez will be 7 million in the year 2025." The purely subjective projection method, while suffering from a number of defects, is commonly used. Unfortunately, the results of such procedures are often quoted and sometimes become widely accepted as more scientific than subjective. The author of this chapter once participated, reluctantly, in a focus group organized to project the population of very small geographic areas in a city for transportation planning purposes. The essential idea of the project was to bring together a number of local experts to produce a consensus population forecast. When totaled, the projection for the city far exceeded the potential growth of the city as a whole.

The term "naïve model" is not as pejorative a reference as it may sound. There are many varieties of naïve models, but generally, such models start with a currently known value, such as the total population from the most recent census, and apply a recent growth rate, also based on census data, to the base value in order to calculate projected values.[3]

Naïve models have a number of advantages over purely subjective and more sophisticated methods. For example, naïve models are based on very few assumptions and these assumptions are usually stated explicitly or are obvious to the user. Naïve models are also inexpensive computationally and anyone can recalculate the projections using alternative assumptions with little more than a handheld calculator. Finally, naïve models often produce projections of population totals similar to those from more sophisticated methods. Indeed, many analysts who use more sophisticated projection methods check their results by comparing their own projections with naïve model comparisons. Nevertheless, naïve models suffer from some serious defects because they do not generally incorporate information on basic demographic processes (births, deaths, and migration) or information on economic and social trends that might directly affect demographic processes.

Econometric methods of population projection are based on the assumption that future population changes in a region are in part (or mainly) determined by the future behavior of key economic variables. Typical variables in this type of analysis are employment, unemployment, value added in manufacturing, and per capita income. Generally, such methods assume that migration is particularly sensitive to levels and changes of economic variables. For example, a common assumption is that people move toward areas of high per capita income and low unemployment and move away from areas of low per capita income and high unemployment. Economic migration models are based on the economist's usual assumption that potential migrants make rational economic decisions. Growing amounts of literature support a link between economic conditions and migration decisions.

Critics of econometric approaches to population projection point to the fact that economic variables are not the sole determinants of migration decisions. That is, people move for a variety of reasons including family ties, attractiveness of alternative locations, or major life-cycle events. Another common criticism of the use of econometric methods for population projection is that it is often more difficult to predict the future of the economic variable (e.g., unemployment) than to predict the size of a population itself.

The cohort-component method is based on the fundamental demographic equation:

$$P_t = P_{t\text{-}1} + B_{t\text{-}1\rightarrow t} - D_{t\text{-}1\rightarrow t} + I_{t\text{-}1\rightarrow t} - O_{t\text{-}1\rightarrow t}$$

where,
P_t = Population in time period t
$P_{t\text{-}1}$ = Population in time period t-1
$B_{t\text{-}1\rightarrow t}$ = Births from time period t-1 to time period t
$D_{t\text{-}1\rightarrow t}$ = Deaths from time period t-1 to time period t
$I_{t\text{-}1\rightarrow t}$ = In-migration from period t-1 to time period t
$O_{t\text{-}1\rightarrow t}$ = Out-migration from period t-1 to time period t

The components in the cohort-component method refer to births, deaths, and migration. The term cohort refers to a group of people with a common characteristic such as age or sex. In the cohort component method, each component of demographic change (births, deaths, and migration) is projected separately for specific cohorts. For example, projections of births, deaths, and migration are often calculated for five-year age and sex groups (cohorts). The projection of total population is then a simple process of adding up the projections for the various cohorts.

The cohort-component procedure has a number of advantages over other methods and is the procedure generally preferred by demographers. This procedure, for example, is based directly on the three basic demographic processes (fertility, mortality, and migration). The cohort-component procedure generates projections of the cohorts as well as the total population. The cohort-component procedure can be combined with other methods. For example, projections of migration based on an econometric model can easily be combined with demographically based projections of births and deaths (hybrid models).

Compared to naïve models and some econometric models, the cohort-component procedure requires more data and is sometimes more computationally intensive, but modern computing technology has virtually eliminated data and computational intensity as a valid criticism of the cohort-component technique. A more serious criticism at the regional and local levels is that the detailed data on fertility and mortality rates that the cohort-component method requires are sometimes not available, requiring researchers to use national or state trends for these critical variables.

No matter which technique is used, there are a number of useful cautions about population projections[4]. First, the probability of producing population projections that are identical in all respects to actual future values is essentially zero. Second, the difficulty of projecting population usually increases as the size of the geographic area and the size of the population base increase. Third, the uncertainty associated with population projections increases as the length of the time horizon of the projection increases. Fourth, the baseline data on which population projections depend are never without error. Finally, human behavior is extraordinarily complex and highly irregular. All three components of demographic change are subject to a great deal of variation over time.

The B+20 Population Model

The population sub-sector is a critical component of the Border Plus Twenty Years Project (B+20) modeling system. While all the sub-sectors are interrelated in some fashion, it is literally the case that if the border region population were stable or declining, there would be little interest in border region environmental or quality of life issues. As a result, the population sector was one of the first to be discussed by the core modeling group and among the first to be implemented in the El Paso-Ciudad Juárez prototype model.

After much discussion, the modeling team concluded that the population sector modeling effort should be based on the following criteria:

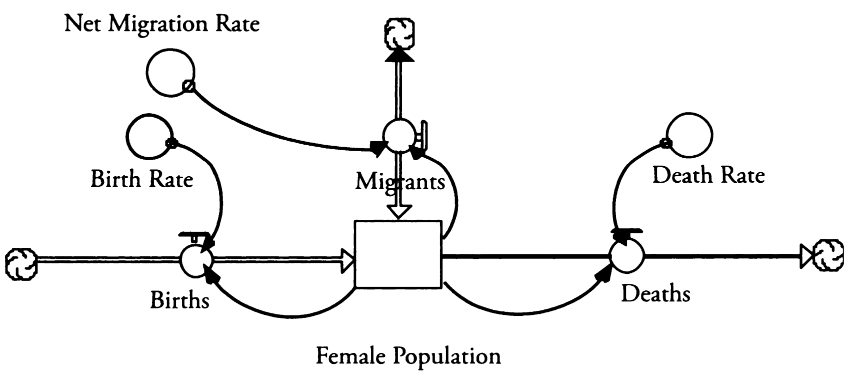
- An expectation that the resulting model was capable of producing realistic benchmark projections of population in a binational metropolitan area
- The structure and parameters of the models should be easily understood by potential users who would not necessarily have a background in demographic analysis

- The basic structure of the model, as implemented in the El Paso-Ciudad Juárez prototype, should be easily adapted to other border twin cities
- The model should reflect the three basic demographic processes of fertility, mortality, and migration in a binational context
- The migration component of the model should be linked in some fashion to economic conditions—such as wage differentials—in the cities under consideration

Consistent with these criteria, the population sub-sector consists of single-year-of-age cohort component models. For each twin city, such as El Paso-Ciudad Juárez, there are four population sub-models. The first two models project population by age and sex for Mexico and the United States at the national levels. The same national models are used for each twin city. Two additional population models project population by age and sex for each twin city. In each of the four cases, the model can also produce population totals or sub-totals of particular age-sex groups.

An easy way to understand the population models is a guided tour of the following diagram (Figure 1), which depicts a general demographic process and not the specifics of the Paso del Norte population models. Details of these models are discussed later.

Figure 1. A General Demographic Process



Source: Author

While this diagram may appear complex, it is really very simple. The square box in the middle of the diagram represents the female population of an area. This box indicates a stock. The arrows going into and out of the box (stock) represent flows. How does the stock change? Fluctuations in the number of people—in this case, females—arise from three sources: fertility, mortality, and migration. In this case, fertility is represented by a flow (circle with a valve) into the population stock. The number of births added to the stock depends on the current population—notice the arrow from the population stock to the flow of births and birth rates—also connected to the flow of births by an arrow.

The other two demographic processes work in a similar, but not identical, way. Notice, for example, that the flow of deaths is in the opposite direction from the flow of births. Deaths depend on the current size of the population and death rates. Migration—look at the top of the population stock—differs from the flow of births and deaths because it is a bidirectional flow. An important feature of the model is that users can quickly and easily adjust the baseline birth, death, and migration rates.

The diagram describes the essential features of the population models in the Paso del Norte model, but some important details have been ignored. First, the single box representing population in the diagram above is misleading. The Paso del Norte population models contain many such population boxes. For example, the national population box for Mexico contains 100 boxes for the female population and another 100 boxes for the male population. Further, the circles representing birth, death, and migration rates are also age and sex specific. That is, there are birth, death, and migration rates for each single year of age by sex. In short, there are approximately 2,400 values of baseline parameters for the four population models.

The base year population data for all four models are from the U.S. and Mexican national population censuses conducted in 2000 (U.S. Bureau of the Census 2002; INEGI 2001a, 2001b). For the United States, age-specific birth and death rates were obtained from the National Center for Health Statistics (2002a, 2002b). U.S. migration rates were obtained from the U.S. Bureau of the Census's population projection documents (U.S. Bureau of the Census 1996, 2000). The migration rates were adjusted to reflect the 2000 census population numbers.

For Mexico, the age-specific birth rates were derived from census data. The Mexican census provides age-specific birth rates for five-year cohorts. The five-year cohort rates were interpolated and smoothed to obtain single-year rates. Mexican death and migration rates were obtained from the Consejo Nacional de Población.

Projection accuracy is not necessarily the most important aspect of the B+20 model. The model emphasizes relationships among sectors and feedback effects so that policymakers can examine different long-run scenarios and policy options. Nevertheless, the benchmark population projections from the B+20 model are well within the range of other published projections. As can be seen in Table 2, the projections at the national level for both Mexico and the United States closely approximate the medium projections of the United Nations. Table 3 contains similar comparisons for both El Paso and Ciudad Juárez. Again, the B+20 model projections are reasonably close to the medium variant of the other projections.

Table 2. National Population Projection Comparisons for 2020

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mexico	117,228	125,176	133,137	122,089
United States	332,033	344,270	356,530	344,618

Note: B+20 model projections are baseline projections from the Paso del Norte model run of 13 February 2004.
Source: United Nations 2003

Table 3. El Paso and Ciudad Juárez Population Projections for 2020

City	PW Low	PW Medium	PW High	B+20 Model
El Paso	733,525	766,388	808,250	801,073
Ciudad Juárez	1,644,206	2,019,855	2,348,576	1,901,120

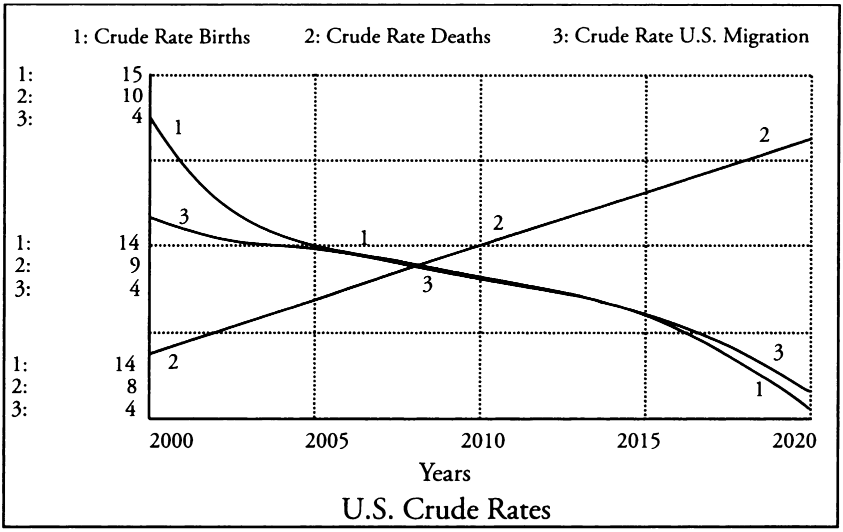
Note: Peach-Williams (PW) (Low, Medium, and High) projections were produced by James Peach and James Williams of New Mexico State University. The PW projections will be released in a forthcoming SCERP document.
Source: Author

The demographic models also demonstrate the importance of analyzing changing age-sex distributions. Consider, for example, the crude birth, death, and migration rates displayed in Figure 2. The crude birth and death rates decline over the 20-year projection period while the crude death rate increases. What accounts for these non-linear changes in crude rates? The answer is a changing age-sex distribution. Recall that a crude rate expresses the number of births, deaths, or migrants per 1,000 people. Even if age-specific rates, such as the probability of dying at a particular age, remain constant, the crude rates will change if the population is aging. In other words, the upward trend in the crude death rate occurs because the population is getting older and not because people of a given age are dying more frequently. Capturing the age-sex dynamics is important because many other critical variables in the model (including labor force participation) are also age-dependent.

Links to Other Sectors

Direct and indirect links between the population sector and nearly all other sectors of the B+20 model are apparent in the overall flow diagram. In many cases the links are bi-directional, reflecting the fact that population change affects other sectors (for example, the growth of total population is an important determinant of both residential and industrial water use), as well as the fact that other sectors affect the growth of the region's population (for example,

Figure 2. U.S. Crude Rates



Source: Author

economic expansion in one city may affect population growth in the other city). It is not possible or desirable to discuss all the links, but some of the more important are described below.

At the national level, population by age and sex is the basis for labor force calculations in the economic sector. In turn, economic conditions in the two nations directly affect the flow of migrants from Mexico to the United States. Because national economic conditions affect economic conditions in border cities, the national level population data also affect local economic conditions.

At the city level, the economic and population sectors are linked in several ways. As in the national models, city population size and its age-sex distribution are used to derive the size of a city's labor force and potential employment. Because total output in the economic sector is a function of the size of the labor force and size of the capital stock, population growth or decline has a direct impact on each city's total output. Because total population is also a critical input into total employment, the population sector is also directly linked to output per worker in each city. In turn, the relative output per worker in each city is linked directly to migration flows from one city to another.

In addition, population is a critical input into the water, land use, air quality, and quality of life sectors. The relationships between these sectors are often subtle and indirect. For example, an increasing population will increase water consumption, possibly resulting in a water supply gap in one or both cities. A water supply gap may result in a decrease in regional economic activity, which may subsequently reduce migration flows to the area. In brief, the population sectors of the model affect, and are affected by, all other sectors of the model.

Endnotes

[1] Mexico's population was 7.35 times as large in 2000 as it was in 1900. The U.S. population was 3.77 times as large in 2000 as it was in 1900.

[2] Demographic momentum—the tendency of a population to grow due to its age-sex distribution even in the face of declining fertility rates—suggests that Mexico's population will continue to grow substantially during the first decade or two of this century.

[3] A common variation of the naïve model is the so-called ratio method, in which a local area population projection is constructed from an existing projection of a larger area. For example, projections for a city that currently contains about 5% of its state population could be derived from a state-level projection by assuming that this ratio will remain relatively constant.

[4] See the discussion in: Peach and Williams. 1987. *Projections of the Population of New Mexico Counties by Age and Sex: 1980–2020.* Las Cruces, N.M.: New Mexico State University.

[5] A crude rate expresses the number of births (deaths or migration) per 1,000 people. Crude rates should not be confused with age-specific birth rates or total fertility rates.

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II-4

The Economies of El Paso and Ciudad Juárez

Christopher A. Erickson

Abstract

Any model that seeks to explain the interaction between human populations and the environment must take into account economic activity. For a given population, the level of economic development will determine the impact of human activity on the environment. Pollution generated from mining, manufacturing, and traffic is an example of how economic development can adversely affect the environment. Moreover, the higher per capita incomes associated with economic development generates demand for imports from developing countries, thereby increasing pollution in those countries.

Economic development has positive implications for the environment as well. With higher incomes people demand greater quality of life, one aspect of which is an improved environment. Indeed, it is axiomatic among development economists that people concerned literally with providing adequate nutrition for their families will not be interested in diverting resources to protecting the environment (this result arises as a straight-forward application of Maslow's Hierarchy of Needs). Economic development creates resources that can be used to deploy mitigating technology, such as smoke stack

scrubbers and sewage treatment plants. It is no coincidence that environmental laws are stronger and more strictly enforced in developed countries than in developing countries.[1]

The complicated interaction between the environment and economic activity is evident in the Paso del Norte region. Environmental stresses originating in one region influence environmental quality in others. The consequence of rapid economic growth in Ciudad Juárez, Chih., for example, has been the deterioration of air quality in El Paso, Tex., ultimately resulting in El Paso being designated by the U.S. Environmental Protection Agency (EPA) as a nonattainment zone for three criteria pollutants (ozone, particulate matter, and carbon monoxide). That is, economic development in the relatively low-income Ciudad Juárez has resulted in unacceptably high pollution in relatively high-income El Paso.[2] Water quality in the two cities is similarly linked.

This chapter develops a model for the El Paso-Ciudad Juárez border economy as part of the larger Border Plus Twenty Years (B+20) Project. Indeed, the economy is the driver behind the evolution of the other sectors of the model. A description of the El Paso and Ciudad Juárez economies is herein provided. Overall characteristics of the border economy are discussed. Particular emphasis is placed on the connections between the local and national economies, and between the U.S. and Mexican economies. The final section addresses documentation of the Paso del Norte economic model. A simple production function is specified, the labor market is modeled, and a reduced-form equation for the production function is derived. As is shown, the dynamics of production depends on the trajectory of population and the unemployment rate. The unemployment dynamics are modeled through the introduction of the business cycle. Further refinements of the model are discussed, including the modeling of employment by industry.

Las Economías de El Paso y Ciudad Juárez

Christopher A. Erickson

Resumen

Cualquier modelo que busca explicar la interacción entre las poblaciones humanas y el medio ambiente debe tomar en cuenta la actividad económica. Para cualquier población, el nivel de desarrollo económico determinará el impacto de la actividad humana en el medio ambiente. La contaminación generada de la minería, manufactura, y el tráfico es un ejemplo de cómo el desarrollo económico puede adversamente afectar el medio ambiente. Además, los altos ingresos per capita asociados con el desarrollo económico generan demanda por importaciones de países en desarrollo, por lo tanto incrementando la contaminación en esos países.

El desarrollo económico también tiene implicaciones positivas para el medio ambiente. Con ingresos más altos las personas demandan mejor calidad de vida, un aspecto del cual es un medio ambiente mejorado. Ciertamente, es axiomático entre economistas de desarrollo que las personas preocupadas literalmente de proporcionar alimentación adecuada a sus familias no estarán interesadas en desviar recursos para proteger el medio ambiente. El desarrollo económico crea recursos que pueden ser utilizados para desplegar tecnologías atenuantes, como plantas de tratamiento de aguas residuales. No es una coincidencia que las leyes ambientales son más fuertes y más estrictamente aplicadas en países desarrollados que en países en desarrollo.

La interacción complicada entre el medio ambiente y la actividad económica es evidente en la región del Paso del Norte. Las presiones ambientales originadas en una región influencian la calidad ambiental en otra. La consecuencia de un rápido incremento económico en Ciudad Juárez, por ejemplo, ha significado el deterioro de la calidad

del aire en El Paso resultando ultimadamente en la designación por la Agencia de Protección Ambiental de los Estados Unidos (por sus siglas en inglés EPA), como una zona de no logro para tres contaminantes (ozono, materia particulada y monóxido de carbono). Esto es, el desarrollo económico en Ciudad Juárez, como una ciudad con un ingreso relativamente bajo, ha resultado en una alta contaminación inaceptable en El Paso, ciudad con un ingreso relativamente alto. La calidad del agua en las dos ciudades está unida similarmente.

Este capítulo desarrolla un modelo para la economía fronteriza de El Paso-Ciudad Juárez como parte del amplio Proyecto Frontera Más Veinte Años (F+20). Ciertamente, la economía es el motor detrás de la evolución de los demás sectores del modelo. En este trabajo también se proporciona una descripción de las economías de El Paso y Ciudad Juárez. Se discuten las características generales de la economía fronteriza. Se da un énfasis particular a las relaciones entre las economías de México y los Estados Unidos. La sección final aborda documentación del modelo económico del Paso del Norte. Se especifica una función de producción simple, se modela la fuerza de trabajo, y se deriva una ecuación de forma reducida para la función de producción. Tal y como se demuestra, las dinámicas de la producción dependen de la trayectoria de la población y del índice de desempleo. Las dinámicas de desempleo son modelados a través de la introducción del ciclo de negocio. De igual manera se discuten mejoras posteriores al modelo, incluyendo el modelado de empleo por industria.

The Economy of Paso del Norte

The Border

The U.S.-Mexican border region faces a unique set of circumstances that arises from the juxtaposition of two economies at very different levels of development. The border is 2,000 kilometers (km) long, stretching from San Diego, Calif.-Tijuana, B.C., on the Pacific coast to the Gulf of Mexico near Brownsville, Tex.,-Matamoros, Tam. It is the longest border between a developed and developing country in the world and is also the most frequently crossed. Adjusting for purchasing power parity, per capita income in the United States is about four times that of Mexico ($36,100 vs. $9,100).[3] The difference in per capita income leads to significant differences in important quality of life dimensions, as is obvious to even the most casual observer. Crossing the border from the United States to Mexico, one leaves a relatively prosperous developed country and enters a less-developed country. Living conditions are more crowded, the infrastructure is not as well maintained, and sanitation is poorer.

The situation is further complicated by the relative positions of the border communities within their respective countries (Erickson and Eaton 2001). The northern frontier of Mexico is characterized by the low incomes typical of developing countries, yet it is the wealthiest region in Mexico. La Frontera Norte is more industrial and more urban than most other regions of Mexico. On the other hand, the U.S. borderlands are among the poorest in the United States (Peach and Williams 2000). Per capita income is less than 80% of the national average and about 60% of the national average if San Diego is excluded. Unemployment is 50% greater than the national average. The poverty rate on the border is 25% compared to 13% for the United States as a whole.

All along the border are located a series of formal ports-of-entry. These serve as conduits for both commercial and migration flows, thereby creating economic opportunities (Forster and Hamlyn 2002). Most of the population on both sides of the border resides in communities that have developed around these ports-of-entry (Peach and Williams 2000). The largest of these are the twin cities of San Diego-Tijuana; Calexico, Calif.-Mexicali, B.C. (Imperial Valley); Nogales, Ariz.-Nogales, Son. (Ambos Nogales); El Paso, Tex.-Ciudad Juárez, Chih. (Paso del Norte); Eagle Pass, Tex.-Piedras Negras, Coah.; Laredo, Tex.,-Nuevo Laredo, Tam. (Dos Laredos); McAllen, Tex.-Reynosa, Tam.; and Brownsville-Matamoros.

Maquiladora Industry

Businesses often locate along the border to take advantage of the differences between the two countries in terms of wages and working standards. This is especially true of the maquiladora (or maquila) industry, which owes its existence to the exploitation of labor cost differentials between the United States and Mexico. A maquiladora is a facility that assembles components from parts manufactured by other firms, usually performing this task under contract with the original manufacturer. Because such assembly processes are typically labor-intensive, locating maquiladoras in low labor cost countries offers the potential for substantial savings for U.S. manufacturers. This, coupled with easy access to U.S. markets, makes the location of maquiladoras in Mexico, especially along the country's northern border, an attractive alternative to the operation of assembly plants in the United States.[4] Maquilas have become the pre-eminent form of industrial production along the U.S.-Mexican border.

Mexico's maquila program was formally initiated in 1965 as a means of attracting foreign investment, increasing exports, and fostering development, particularly along the border it shares with the United States. From the start, the program was criticized for its limited contribution to Mexican economic development. Maquiladoras used relatively few domestic intermediate goods and technology transfer to the rest of the Mexican economy was limited. At the same time, maquilas put substantial pressure on the Mexican infrastructure.

Before the signing of the North America Free Trade Agreement (NAFTA), all production generated in Mexican plants had to be returned to the originating country or exported to a third country. NAFTA initiated a two-phase change in the maquila program. During the first phase, from January 1994 to December 2000, maquilas continued to benefit from a waiver on Mexican import duties on raw materials and components, but also benefited from preferential duties on products satisfying NAFTA rules of origin (Coronado de Anda and Matulewicz 2003). Starting in 1994, the restrictions on the sale of maquila production domestically in Mexico were phased out. In 1994, maquilas were allowed to sell up to 55% of the value of the previous years' imports within Mexico. Thereafter the limit was increased by 5% until 2000, at which time the maquilas' restrictions on domestic sales ended (Watkins 1994).

The maquila industry is controversial. Many labor activists criticize the maquilas for the poor working conditions and low wages. Current salaries for laborers, who are often young women from the interior of Mexico, are less than $1.50 per hour.[5] Moreover, working conditions are inferior to those typically found in the United States, and living conditions are poor. Because the industry is not subject to U.S. labor laws, long workweeks, under-age employment, and dangerous working conditions are common (Dwyer 1994). Defenders of the maquila industry, while acknowledging that wages and working conditions in Mexican factories are low by U.S. standards, argue that wages are high compared to the country's interior and even higher when compared to many developing countries. Indeed, Mexico is not considered a low-wage country by international standards. Wages in the less-developed areas of East Asia, for example, are lower than in Mexico.

A more fundamental argument against maquilas is the role they play in Mexican development. In particular, in most cases, maquilas import materials from the United States and then export their production back to the United States. Often, even managerial and technical staffs are supplied from the United States. In essence, maquilas are extensions of U.S. corporate supply chains. Thus, there is little opportunity for backward links and forward links from the maquila sector to the rest of the Mexican economy (Sklair 1989). As a consequence, technology transfer is limited and economic development is slowed. The problem is acerbated by a deliberate policy of the Mexican government to maintain low wages in the maquila industry.[6] It is difficult to conceive of a policy more successful at promoting industrialization, yet less successful in promoting overall economic development, than the Mexican maquila program.

Another concern with the maquila industry is its impact on the environment. One of the major sources of air and water pollution in the border region's twin cities is the maquila industry. Many observers have pointed to environmental regulation as an important consideration in locating on the border. They argue that pollution-intensive industries seek to escape strict U.S. enforcement of environmental laws by relocating across the border to Mexico, where, it is argued, environmental regulations are less strictly enforced. In effect, the U.S. exports pollution to Mexico through the maquila industry.

On the other hand, transnational corporations look at all costs, not just regulatory costs, in deciding where to locate production.[7] Labor, transportation, material, administrative, and regulatory costs are all important considerations. Indeed, labor costs are traditionally the primary reason for locating production in Mexico. Moreover, while it is probably true that environmental laws are less strictly enforced in Mexico than in the United States, Mexico enforces environmental laws more strictly than many other developing countries. While there is some evidence at the margin of regulatory-induced industrial migration to the border, the effect is likely small compared to other factors.

The dominance of the maquila industry along the border represents a transition period in U.S.-Mexican trade between an era of high tariffs with little trade and the current era of NAFTA. NAFTA eliminated most tariffs on North American value-added products, thereby eliminating the special status enjoyed by the maquila industry. In essence, NAFTA transformed all Mexican manufacturing into maquilas (from the prospective of tariffs). Trade between the United States and Mexico has increased dramatically. Currently Mexico is the second largest trading partner of the United States, representing 9.5% of U.S. international trade. Some 75% of Mexican trade is with the United States. The dramatic increase in trade since the passage of NAFTA has increased the exposure of Mexico to the U.S. business cycle.

El Paso

El Paso, like other cities on the border, is characterized by low incomes, at least by U.S. standards. In 2000, per capita personal income was $18,535, which was 62.9% of national per capita income. Part of the reason for low per capita income is the high unemployment rate, which was at 8.7%, compared to 6.1% for the nation as a whole in November 2002.[8] A second reason for low earnings in El Paso is low salaries. In 2000, average earnings per job were 78.8% of the national average. A third factor is a higher dependency ratio—El Paso families tend to have more dependent children living at home, for example. More fundamentally, low incomes can be explained by low education levels, poor language skills, and racism that characterizes border communities.

Table 1 compares employment in El Paso to employment nationally by industry. The first column shows the share of employment by industry in El Paso, while the second column shows the same figure for the United States. The third column shows the difference between the two columns. Employment in agriculture and agriculture-related industries is less than the national average, but not out of line with other urban areas. El Paso employment shares exceed national averages in manufacturing and retail, as well as in transportation, public utilities, and communications (TPUC). Finance, insurance, and real estate (FIRE); general services; and government are approximately the same as the national average, although government employment is greater than average while employment in FIRE and general services is less than average.

The sensitivity of the El Paso economy to national business cycles is about average. Employment in cyclically sensitive industries—mining, construction, manufacturing, and TPUC—as well as in the cyclically insensitive industries such as FIRE, general services, and government, is about at the national average. Thus, factors driving the national business cycle in the national economy will also be present in the El Paso business cycle. One mitigating factor is the relative importance of oil and natural gas in the West Texas economy. This industry tends to be counter-cyclical, a fact that tends to mitigate the business cycle in El Paso. Countering this is the relative importance of textiles, which tend to be highly cyclical compared to other industries.

Anecdotal evidence would suggest that the concentrations in TPUC and retail are generated from transborder trade. Transborder drayage operations require increased warehouse and trucking services, which increases overall TPUC employment. Mexican shoppers, attracted by the greater variety and high quality of U.S. goods, tend to patronize retail establishments near pedestrian border crossings. To further explore these issues, detailed earnings data by industry are presented in Table 2.[9] Earnings within TPUC in El Paso exceed the national average in railroad transportation and for trucking and

Table 1. Comparison of Employment by Industry

Industry	Employment Share		
	El Paso	U.S.	Difference
Farm employment	0.30%	1.90%	-1.60%
Ag. services, forestry, fishing, and other	0.60%	1.30%	-0.70%
Mining	0.20%	0.50%	-0.30%
Construction	5.80%	5.70%	0.10%
Manufacturing	12.00%	11.40%	0.60%
Transportation and public utilities	5.80%	4.90%	0.90%
Wholesale trade	4.50%	4.50%	0.00%
Retail trade	17.20%	16.30%	0.90%
Finance, insurance, and real estate	6.20%	8.10%	-1.90%
Services	26.90%	31.80%	-4.90%
Government and government enterprises	20.50%	13.60%	6.90%
Total full-time and part-time employment	100.00%	100.00%	0.00%

Source: U.S. Bureau of Economic Analysis

warehousing, consistent with the theory that transportation employment arises from activity associated with the border. (Earnings within TPUC also exceed national averages in electricity, natural gas, and sanitation, which reflects the role of west Texas as a producer of natural gas.) Retail earnings are particularly strong in automobile sales, general merchandise, and miscellaneous merchandise—all categories in which Mexican shoppers are considered important customers. The earnings data, coupled with anecdotal evidence, points to the conclusion that above-average employment in TPUC and retailing is driven by transborder trade.

Table 2. Comparison of Earnings Share by Industry

Industry	El Paso	U.S.	Difference
Transportation communications and public utilities	8.31%	6.80%	1.51%
Railroad transportation	0.72%	0.23%	0.49%
Trucking and warehousing	2.48%	1.43%	1.05%
Water transportation	0.00%	0.15%	-0.15%
Other transportation	0.00%	1.65%	-1.65%
Local and interurban passenger transit	0.23%	0.23%	0.00%
Transportation by air	0.59%	0.99%	-0.39%
Pipelines, except natural gas	0.00%	0.02%	-0.02%
Transportation services	0.46%	0.41%	0.05%
Communications	1.88%	2.13%	-0.25%
Electric, gas, and sanitary services	1.93%	1.22%	0.71%
Retail trade	10.17%	8.70%	1.46%
Building materials and garden equipment	0.37%	0.51%	-0.14%
General merchandise stores	1.30%	0.93%	0.37%
Food stores	1.28%	1.24%	0.04%
Automotive dealers and service stations	1.79%	1.45%	0.33%
Apparel and accessory stores	0.49%	0.40%	0.08%
Home furniture and furnishings stores	0.52%	0.60%	-0.08%
Eating and drinking places	2.56%	2.03%	0.54%
Miscellaneous retail	1.85%	1.53%	0.32%

Source: Bureau of Economic Analysis

Ciudad Juárez

Ciudad Juárez is wealthy compared to Mexico as a whole, primarily because of the maquila industry, which is located there because of the city's proximity to the border. About 25% of all Mexican maquila employment is located in Ciudad Juárez.[10] The Ciudad Juárez maquila industry has long been characterized by labor shortages. As a consequence, unemployment in Ciudad Juárez averages only 52% of the Mexican national average. The industry provides a large number of jobs. Maquiladoras in Ciudad Juárez employed 289,000 people in 2001, of which 265,000 were hourly employees *(obreros)* and 24,000 were salaried employees *(empleados)*. The median wage paid is $7,800 per year for hourly employees and $30,000 per year for salaried employees.

The maquila industry has recently fallen on hard times. Employment peaked in October 2000 and had declined by 25% by September 2002. The cause of the decline is controversial—different authorities point to different causes. One reason given is the slowing in the U.S. economy. However, the sharp decline in maquila production seems excessive given the relatively mild decline in the U.S. economy. Many observers believe that a major cause of the employment decline in Ciudad Juárez has been the loss of maquiladoras to China as a result of its entry into the World Trade Organization (WTO). The significance of this is difficult to assess. It is true that employment declines occurred during previous recessions, between 1983 and 1984 (6%) and 1990 and 1991 (9%), although those declines were for a shorter duration and were smaller in magnitude.

The Model

Basic Structure of the Model

The comprehensive approach envisioned by the Border Plus Twenty Years (B+20) Project requires compromises in the development of any one sector of the model for the overall model to be operational. Because the emphasis is on the interactions among the sectors, internal details of a given sector model are downplayed. These sorts of compromises are evident in the economy sector model described here. The model consists of a simplified production function coupled with a labor market and highly stylized business cycle. On the other hand, the model recognizes transborder interaction between national and local economies and through the inclusion of four sub-sectors—the United States and Mexico at the national level, and El Paso and Ciudad Juárez at the local level. This allows for a more detailed modeling of transborder economic interactions than is typical of most modeling efforts.

Economists have developed a number of models for evaluating an aggregate economy. Selecting a model to use in a given setting depends on the goal. In the context of the B+20 project, which seeks to evaluate the effects of various policies over a 20-year period, a relatively simple model that still captures the essence of long-run economic dynamics is needed. A model that achieves these goals is Solow's neoclassical growth model (see, for example, Jones 2002). The Solow growth model assumes that the economy uses two inputs—capital and labor—to produce a single product.[11]

The production function, which specifies the relationship between capital and labor inputs and production, is given by Equation 1:

$$Y_{it} = F(E_{it}, K_{it}, A_{it})$$

where,
Y_{it} = production per period
E_{it} = number of workers employed in production
K_{it} = the capital stock
A_{it} = a parameter-capturing technology[12]

Here, as well as in the rest of the chapter, the subscript $i \in \{US, Mex, EP, CJ\}$ indicates the sub-sector in which production takes place, and the subscript t = (1,2,3,...T)indicates the time period. Equation 1 says that production depends on employment, capital stock, and technology.

Operationalizing the model requires that a functional form for the production function be specified. Here, in Equation 2, it is assumed that production function in Equation 1 is Cob-Douglas:

$$Y_{it} = A_{it} K_{it}^{\beta} E_{it}$$

where,
Y_{it} = a parameter indicating the effect of capital deepening on labor productivity

The next step in operationalizing the model is to specify the accumulation rules for the stock variables of the model—A_{it}, K_{it} and E_{it}. Ideally, accumulation rules would be specified for each of the three stock variables. Unfortunately, reliable data for the capital stock are not available at the local level for El Paso and Ciudad Juárez, nor are they available at the national level for Mexico. Moreover, even for the United States, for which better data are available, disentangling the effects of capital deepening and technological progress on labor productivity is notoriously difficult. Therefore, a strategy of modeling labor productivity directly is adopted in Equation 3:

$$\alpha_{it} = A_{it} K_{it}^{\beta}$$

where,
α_{it} = labor productivity

Equation 3 says that labor productivity depends on two factors: technological progress, which is captured by A_{it}, and capital deepening, which is captured by K_{it}. α_{it} is assumed to increase at an exogenously determined rate, g_i. That is, $\alpha_{it} = (1+g_i)^t \alpha_{i0}$. The initial level of productivity, α_{i0}, is set to be consistent with the initial calibration of the model, i.e., $\alpha_{i0} = Y_{i0}/E_{i0}$.

Turning to the labor market, the following identity describes the relationship between the labor force, employment, and unemployment:

$$L_{it} \equiv E_{it} + U_{it}$$

where,
L_{it} = labor force
U_{it} = number of unemployed workers

Equation 4 says that, by definition, a labor force participant is either employed or not employed but seeking work. Those in the second category are considered unemployed. A person who is neither employed nor seeking work is not a labor force participant. The labor force is assumed to depend on population:

$$L_{it} \equiv \lambda_i P_{it}$$

where,
P_{it} = population
λ_i = the crude labor force participation rate

Substituting Equation 5 into Equation 4 and rearranging yields Equation 6:

$$E_{it} = (1-u_{it})\lambda_i P_{it}$$

where,
$u_{it} = U_{it} / L_{it}$= unemployment rate

Equation 6 indicates that the number of employed workers depends on population, the crude labor participation rate, and the rate of unemployment. Substitution of Equation 6 into Equation 2 results in the following, Equation 7:

$$Y_{it} = (1+g_{it})^t \alpha_{0t}(1-u_{it})\lambda_i P_{it}$$

This shows that the dynamics of production are driven by the population trajectory and the rate of unemployment. The population trajectory is taken from the demographic sector of the B+20 model. The rate of unemployment is determined by the business cycle, which is discussed in detail in the next section. Equation 7 also shows that to calibrate the model requires determining the value of g_i, α_{0i}, and λ_i. The values for these variables are given in Table 3.

Table 3. Initial Values Used to Calibrate the Simulation Model

Symbol	Variable	Value
g_i	Annual Productivity Growth	
	El Paso	2%
	Ciudad Juárez	2%
	United States	2%
	Mexico	2%
α_{Oi}	Initial Productivity	
	El Paso	50.00
	Ciudad Juárez	20.00
	United States	73.30
	Mexico	17.66
λ_i	Labor Force Participation Rate	
	El Paso	41%
	Ciudad Juárez	48%
	United States	51%
	Mexico	56%
U_{Nation}	Full Employment/Unemployment	
	United States	5%
	Mexico	5%
$\varphi_{i,i}$	Unemployment Sensitivity to an Employment Shock	
	United States/United States	1
	Mexico/Mexico	1
	Mexico/United States	1
$\Psi_{Local,National}$	Local Unemployment Sensitivity to National Unemployment	
	El Paso/United States	0.75
	Ciudad Juárez/Mexico	0.50
θ_{ij}	Industry Share	
	El Paso manufacturing	12.0%
	El Paso trade	24.7%
	El Paso other	66.3%
	Ciudad Juárez maquial	64.6%
	Ciudad Juárez trade	30.4%
	Ciudad Juárez other	15.0%

Source: Author

Business Cycles

The trajectory of the unemployment rate is determined by the business cycle. The business cycle, in turn, is modeled by assuming that recessions arrive at random intervals. This strategy was chosen for three reasons. First, there are theoretical reasons to believe that business cycle peaks and troughs are random events (Hall 1978). Second, several empirical studies have found that modeling the behavior of business cycles as random events is not inconsistent with the actual experience of the U.S. economy (e.g., Neftci 1984). Third and most important, developing a more complete business cycle model would be difficult and arduous yet would not enhance the usefulness of the economy sector to the B+20 Project.

A separate business cycle is developed for each of the sub-sectors. For the United States, the unemployment rate is given by Equation 8:

$$u_{USt} = u_{US} + \varphi_{US} D_{USt}$$

where,
u_{USt} = U.S. unemployment rate in period t
u_{US} = U.S. full employment rate of unemployment
φ_{US} = a coefficient indicating the magnitude of the business cycle
D_{USt} = a dummy variable indicating an employment shock in the form of a U.S. recession[13]

Equation 8 says that U.S. unemployment will be u_{US} percent, except during recessions, when it is $u_{US} + \varphi_{US}$ percent. Consistent with historical experience, the probability of a recession is set at 20% per year and the duration of recessions when they occur is set to one year.

The business cycle for the Mexican national sub-sector is assumed to consist in part on an internal component and in part on the status of the U.S. business cycle:

$$u_{Mext} = u_{Mex} + \varphi_{Mex} D_{Mext} + \varphi_{Mex,US} D_{USt}$$

where,
$u_{Mex,t}$ = Mexican unemployment rate in period t
u_{Mex} = Mexican full employment rate of unemployment
$D_{Mex,t}$ = a dummy variable indicating an employment shock originating domestically in Mexico[14]
φ_{Mex} = a coefficient indicating the sensitivity of the Mexican unemployment rate to Mexican employment shocks
$\varphi_{Mex,US}$ = a coefficient indicating the sensitivity of the Mexican unemployment rate to U.S. employment shocks

Equation 9 indicates that the Mexican unemployment rate depends on the status of the Mexican and U.S. business cycle. If neither economy suffers an employment shock, Mexican unemployment is at its full employment value, u_{Mex}. An employment shock to the Mexican economy increases Mexican unemployment by φ_{Mex} percent. An employment shock in the U.S. economy increases Mexican unemployment by $\varphi_{Mex,US}$ percent. The effects of U.S. and Mexican employment shocks are cumulative. The probability of a domestic employment shock in Mexico is set at 10% and it is assumed to be one year in duration.

Unemployment at the local level is assumed to depend on the unemployment in the respective national economy. Let $u_{EP,t}$ be unemployment in El Paso, and let $u_{CJ,t}$ be unemployment in Ciudad Juárez. Then Equations 10 and 11 are:

$$u_{EPt} = \psi_{EP,US} u_{USt}$$

$$u_{CJt} = \psi_{CJ,Mex} u_{Mext}$$

where,
$\psi_{EP,US}$ = sensitivity of El Paso unemployment rate to changes in U.S. unemployment rate
$\psi_{CJ,Mex}$ = defined similarly

Examination of Equations 8 through 11 shows that calibration of the model requires values for u_{US}, u_{Mex}, φ_{US}, φ_{Mex}, $\gamma_{Mex,US}$, $\psi_{EP,US}$, and $\psi_{CJ,Mex}$. These values are given in Table 3.

Further Refinements

Because employment in different industries may have different effects on the environment, especially on air quality, the model of employment is further refined to include employment by major industry. To accomplish this, employment in each industry is assumed to be a fraction of total employment:

$$E_{ijt} = \theta_{ijt}E_{it} = \theta_{ijt}(1-u_{it})\lambda_i P_{it}$$

where,
E_{ijt} = employment in region i by industry j in time period t
θ_{ijt} = share of total employment of the industry

The second equality in Equation 12 makes use of Equation 5. The industries modeled for Ciudad Juárez include maquila, retail and wholesale trade, and other; for El Paso the industries modeled include manufacturing, retail and wholesale trade, and other.

The trajectory of θ_{ijt} varies by industry. For each industry, θ_{ijt} consists of two components: a fixed share based on the long-term share of employment of that industry (denoted by $\bar{\theta}_{ijt}$), and an adjustment factor for the sensitivity of the industry to the business cycle (denoted by η_{ijt}). Thus, the trajectory of θ_{ijt} is given by Equation 13:

$$\theta_{ijt} = \bar{\theta}_{ijt}\eta_{ijt}$$

Table 4 gives the formula for the adjustment factor for each of the six industries included in the model. For the maquila industry, the adjustment factor is assumed to depend on employment growth in the U.S. and Mexican national economies. Given the export orientation of the maquila industry, the effect of the growth in the United States is given a greater weight than Mexican growth. The Ciudad Juárez trade sector adjustment is assumed to depend on growth of Mexican employment and on growth of maquila employment. Both the adjustment factor for El Paso manufacturing employment and El Paso trade employment are assumed to depend on growth employment in the Ciudad Juárez maquila industry.

Finally, other employment in both Ciudad Juárez and El Paso are assumed to track the general business cycle. That is, the adjustment factor for other employment in both cities is unity.

Table 4. Industry Cyclical Adjustment Factor

El Paso manufacturing	= 1 + % Δ Maquila Employment
El Paso trade	= 1 + % Δ Maquila Employment
El Paso other	1
Ciudad Juárez maquila	= 5 x % Δ U.S. GDP + % Δ Mex GDP
Ciudad Juárez trade	= % Δ Maquila Employment + % Δ Mex GDP
Ciudad Juárez other	1

Source: Author

Summing employment by industry determines adjusted total employment in Equation 14:

$$E'_{it} = \sum_i E_{ijt} = \sum_j \bar{\theta}_{ij}\eta_{ijt}(1 - u_{it})\lambda_1 P_{it}$$

where,
E'_{it} = adjusted employment

Given that each η_{ijt} is a function of national employment, which in turn each depend on the national unemployment rates, it follows from Equation 14 that E'_{it} is a nonlinear function of the national unemployment rates. Using Equations 6 and 12 through 14 allows recovery of the El Paso and Ciudad Juárez unemployment rates in Equation 15:

$$u'_{it} \equiv \frac{U'_{it}}{L_{it}} = \frac{L_{it} - E'_{it}}{L_{it}} = \frac{\lambda P_{it} - \sum_j \bar{\theta}_{it}\eta_{ijt}(1 - u_{it})\lambda_1 P_{it}}{\lambda_1 P_{it}} = 1 - \sum_j \bar{\theta}_{it}\eta_{ijt}(1 - u_{it})$$

where,
u_{it} = adjusted unemployment rate

U'_{it} = adjusted unemployment

Substituting Equations 11 through 13 into Equation 3 yields Equation 16:

$$Y_{it}' = (1+g_i)^t \alpha_{0t} \sum_j \bar{\theta}_{ij} \eta_{ijt} (1-u_{it}) \lambda_1 P_{it}$$

where,
Y'_{it} = adjusted production

Equation 16 says that production in El Paso and Ciudad Juárez is a nonlinear function involving population, the status of the adjustment factor for each of the six industries, and the status of the Mexican and U.S economies. Evaluation of Equation 16 reveals that in addition to the values previously specified, calibration of the model requires values for $\bar{\theta}_{ij}$, which are given in Table 2.

Endnotes

[1] The complicated interaction between economic development and the environment is summarized in the relationship referred to as the Environmental Kuznets Curve (EKC), which supposes an inverted-U relationship between development and pollution. The EKC assumes three stages of development. In the initial stage of development, increased economic activity results in increased pollution as production is shifted from relatively benign traditional agriculture toward industrial production. In the later stage, pollution drops as stricter enforcement of environmental standards take effect. At the middle stage of development, a balance is struck between increasing industrialization and increasing environmental enforcement so that pollution levels peak. There are two versions of EKC. The first version, for which there is strong evidence, measures pollution per unit of gross domestic product (GDP). The second version, for which there is weak or contradictory evidence, measures pollution in absolute terms. The failure of EKC in absolute terms means that economic

development, as measured by GDP, will generally result in environmental degradation. For further discussion of EKC, see Wheeler 2001.

[2] It might be argued that nonattainment status is determined by the U.S. Environmental Protection Agency (EPA) in accordance with federal law, therefore, it does not necessarily reflect local tastes for environmental quality. Rather, nonattainment status is based on national standards. Nevertheless, the basic argument still holds: Low environmental standards in the low-income community results in the compromise of standards in the high-income community.

[3] These are estimates for 2000, according to the CIA World 2002 Fact Book available at http://www.cia.gov/cia/publications/factbook/index.html.

[4] An important additional incentive for locating maquilas in Mexico is the favorable duty treatment that North American content enjoys under NAFTA.

[5] This number is derived from data provided by INEGI (www.inegi.gob.mx) in 2003 and is based on the author's calculations. The figure assumes an exchange rate of 10 pesos to the dollar and includes the value of fringe benefits.

[6] Generally speaking, wages in Mexico are not determined in the market. Instead, wages are set by negotiation between semi-official labor unions and the federal government. Thus, the central government has considerable influence over wages.

[7] If this was not true then all maquilas would relocate from Mexico to, say, Indonesia, where wages are far lower.

[8] The source of this section is the U.S. Bureau of economic activity.

[9] The detail presented in Table 2 is not available for employment at the SMA level.

[10] All data reported in this section are taken from www.inegi.gob.mx.

[11] The single output can be thought of as consisting of units of gross domestic product at the national level or as units of personal income at the regional level.

[12] A clarification concerning stocks verses flows is appropriate at this point. The STELLA® modeling software treats Y_{it}, A_{it}, K_{it} and E_{it} as stock variables. From an economic point of view, however, Y_{it} is a flow variable (e.g., income per year). Care needs to be taken to avoid confusion.

[13] That is, $D_{it} = \begin{cases} 1 & \text{if recession in economy.} \\ 0 & \text{otherwise.} \end{cases}$

[14] See footnote 12.

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II-5

Modeling Water Availability and Use in the Paso del Norte Region

Craig B. Forster and Edwin J. Hamlyn

Abstract

Water used by the Paso del Norte urban and agricultural communities is obtained from surface flows in the Rio Grande/Río Bravo and groundwater from the Hueco and Mesilla Bolsons (aquifers). This chapter outlines the key links involved in a system model sector that represent how water is obtained from the hydrologic system and used in urban and agricultural activities that, in turn, affect the quality of life in Paso del Norte. The systems thinking approach outlined in Chapter I-1 has been adopted for this chapter. The focus here is only on the key features of the water sectors and the way they might be affected by future climate variability. This chapter outlines in narrative form the general characteristics of the water sectors and provides detail about how the narrative is quantitatively represented in the Border Plus Twenty Years (B+20) model. Overviews of the water-related aspects of the Paso del Norte region are provided by several authors (U.S. Bureau of Reclamation No Date; Winter, et al. No Date; Policy Research Project 1999; Turner 2000; Turner, et al. 2003) and form an important basis for the model's development. The general setting of Paso del Norte is outlined in Chapter II-1.

Modelado de la Disponibilidad y Uso del Agua en la Región Paso del Norte

Craig B. Forster y Edwin J. Hamlyn

Resumen

El agua usada por las comunidades urbanas y agrícolas del Paso del Norte es obtenida de flujos de la superficie en el Río Grande/Río Bravo y del subsuelo de los acuíferos de el Hueco y Mesilla Bolsons. Este capítulo delimita los lazos claves involucrados en un sector de sistema de modelo que representa cómo es obtenida el agua a través del sistema hidráulico y usado en actividades urbanas y agrícolas que, a su vez, afectan la calidad de vida en el Paso del Norte. El enfoque de sistema de pensamiento delimitado en el Capítulo I-1 ha sido adoptado para este capítulo. El enfoque aquí es solo en las características básicas de los sectores de agua y en la manera en que pueden ser afectadas por variables climáticas futuras. Este capítulo delimita en forma narrativa las características generales de los sectores de agua y proporciona detalles sobre cómo la narrativa es representada cuantitativamente en el modelo Frontera Más Veinte Años (F+20). Diversos autores proporcionan visiones generales de aspectos relacionados con el agua de la región del Paso del Norte y forman una base importante para el desarrollo del modelo. El escenario general del Paso del Norte se delimita en el Capítulo II-1.

Introduction

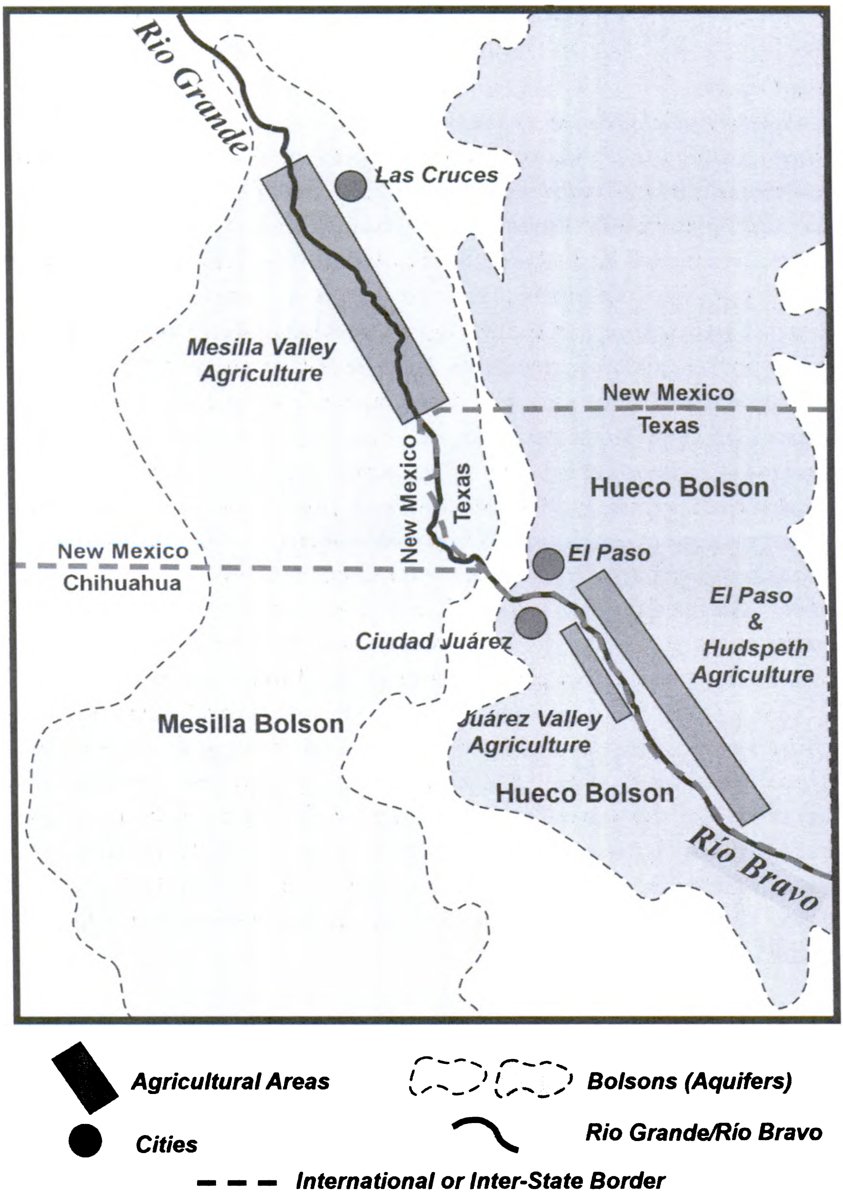
The geographic extent of the area incorporated in the model sector is shown in Figure 1. The principal aquifers (Hueco and Mesilla Bolsons) underlie much of Paso del Norte and form a critical source of water for the region. The Mesilla aquifer extends from north of Las Cruces, N.M., to well southwest of Ciudad Juárez, Chih.

Surface water originating in the upper watershed of the Rio Grande is used to support agricultural irrigation in both the United States and Mexico. Ciudad Juárez depends solely on groundwater pumped from the Hueco Bolson while El Paso, Tex., pumps water from both the Hueco and Mesilla Bolsons while also drawing water from the Rio Grande.

A schematic view of the key features and links in the model is shown in Figure 2. Water stored in the Elephant Butte and Caballo reservoirs (located upstream of Las Cruces) is released to the Rio Grande, principally during the agricultural growing season, and flows across the U.S.-Mexican border before leaving the area of interest at Fort Quitman, Tex. As the water travels downstream, some is withdrawn for use by agriculturalists; water not consumed in evapotranspiration processes is returned to the river as agricultural runoff. El Paso also withdraws water from the Rio Grande and returns treated wastewater to the river. During its travel downstream, the chemical quality of the water (represented in the model by the concentration of total dissolved solids) varies as evapotranspiration concentrates salts, irrigation water is withdrawn, and agricultural runoff and treated (or untreated) wastewater flows to the river. The Border Plus Twenty Years (B+20) water sectors quantitatively account for the flows of water and dissolved solids through both surface water and groundwater of the binational watershed.

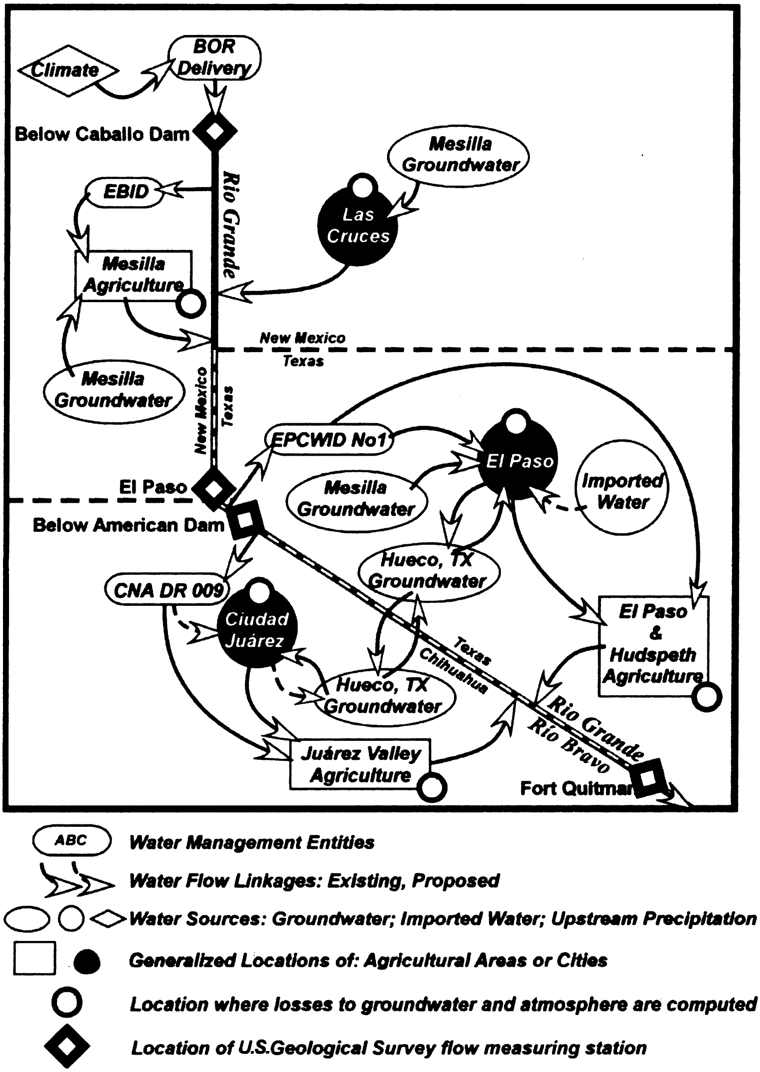
This chapter outlines in narrative form the general characteristics of the water sectors and the ways that water flows and water quality might vary over time as different policy options are enacted. Overviews of the water-related aspects of the Paso del Norte region are provided by several authors (U.S. Bureau of Reclamation No Date; Winter, et al. No Date; Policy Research Project 1999; Turner 2000; Turner, et al. 2003) and form an important basis for the model's development.

Figure 1. Map of Principal Water Sources and Water Use Areas in the Paso del Norte Region



Source: Modified from Paso del Norte Water Task Force 2001

Figure 2. Schematic of Links between Water-Related Elements of the B+20 Model



Note: Water management entities shown in the figure are: U.S. Bureau of Reclamation (BOR), Elephant Butte Irrigation District (EBID), El Paso County Water Improvement District No. 1 (EPCWID No. 1), and Comisión Nacional de Agua Distrito Regio 009 (CNA DR 009). Drawing is not to scale and only approximate locations are shown.
Source: Authors

The story of the water sector begins with the surface water that enters the model by flowing south in the Rio Grande (Figure 2). The annualized rate of flow is controlled by the U.S. Bureau of Reclamation (BOR) in response to the requests of downstream agricultural water users and climate variations that cause changes in the volume of water stored in upstream reservoirs such as Caballo and Elephant Butte, located 60 miles (97 kilometers [km]) and 80 miles (129 km) north of Las Cruces, respectively. The lack of precipitation (about eight inches, or 0.2 meters, per year) and high evaporation rates (about 100 inches, or 2.54 meters, per year) in Paso del Norte mean direct rainfall provides little water for either human use or groundwater recharge.

While flowing south, a portion of the river flow is delivered to the Mesilla Valley agricultural area where, in times of drought, surface flows may be augmented by groundwater pumped from the northern reaches of the Mesilla Bolson. With agricultural use, a portion of the water delivered to the Mesilla Valley is returned to the Rio Grande after seepage losses to the groundwater system and losses to the atmosphere by evapotranspiration. In the Mesilla Valley, salts leaching from the soil cause a higher level of total dissolved solids in the water returned to the river than was in the water originally obtained from the combined river and groundwater sources.

In the city of Las Cruces, water is pumped from the Mesilla Bolson in response to urban water demand. Strong population growth suggests that urban water use will increase even if future per capita consumption is reduced. After use, the water is treated and discharged to the Rio Grande to augment deliveries from upstream reservoirs and return flows from the Mesilla Valley agricultural area. Again, one sees that a portion of the water used in Las Cruces is lost to the groundwater system by seepage and to the atmosphere by evapotranspiration. Urban water use here also leads to an increase in the concentration of total dissolved solids in the water discharged to the Rio Grande.

After the Rio Grande delivers water from New Mexico to Texas, El Paso County Water Improvement District #1 (EPCWID No. 1) takes its share of river water but leaves the 60,000 acre-feet (~74 million m^3) per year promised under a treaty with Mexico. The bulk of EPCWID No. 1 water is delivered to agriculturalists in the counties of El Paso and Hudspeth. The agricultural water delivered directly from the Rio Grande is augmented by treated wastewater generated by the city of El Paso. With agricultural use, a portion of the water delivered to the El Paso and Hudspeth agriculturalists is returned to the Rio Grande, minus losses to the groundwater system through seepage and to the atmosphere through evapotranspiration. Here, too, salts leaching from the soil cause the total dissolved solids in the water returned to the river to be greater than that of the water originally obtained from the combined sources.

The city of El Paso obtains the bulk of its water by pumping fresh groundwater from the Mesilla and Hueco Bolsons. An increasing percentage of the water used, however, is surface water delivered from the Rio Grande by EPCWID No. 1. Future plans include the possibility of water being imported from another more distant watershed for use in El Paso. The El Paso Water Utilities (EPWU) Public Service Board is expanding the water available for use by developing the infrastructure needed for extensive water reuse and desalination of brackish groundwater pumped from the Hueco Bolson (El Paso Water Utilities Public Service Board 2004a). Rapid population growth suggests that urban water use will increase even in the face of a decline in per capita consumption. After use, the water is treated and one portion is returned to the Hueco Bolson while another portion is delivered for use by agriculturalists in El Paso and Hudspeth Counties. The remaining portion of the water used in El Paso is lost to the groundwater system by seepage and to the atmosphere by evapotranspiration. As is the case in Las Cruses, urban water use leads to an increase in the concentration of total dissolved solids in the water delivered to either the aquifer or the agricultural areas.

Once the Rio Grande/Río Bravo reaches the border between Texas and Chihuahua, the Comisión Nacional de Agua (CNA) Valle de Juárez Distrito Regio 009 (CNA DR 009) delivers the remaining river flow to the Juárez Valley agricultural area. A 1906 U.S.-Mexican treaty dictates that the flow across the border must be 60,000 acre-feet (~74 million m^3) per year. The agricultural water delivered directly from the Rio Grande is augmented by a mix of treated and untreated urban wastewater generated by Ciudad Juárez.

With agricultural use, a portion of the water delivered to the Juárez Valley agriculturalists is returned to the Rio Grande after seepage and evapotranspiration losses. Salt leaching here results in the same increase in total dissolved solids in the water returned to the river when compared to the water originally obtained from the combined sources.

The city of Ciudad Juárez obtains its water by pumping fresh groundwater from the Hueco Bolson. In the future, it may be possible for surface water to be delivered from Mexico's allotment of Rio Grande/Río Bravo water or for fresh groundwater to be obtained from the Mesilla Bolson. Strong population growth suggests that urban water use will increase—per capita consumption is not expected to decline. After use, some of the water is treated and delivered for use by agriculturalists in Juárez Valley. The remaining portion of this water is lost to seepage and evapotranspiration. This urban water use also leads to an increase in total dissolved solids in the water delivered to the agricultural area.

Both El Paso and Ciudad Juárez are drawing fresh water from the transboundary Hueco Bolson. In 2001, the Paso del Norte Water Task Force (2001) indicated that fresh groundwater in the Hueco Bolson might be depleted by 2020. More recent estimates that account for reduced pumping of the aquifer suggest, however, that the fresh groundwater should be sufficient to meet demand beyond 2030 (El Paso Water Utilities Public Service Board 2004a). The B+20 model is configured to represent two Hueco Bolson subaquifers—this can account for the interaction between wellfields located on each side of the border. Thus, the balance between pumping on each side of the border, moderated by the properties of the aquifer, dictates whether groundwater will flow from Mexico to the United States, or vice versa. As groundwater levels decline across the border, groundwater pumping costs increase. Neither is a trivial issue.

The growing population of Paso del Norte is causing water historically used for agricultural purposes to be redirected for urban use. Although agricultural activity is unlikely to be eliminated in the region, continued water transfers may lead to reduced agricultural production and a decline in the return flows that support surface water flows in the Rio Grande during the irrigation season.

Meanwhile, urban water managers want water to be released from upstream reservoirs throughout the year rather than just during the irrigation season. This would provide a seasonally consistent surface water supply. Shifting the pattern of upstream water releases might provide support for the riparian systems that could benefit from higher instream flows than are currently typical of the winter non-irrigation season. Again, this is a major concern in the overall B+20 model.

Overall growth in the use of municipal and industrial (M&I) water in the cities of Ciudad Juárez and El Paso reflects the growth in population. In tracking water use in this twin city area (the details of water use in Las Cruces are not considered in the model), the B+20 project team recognizes that quality of life (specifically human health effects) is influenced by the percentage of households in each city that receive potable water from well-maintained water distribution systems and release wastewater from well-maintained wastewater recovery systems. Although a direct quantitative link cannot be defined, it is assumed that ongoing programs to upgrade water delivery and wastewater recovery infrastructure in the *colonias* of El Paso County will help reduce the incidence of waterborne disease—the final, but by no means least important, issue.

Water Use and Infrastructure

Water used by the Paso del Norte urban and agricultural communities (Figure 1 and Table 1) is obtained from surface flows in the Rio Grande/Río Bravo and groundwater from both the Hueco and Mesilla Bolsons. The principal cities (with approximate populations in 2000) are Las Cruces (78,000), El Paso (650,000), and Ciudad Juárez (1.2 million). Total population in the rapidly growing Paso del Norte is expected to double to nearly 4 million by 2020. Estimates of future population growth in El Paso and Ciudad Juárez are computed in the demography sector of the B+20 model (described in Chapter II-3). Approximately 180,000 acres (72,800 hectares) of irrigated agricultural land in Paso del Norte produce cotton, forage, pecans, and other crops (Paso del Norte Water Task Force 2003). Little change in irrigated acreage occurred between 1980 and 2000 (Paso del Norte Water Task Force 2001). Estimated rates of change in agricultural land area can be adjusted by the B+20 model user and incorporated into the land use change calculations (Chapter II-6) used to represent the anticipated retirement of agricultural land, which will enable conversion of irrigation water for urban uses.

M&I urban water use in El Paso and Ciudad Juárez is estimated in the system model by computing, at each point in time, the product of per capita use and population for each city. Because some households receive water delivery by truck rather than through pipes into their homes, one usage rate is assigned for those using piped water and another for those using water delivered by truck. Per capita water consumption rates for piped water differ between cities; they range from 104 gallons (394 liters) per person per day in Ciudad Juárez to 162 gallons (614 liters) per person per day in Las Cruces (Table 2). Per capita rates for trucked water are assumed to be 4 gallons (14 liters) per day. Per capita use of piped water is projected to decline over the next 20 years in Las Cruces and El Paso.

Table 1. Water Use by Entity in 2000 (acre-feet per year)

Entity	Rio Grande	Mesilla Bolson	Hueco Bolson	Reuse	Total
Las Cruces	0	20,680*	0	0	20,680
EBID	457,129	68,306	0	0	525,435
EPCWID No. 1	264,127	0	0	0	264,127
EPWU	41,719	25,284	59,417	0	126,420
Ciudad Juárez	0	0	124,000	0	124,000
CNA DR 009	58,990	0	57,255**	57,255	173,500
Total Annual Use					
AF	821,965	114,270	240,672	57,255	1,234,162
Mm^3	1010	141	297	71	1520

Notes:
*7% of the Las Cruces total is from Jornada del Mureto Bolson
**Largely produced from the shallow Rio Grande portion of the Hueco Bolson
Source: Paso del Norte Water Task Force 2001

Water use rates in Ciudad Juárez, however, may increase as more households are connected to piped water and other resources. The B+20 model user is provided with opportunities to estimate how future water use rates might change. In El Paso County, 3.5% of households are not connected to water; the same figure for Ciudad Juárez is approximately 9%. Similarly, even more households are not connected to a sewer system—these homes number approximately 5% in El Paso County and 20% in Ciudad Juárez (SCERP 2002). The Texas Water Development Board has been upgrading both water and sewer systems in the growing *colonias* of El Paso County. The model user can explore the implications of different rates of system upgrade when combined with policies designed to provide full services as *colonias* are constructed or expanded. Computing the number of households not connected to water or sewer services provides a basis for indirectly estimating future changes in aspects of human quality of life (see Chapter II-2) as affected by the incidence of waterborne disease.

Growth in Las Cruces M&I water use is represented in the model by a user-specified growth rate that reflects the combined effects of anticipated population growth and decline in per capita water use. The City of Las Cruces (1998) projects a population growth rate in the range of 1.7% to 3.7% over the period from 2000 to 2010.

The 2 million people living and working in Paso del Norte used about 271,100 acre-feet (334 million m^3) of water in 2000. This is approximately 22% of the combined urban and agricultural water used in Paso del Norte in 2000 (including water reused in El Paso). Doubling the population while maintaining the per capita usage

Table 2. Estimated Per Capita Water Consumption and Total Water Use

City	Year of Estimate	Per Capita Use (gallons per person per day/liters per person per day)
Las Cruces	2000	162/614
El Paso	2000	146/553
Ciudad Juárez	1999	104/394

Source: University of Texas-Houston School of Public Health 2000 rates of Table 2 would require about 542,200 acre-feet (668 million m^3) for M&I use, which is approximately 44% of combined urban and agricultural use in 2000. Accommodating this future growth in water use will require a mix of water management strategies that will likely include various proportions of the following:

- Increased rates of water reuse
- Reduced per capita consumption
- Transfer of irrigation water from the Rio Grande to urban users
- Desalination of brackish groundwater
- Using treated wastewater to recharge groundwater
- Importing water from other watersheds
- Developing new groundwater supplies in Mexico

Recent experience has shown that fresh groundwater should not be pumped from the Hueco Bolson at rates in excess of those currently pumped. This will preserve the groundwater resource as a source of supply during periods of extreme drought and guard against the future storage capacity being reduced due to subsidence (Heywood and Yager 2003; Hutchison 2004).

Surface Water Flows

The Rio Grande/Río Bravo forms the backbone of the Paso del Norte surface water delivery system. The flows available for use in Paso del Norte are dictated by the Rio Grande Project, which in turn receives water from the upstream reaches of the watershed that extend into Colorado. The Elephant Butte and Caballo reservoirs of the Rio Grande Project provide the storage needed to regulate the highly variable upstream river flows that would otherwise enter the model region. The impact of climate variability on water availability is represented in the Paso del Norte model by providing a mechanism (the climate "diamond" shown in Figure 2) to input a pattern of assumed future surface water flows (viewed as releases from Caballo Reservoir) that might enter the model domain.

Turner (2000) states that average flow into Elephant Butte reservoir upstream is 937,570 acre-feet (1.1 billion cubic meters [m^3]) and annual flows range from less than 200,000 acre-feet (247 million m³) to more than 2 million acre-feet (2.5 billion m³). During a typical year, BOR releases 790,000 acre-feet (974 million m³) of water from the reservoirs to downstream users in New Mexico (Elephant Butte Irrigation District), Texas (El Paso County Water Improvement District No. 1), and Ciudad Juárez (Valle de Juárez Distrito Regio 009) (Table 3). During a full supply year, 895,000 acre-feet (1.1 billion m³) are released. During periods of drought (a limited-supply year is designated when only 492,000 acre-feet, or 607 million m³, of water are available), users receive proportionately less water than they would receive in a full supply year. The six drought years out of the seven years leading up to 2003 brought the first instance since 1978 in which water deliveries were reduced below the full supply. In 2003, only 34% of the full supply was allocated to project users (BOR 2004).

River flows are monitored by the U.S. Geological Survey (streamflow records are available from the International Boundary and Water Commission [IBWC] [2004]) at four locations: below the Caballo Dam (station 09.3625.00), at El Paso above the American Dam (station 08.3640), below the American Dam (station 08.3650), and at Fort Quitman (station 08.3705). Figure 3 shows variations in calendar-year annual river flows over the period from 1939 to 2003 at the four locations on the Rio Grande/Río Bravo. The progressive

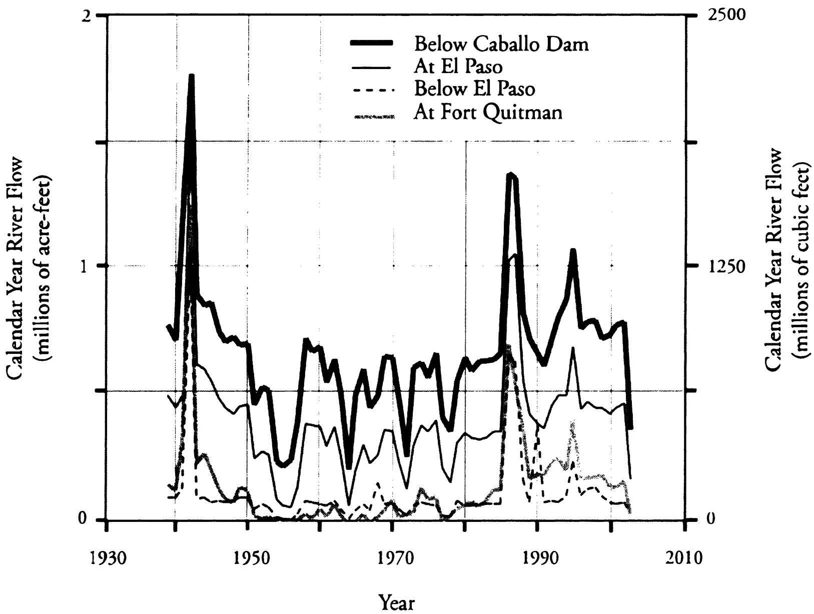
Table 3. Water Delivered at Project Headgates (acre-feet per year; million m³)

	EPCWID No. 1		EBID		Mexico		Total	
	AF	Mm³	AF	Mm³	AF	Mm³	AF	Mm³
Full supply*	360,000	444	475,000	586	60,000	74	895,000	1104
Limited supply*	217,000	268	285,000	352	33,400	41	535,400	661
2003**	122,400	151	161,500	199	20,400	25	304,300	375
Percent of total	40%		53%		7%		100%	

Sources: *U.S. Department of the Interior 1980; **Computed using data from BOR 2004 decline in river flows when moving downstream from station to station shows that the various draws from, and discharges to, the river lead to a net loss at each step in the system that has produced minimal river flows below both El Paso and Fort Quitman. The B+20 project team has identified apparent linear relationships between Caballo Dam releases and downstream flows that are used to provide a practical basis for ensuring that the aggregated model output produces plausible river flows at each low monitoring station in the system.

The timing of water releases from the Elephant Butte and Caballo reservoirs is dictated by climate variability, the need to spill excess water from overfull reservoirs, and the pattern of use of crop irrigators in downstream agricultural lands. Agricultural activity is strongly seasonal, thus, water releases from the reservoirs are also seasonal and produce high flows during the summer and minimal flows during the winter. Growing interest in drawing on surface water for urban use has led to a similar interest in providing surface flows throughout the year. Although providing a more uniform supply of water for urban use, this approach leads to reduced water availability for irrigation because water is sometimes released at times when it cannot be used by the irrigators. Furthermore, carriage losses are expected to increase with year-round flows (Winter, et al. No Date). Meanwhile, the timing and magnitude of river flows are very different from those that supported native riparian habitats prior to dam construction. Periods of reservoir filling during winter and spring seasons (particularly during drought years such as those of the mid-1950s) eliminate the former peak flows and enable water managers to release water from the reservoirs in direct response to requests from those desiring a carefully controlled sequence of irrigation deliveries during the growing season.

Figure 3. Variations in Rio Grande/Río Bravo Flows from 1939 to 2003 Monitored by the U.S. Geological Survey at the Locations Shown in Figure 2



Source: Authors; graphed using data from BOR 2004

The user-adjustable climate (indicated as a "diamond" in Figure 2) provides the opportunity to input a pattern of Caballo Reservoir releases that reflect how possible future climate scenarios might lead to various reservoir management and water release strategies. The water released from the reservoir is partitioned—53% is delivered to EBID while the remaining 47% stays in the river to be augmented by EBID and Las Cruces return flows before being delivered to EPCWID No. 1 and Mexico.

Irrigation in the Mesilla Valley is supplied by surface water that may be augmented with groundwater from the Mesilla Bolson. EBID is allocated water from the river for approximately 91,000 acres (36,800 hectares) (Turner 2000). The default, but user adjustable, groundwater extraction rate is zero. A default value of 60% is assigned to represent the loss of water to shallow groundwater and the atmosphere that would otherwise return to the river. The aggregate losses from the diversions to EBID are estimated by adjusting the loss function in the model until plausible river flows, in comparison to flows measured at El Paso, are obtained downstream of the returns from both Mesilla Valley and Las Cruces. Thus, carriage losses from water flowing in the main stem of the river between the EBID diversion and return locations are included in this aggregate estimate of water loss upstream of El Paso.

Las Cruces currently obtains water by pumping groundwater from the Mesilla Bolson. In 2000, Las Cruces used 20,680 acre-feet (26 million m^3) of water (Paso del Norte Water Task Force 2001). Garcia (2000) suggests that approximately 50% of the water used is discharged to the Rio Grande. Meanwhile, concern about the depletion of its groundwater resource leaves Las Cruces water managers planning to access surface water from the Rio Grande. An option is provided in the model to draw on surface water as the groundwater resource is depleted.

EPCWID No. 1 typically diverts approximately 360,000 (444 million m^3) acre-feet per year from the Rio Grande. The bulk of the water (roughly 310,000 acre-feet, or 382 million m^3) is used to irrigate 69,000 acres (27,900 hectares) of agricultural land in El Paso and Hudspeth Counties (Turner 2000). In recent years, EPCWID No. 1 has supplied El Paso with nearly 50,000 acre-feet (62 million m^3) of surface water per year (Turner 2000). In years with full supply, this is only 14% of the water allotted to EPWCID No. 1. In low flow years such as 2003, however, delivering 50,000 acre-feet (62 million m^3) to El Paso would account for more than 40% of the 122,400 acre-feet (151 million m^3) available for use by EPWCID No. 1. It seems unlikely that the urban water deliveries would be sustained during low flow years. The B+20 model user is provided with the option of adjusting the annual amount of surface water delivered to El Paso for urban uses. In the model, it is assumed that all water diverted for irrigation and urban purposes is either returned to the river as agricultural return flow, injected into the Hueco Bolson, lost to shallow groundwater recharge, or lost by evapotranspiration to the atmosphere. A default value of 60% consumed is assigned in the model. The aggregate losses from the diversions to EPWCID No. 1 are estimated by adjusting the loss functions until plausible river flows (in comparison to flows measured at Fort Quitman) are obtained downstream of the returns from both Texas and Chihuahua.

The 1906 water treaty brokered with Mexico requires that 60,000 acre-feet (74 million m^3) be delivered to Mexico during years with full supply. Proportionately less water is delivered in years when reduced supply is available in upstream reservoirs. Currently, the water delivered to Mexico is used to irrigate nearly 20,000 acres (8,090 hectares) of agricultural land in the Juárez Valley (Turner 2000). The treaty water used in Juárez Valley is augmented with wastewater discharged by Ciudad Juárez (76% of the wastewater is currently treated) (SCERP 2002). The B+20 model user can explore the possible impact of diverting Mexico's allotment for use in Ciudad Juárez before sending the return flow to agriculturalists in Juárez Valley. Adopting this approach would reduce the amount of water delivered to Juárez Valley because consumptive urban uses release a portion of the water to shallow groundwater and the atmosphere. In such cases, a default (but user-adjustable) 50% consumptive loss during urban use is assumed. Ultimately, it is assumed that all water diverted for irrigation and urban purposes is either returned to the river as agricultural return flow, lost to shallow groundwater recharge, or lost by evapotranspiration to the atmosphere. The aggregate losses from the diversions to CNA DR 009 are estimated by adjusting the loss functions in the model until plausible river flows (in comparison to flows measured at Fort Quitman) are obtained downstream of the returns from both Texas and Chihuahua.

Groundwater Dynamics

Groundwater is an important source of urban water supply for Las Cruces, El Paso, and Ciudad Juárez. All these cities used groundwater in 2000; El Paso also used surface water in addition to groundwater. Groundwater is also used to augment surface water supplies for agricultural irrigation in the Mesilla and Juárez Valleys. Given the focus of the system model on interactions between El Paso and Ciudad Juárez, the dynamics of non-Hueco aquifer performance in response to Las Cruces urban supply and the agricultural supplies for the Mesilla and Juárez Valleys can be neglected. Thus, changes in water stored in aquifers other than the Hueco Bolson are not computed in the system model. The dynamic response of the Hueco Bolson to pumping is included in the model because groundwater pumping by El Paso and Ciudad Juárez cause important changes in the groundwater flow system (Heywood and Yager 2003; Hutchison 2004).

Heywood and Yager (2003) use an advanced, three-dimensional groundwater flow model to develop a comprehensive overview of the dynamics of the Hueco Bolson and to explore alternative groundwater management scenarios. Their work provides an excellent foundation for developing the relatively simple representation of the water sector contained in the B+20 model. Two aquifer sub-components are considered in the model: one tapped by the EPWU Public Service Board and the other tapped by Ciudad Juárez. Each aquifer sub-component is viewed as containing the volume of freshwater available for use by each of the two cities. Heywood and Yager (2003) indicate that pumping can recover only 25% of the 9.4 million acre-feet (11.6 billion m^3)—which equals roughly 2.4 million acre-feet (2.9 billion m^3)—of fresh water stored in the El Paso sub-component of the Hueco Bolson. The Paso del Norte Water Task Force (2001) suggests that 600,000 acre-feet (740 million m^3) of fresh water might be recovered from the Ciudad Juárez sub-component.

The project team used the modeling results of Heywood and Yager (2003) to define the relationships needed to compute the aggregate rates of groundwater flow toward and between the two aquifer sub-components. Fresh groundwater recharges the two sub-components (Table 4) by:

- Eastward flow from the Franklin Mountains
- Southward flow from New Mexico
- Westward flow from the east
- Reinjection of treated wastewater
- Downward flow of surface water from the Rio Grande

Heywood and Yager (2003) compute the 2002 recharge rates and the rate of groundwater transfer from the El Paso sub-component to the Ciudad Juárez sub-component. The project team has apportioned these estimates to characterize the recharge rates for each aquifer sub-component (Table 4) using insight provided by Heywood and Yager (2003) and Hutchison (2004).

EPWU finds that groundwater pumping in excess of 50,000 acre-feet (61.7 million m^3) per year causes serious groundwater mining and consequent water level declines. By drawing increasing amounts of water from the Rio Grande, combined with withdrawals from the Mesilla Bolson, the need for groundwater pumping from the Hueco Bolson has been reduced and water levels have risen. Heywood and Yager (2003), however, estimate that about 11,000 acre-feet (13.6 million m^3) was removed from storage in 2002 while pumping 31,151 acre-feet (38.4 million m^3) from the aquifer. Pumping rates in Ciudad Juárez have not declined as they have in El Paso because the Hueco Bolson is the sole source of water for Ciudad Juárez. Pumping in Ciudad Juárez currently exceeds the 124,000 acre-feet (153 million m^3) pumped in 2000. Thus, current pumping rates greatly exceed the estimated recharge rate of 40,000 acre-feet (49.3

Table 4. Rates of Groundwater Recharge and Groundwater Transfer in 2002 for the El Paso and Ciudad Juárez Aquifer Sub-Components (acre-feet per year; million m^3 per year)

Flow	El Paso Sub-Component		Ciudad Juárez Sub-Component	
	AF	Mm^3	AF	Mm^3
Southward flow	16,000	19.7	0	0.0
Eastward flow	5,000	6.2	640	0.8
Westward flow	9,000	11.1	1,500	1.9
Induced vertical recharge	22,000	27.1	13,000	16.0
Reinjection of treated wastewater	2,500	3.1	0	0.0
Flow from El Paso to Ciudad Juárez	-32,000	-39.5	32,000	39.5
Net flow into sub-component	20,500	25.3	40,000	49.3

Sources: Adapted From Heywood and Yager 2003 and Hutchison 2004 million m^3) to the Ciudad Juárez sub-component and continue to cause water level declines and fresh groundwater depletion in the Hueco Bolson. The system model uses plausible estimates of aquifer hydraulic properties and water level declines derived from Heywood and Yager (2003) to compute changes in future recharge rates (such as flow from El Paso to Ciudad Juárez and southward flow from New Mexico). Those recharge rates change in response to changes in future pumping rates and alternative water management strategies, including reinjection of treated wastewater, greater use of surface water, and desalination of brackish groundwater, among other strategies.

Water Salinity

The total dissolved solids (TDS) concentration of water moving through or stored within the Paso del Norte water system has implications for both urban and agricultural water use and reflects water salinity. Dissolved solids include calcium, chlorides, nitrates, phosphorus, iron, sulfur, and other ions and particles that will pass through a filter with pore size of two microns. Because TDS does not pose a health hazard, this constituent is listed as one of the U.S. National Drinking Water Secondary Standards, rather than a primary drinking water standard, by the U.S. Environmental Protection Agency (EPA). The U.S. drinking water standard for TDS is 500 milligrams per liter (mg/L). Peterson (1999) notes that saline water (water with elevated TDS concentrations) can lead to reduced crop yields and may be unacceptable for livestock, depending on the sensitivity of a particular type of crop or livestock. As a general rule, irrigation water with TDS less than 700 mg/L is safe for most crops while TDS concentrations greater than 1,750 mg/L are likely hazardous to any crop (Peterson 1999). Most stock animals can thrive on water with TDS concentrations greater than 2,000 mg/L. TDS concentrations greater than 1,000 mg/L may create difficulties for many industrial processes.

TDS concentrations vary in response to both natural and anthropogenic processes that lead to dilution or concentration of dissolved constituents. Turner (1991) indicates that the average TDS of water flowing in the Rio Grande increases when moving from Elephant

Butte Dam (320 mg/L) to El Paso (550 mg/L). Because winter flows are small compared to those in the irrigation season, TDS in the non-irrigation season at El Paso is typically approximately 1,600 mg/L (Turner, et al. 1997). Hogan, et al. (2002) suggest that TDS increases downstream due to both natural and anthropogenic causes. Saline groundwater discharging to the river is diluted during the irrigation season or during years with higher river flow. During the winter low flow season of the drought that started in 1954, however, TDS concentrations rose to nearly 4,000 mg/L in 1956 and 1957 (Turner, et al. 1997). Municipal uses typically add only 200 mg/L to 300 mg/L (Turner, et al. 1997), so urban contributions are unlikely to cause the high TDS values. Evaporation and transpiration (plant uptake) of irrigation water can concentrate between two times and five times the initial TDS concentration, unless adequate water is applied to leach salts from the root zone. Desalination processes can produce water for use with 1 mg/L to 500 mg/L of TDS while also creating briny wastewater (TDS greater than 10,000 mg/L). Turner, et al. (1997) showed that a pilot reverse osmosis desalination plant in El Paso using a dual membrane process with micro- and ultra-filtration yielded 85% removal of TDS.

The B+20 model is tuned to produce plausible TDS concentrations at each flow monitoring point shown in Figure 2 when using the water flow estimates computed within each part of the system. A straightforward mass balance calculation is used, assuming instantaneous and complete mixing, wherever two water flows with differing TDS concentrations converge (such as where agricultural return flows or urban wastewater discharge is returned to the mainstem of the river). Because the relative contributions of groundwater discharge, agricultural runoff, and urban wastewater discharge to water cannot be readily identified, the flow and salinity input parameters are adjusted within reasonable limits to yield plausible computed TDS concentrations at the El Paso and Fort Quitman monitoring stations.

Water Management Futures for Paso del Norte

An approximate doubling of population in Paso del Norte from 2 million to 4 million people by 2020 leads the Paso del Norte Water Task Force (2001) to expect an increase in M&I use from 321,137 acre-feet (396 million m^3) to 565,757 acre-feet (698 million m^3) between 2000 and 2020—a 76% increase. At the same time, EPCWID No. 1 anticipates a decline from 179,842 acre-feet (222 million m^3) in 2000 to 161,470 acre-feet (199 million m^3) by 2020 in response to retiring agricultural land in El Paso County through urban expansion and fallowing. Because insufficient water is currently available to irrigate all prospective agricultural land in Juárez Valley, it is unlikely that agricultural land will be retired as a consequence of urban expansion.

Several options are currently being explored to both obtain the water needed in the coming decades and reduce per capita water use. These options include:

- Reusing treated wastewater for nonpotable applications
- Reinjecting treated wastewater into the Hueco Bolson
- Importing water from more distant watersheds
- Reducing per capita water use, such as through conservation
- Increasing urban use of Rio Grande/Río Bravo surface water by converting agricultural water to urban use
- Desalinating brackish groundwater from the Hueco Bolson

Each option is considered feasible, but implementation costs are variable and generally expensive. Note, however, that if the EPWU maintains a good bond rating it will be able to continue borrowing the funds needed to implement changes in the parts of the system it manages. Additional non-local funds may become available through U.S. or Mexican state or national governments or the North American Development Bank (NADBank). At this stage in the model's development, however, the economic aspects of various water management options are not represented. It is interesting to note that none of the options being discussed include a serious plan for obtaining the water needed to mitigate environmental impacts and restore instream flow.

One incentive for change is presented by the Drought and Water Emergency Response Management Plan implemented by EPWU. It instigates various response options when certain water quantity or quality criteria thresholds are crossed (Table 5). For example, Stage 2 conditions are instigated when "...EPCWID No. 1 declares a surface water allotment of less than 2.5 acre-feet (3,080 m^3) per acre (0.41 hectare) on or before March 15th and river water quality is projected to exceed 300 parts per million (ppm) of sulfates or 1,000 ppm (the equivalent of 1,000 mg/L) of total dissolved solids in April, May or September; or when water demand is projected to exceed 95% of available capacity as determined by EPWU" (El Paso Water Utilities Service Board 2004b). A Stage 2 drought was declared in 2003. At least one industrial water user has indicated that it will leave the city of El Paso and relocate elsewhere if Stage 2 drought conditions are declared in the future.

The B+20 model provides the opportunity to explore how different mixes of current and planned water management options might be configured to maximize use of the available water across a range of climate futures. Currently, the user can adjust groundwater pumping rates, reinjection rates, surface water use, conservation rates and water import rates as well as convert water from agricultural to urban use. The model is easily reconfigured to include the recent discovery that desalination of brackish groundwater is now an economically viable option for EPWU.

Although El Paso and Las Cruces appear to have established sources of water for supplying their growing populations beyond 2020, Ciudad Juárez must soon develop additional water resources because freshwater in its sub-component of the Hueco Bolson continues to decline. Heywood and Yager (2003) indicate that Ciudad Juárez plans to cap extraction from the Hueco Bolson at 150,000 acre-feet (185 million m^3) per year. Prospective alternatives include:

- Extracting groundwater from the southward extension of the Mesilla Bolson (the Conejos-Medanos Bolson), which has an estimated capacity of 51,134 acre-feet (63.1 million m^3) to 76,500 acre-feet (94.4 million m^3) per year
- Accessing groundwater in Minas de Bismark Aquifer and the Acuifero Somero (Rio Grande Alluvium)

Table 5. Drought Management Stages in the El Paso Drought and Water Emergency Management Response Plan

[illegible]	[illegible]
1	A voluntary reduction of 25% in indoor, outdoor, and industrial water use by EPWU customers and those of other water purveyors and well operators
	Increased public education
	Citations will be issued for violations of the Water Conservation Ordinance and the Drought and Water Emergency Management Response Plan, consistent with Civil Service rules
2	Outdoor watering limited to once per week
	Parks, schools, and golf courses will reduce consumption by 25% (except those exempted by using reclaimed water)
	New landscape watering permits will be restricted
	Swimming pools cannot be drained and refilled with potable water
	Drought Plan violators may be required to install a flow restriction device
3	All outdoor watering is prohibited, except when performed with a bucket or permanent drip irrigation system, subsurface irrigation, or where reclaimed water is used
	The irrigation of golf courses with potable water supplied by El Paso Water Utilities and the irrigation of municipal golf courses is prohibited
	Most car, trailer, truck, or boat washing is prohibited
	No swimming pools shall be filled
	All water use for construction, dust control, and/or compaction is prohibited, except with reclaimed water or brackish groundwater
	Restrictions on new water meter connections

Source: El Paso Water Utilities Service Board 2004b

- Ciudad Juárez using a portion of the Mexico treaty allotment (38,240 acre-feet, or 47.2 million m^3) and delivering the remainder to CNA DR 009, along with the treated wastewater, for agricultural use

A key contribution of the water sector to the B+20 model is the opportunity for users to explore how future variations in climate might lead to preferred options for obtaining water for the U.S.-Mexican border community while recognizing the hydrologic and technical feasibility of different options. Until the cost of each alternative is considered, however, it is difficult to link changes in the water sector to responses in other model sectors. For example, if the total federal funds available for transportation, airshed management, and water and wastewater infrastructure are limited, it would be important to evaluate tradeoffs associated with spending money in each sector to optimize quality of life goals. If broad constraints (rather than sector-specific constraints) will be imposed on funding, it will be important to include a water-related economy in the next phase of model development.

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II-6

Land Use Changes in the Paso del Norte Region: A Brief History

Sergio Pena, Cesar Fuentes, and Craig B. Forster

Abstract

An objective of the Border Plus Twenty Years (B+20) Project is to construct a system dynamics model of the processes of urban growth and urban sprawl. This chapter provides an historical background that describes urban growth in the El Paso, Tex.-Ciudad Juárez, Chih., twin city region, also known as Paso del Norte, and explains the land use sector of the model.

The Paso del Norte land use model begins with some basic assumptions that take into account how economic and demographic processes trigger the demand for urban land in the form of residential and non-residential uses such as industrial, commercial, and roads, among others. The process can be described as a negative sum game where the gains of land in one sector are the losses of land in another. In this particular case in the model, the gains in urban land have been at the expense of dry land and farming land capture; the variables have been denominated as conversion rate to urban land.

Cambios del Uso del Suelo en la Región Paso del Norte: Una Historia Breve

Sergio Pena, Cesar Fuentes, y Craig Forster

Resumen

Un objetivo del Proyecto Frontera Más Veinte Años (F+20) es construir un modelo de sistema de dinámicas del proceso del crecimiento urbano y de la desorganización urbana. Este capítulo proporciona un antecedente histórico que describe el crecimiento urbano en la región de ciudad gemela de El Paso, Tex.-Ciudad Juárez, Chih., también conocida como Paso del Norte, y explica el sector del uso del suelo del modelo.

El modelo del uso del suelo del Paso del Norte comienza con suposiciones básicas que toman en cuenta cómo el proceso económico y demográfico provoca la demanda por tierra urbana en la forma de usos residenciales y no-residenciales como industriales, comerciales y carreteras, entre otras. El proceso puede ser descrito como un juego total negativo en el cual las ganancias de suelo en un sector son las pérdidas de suelo en otro. En este modelo particular, las ganancias en suelo urbano han sido a expensas de suelo seco y captura de suelo ganadero; las variables han sido denominadas como ritmo de conversión a suelo urbano.

The Twin Cities of El Paso and Ciudad Juárez

The binational conurbation of El Paso, Tex., and Ciudad Juárez, Chih., currently extends for 134,029 acres (209 square miles, or approximately 541 square kilometers). It is home to nearly 1.9 million people; 637,859 live in El Paso and 1,217,818 in Ciudad Juárez. El Paso accounts for 59.5% of the developed land but only 34.4% of the population living in Paso del Norte. El Paso has a density of 0.799 people per acre; Ciudad Juárez's density is 22.4 people per acre[1].

El Paso and Ciudad Juárez have experienced not only different rates of growth, but different patterns of growth that have had an impact on their form, density, and the rate at which they have expanded their urban boundaries. The urban boundary of Ciudad Juárez between 1990 and 2000 increased its size 1.5 times, whereas the urban boundary of El Paso in the same 10 years grew by a factor of .855—nearly half the rate of Ciudad Juárez (City of El Paso 1999).

Economics and demographics are the driving forces of urban growth. An important economic force in the region has been the exponential growth of the maquiladora industry on the Mexican side of the border. This industry has had a substantial impact on population growth, urban growth, and land use in both El Paso and Ciudad Juárez.

At the peak of the economic boom in 2000 in the United States, the number of maquiladora plants in Mexico reached 3,703 and they employed more than 1.3 million people. Nearly one in two plants were located in cities along the Mexican side of the border. Tijuana, B.C., and Ciudad Juárez contained about one-third of the plants and their employees (INEGI 2000). This economic boom also became associated with an important wave of migration. Demographic trends show that on the Mexican side, the population of the border cities has increased greatly since 1970. For example, Ciudad Juárez tripled its population in 30 years from 407,370 in 1970 to 1,217,818 in 2000.[2] On the other hand, El Paso has decreased its rate of population growth to the point of almost stagnating. However, this does not mean that the urban spatial growth has stopped. It is important to point out that El Paso has seen increased demand for land to accommodate international trade and the maquila industries; the amount of land used for warehousing, transportation, commercial, and industrial use has increased.

Population Growth Rates and Urban Growth in Ciudad Juárez

Historically, Ciudad Juárez has experienced one of the fastest rates of population growth in the country. From 1856 to 1960 the city remained relatively compact. It was characterized by a higher population density and less vacant land than cities north of the border (Arreola and Curtis 1993). In 1856, Ciudad Juárez's population density was high for the small city (482 inhabitants per hectare[3]). After the Mexican Revolution, the city began to experience population pressures as a product of immigration flows from central Mexico. In 1921, the Ciudad Juárez population was growing at a rate of 5.5%, reaching 19,457 inhabitants. In the 1930s its population reached nearly 40,000, and the urban area had grown to 471 hectares. During the 1940s these indicators slowed their pace. Ciudad Juárez's population growth rate was only 2.0% and the urban area increased by only 92 hectares over the decade (Fuentes 2000).

Beginning in the 1950s, the city embarked on another phase of spatial expansion. Ciudad Juárez experienced the highest rate of population growth in its history in 1950 (9.2%) and its urban area grew to 800 hectares. As a result of immigration flows, the city became relatively densely inhabited (164 inhabitants per hectare, up from 85 persons/hectare in 1930). The city's population continued to grow at a high rate of 7.2% in 1960 and its urban area reached 1,894 hectares.

Ciudad Juárez experienced two periods of expansion during this era. The first, from 1856 to 1930, is characterized by a high population growth rate and physical expansion. The second, from 1931 to 1960, began with a decrease in population growth rate and population density. Throughout this period, however, Ciudad Juárez could be characterized as a relatively compact city.

In the 1970s, the city's urban growth was affected by intense immigration flows and the location of industrial parks. The great supply of jobs generated by the maquiladora industry attracted a large number of workers who eventually became integrated into the city. The number of inhabitants grew from 276,995 in 1960 to 424,135 in 1970. The urban area increased from 1,894 hectares in 1960 to 5,608 hectares in 1970, a growth rate of 10.8%. Due to spatial expansion, the population density decreased from 146 inhabitants per hectare in 1960 to 75 inhabitants per hectare in 1970.

During the next decades the city continued to experience high population growth. Because the urban area grew more quickly than the population, the population density of the city continued to decline. The city population passed 567,365 inhabitants in 1980 to reach 798,499 inhabitants in 1990. The urban land reached 9,395 hectares in 1990 and the population density continued declining to 57 inhabitants per hectare. In 2000, the population growth rate was similar to the urban area growth rate. Thus, population density has stabilized. During the period from 1970 to 2000 the city grew in an unstructured pattern of urban sprawl, as Table 1 shows.

Land Use in Ciudad Juárez

In the case of Ciudad Juárez, recent land use changes are related primarily to the effects of the industrialization process. The first industrial park was established in 1967 on the northeast side of the city; it has an extension of 174.2 hectares (Fuentes 1992). Previously, this land had been used for irrigated agriculture[4] purposes, primarily to grow alfalfa and cotton. In the early 1970s, two new industrial parks were opened and occupied 125.8 hectares, but only 81.8 hectares had previous agricultural use. The commercial land use represented 305 hectares; all of them were located in the central business district and on the main arterial network.

In 1980, the city limits had an extension of 15,227 hectares, of which 9,385 hectares were urban land. Residential use occupied 6,061 hectares, industrial use 378, commerce and service 688, open spaces 401, and internal roads 1,857. Four years later, the urban area reached 13,170 hectares, consisting of 6,452 hectares for resi-

Table 1. Population and Urban Growth in Ciudad Juárez: 1856–2000

Year	Population	Population Rate of Growth (%)	Urban (ha)	Population Density (Pop./ha)
1856	4342	Base	9	482
1894	7582	1.4	60	126
1900	8,218	3.5	61	134
1910	10,621	2.5	119	89
1921	19,457	5.5	N.D.	N.D.
1930	39,669	7.9	471	84
1940	48,881	2.0	563	87
1950	131,308	9.1	800	164
1960	276,995	7.2	1,894	146
1970	424,135	5.2	5,608	75
1980	567,365	4.4	9,395	60
1990	798,499	3.4	14,049	57
2000	1,217,818	4.2	21,572	56

Note: N.D. = no data
Source: Fuentes 2000

dential use, 681 for industrial use, 380 for commerce and service, 461 for open space, 1,529 for urban vacant land, 2,150 for internal roads, and 656.5 for other uses (Table 2).

Industrial growth toward the northeast and southeast also demanded the establishment of residential and commercial areas. From 1984 to 1988, land with residential and industrial uses increased 337.49 hectares and 159.13 hectares, respectively. In 1995, urban land totaled 18,767 hectares and was distributed as follows: residential use reached 8,416 hectares, industrial use 1,209 hectares, commerce and services 1,075, mixed use 617, open spaces 446, internal roads 4,785, and urban vacant land 2,219.

Table 2. Land Use in Ciudad Juárez (1985, 1995, and 2001)

Land Use/Year	1984		1995		2001	
	Surface	%	Surface	%	Surface	%
Residential	6,452	48.9	8,416	44.8	9,992	45.1
Industrial	681	5.7	1,209	6.4	1,844	8.3
Commerce and service	380	2.9	1,075	5.7	1,638	7.4
Mixed use	656	4.9	617	3.2	503	2.2
Open space	461	3.5	446	2.3	605	2.7
Internal road	2,150	16.3	4,785	25.5	5,040	22.7
Urban land vacant	1,529	11.6	2,219	11.8	2,500	11.3
Total	13,170	100	18,767	100	22,122	100

Source: City of Juárez 1985; 2001

The land use of the city has not been modified substantially since 1995. Residential use totals 45.17% of the urban area, the roads system has reduced its area by three percentage points and totals 22.78%, the industrial land use has increased its portion from 6.44% in 1995 to 8.34% in 2001, and the commerce and service surface increased to 7.40%.

Table 2 shows that in relative terms, the residential use of land has constituted a constant portion of total land use since 1984. However, industrial use has increased from 5.7% in 1984 to 8.3% in 2001. Since 1995 nine industrial parks have been added, for a total of 23 parks. The last nine industrial parks are located near working-class neighborhoods and main roads.

The traditional pattern of urban growth that consists of the centralization of commercial and service land use has not occurred in Ciudad Juárez; instead, the pattern of growth can be described as suburban sprawl. Four factors appear to account for this growth pattern: the southward location of warehouses adjacent to residential areas, deficient public transportation resulting in difficult access to the central business district, huge economic investment in freeways, and exhaustion of the traditional economic base of the central business district (Fuentes 2001).

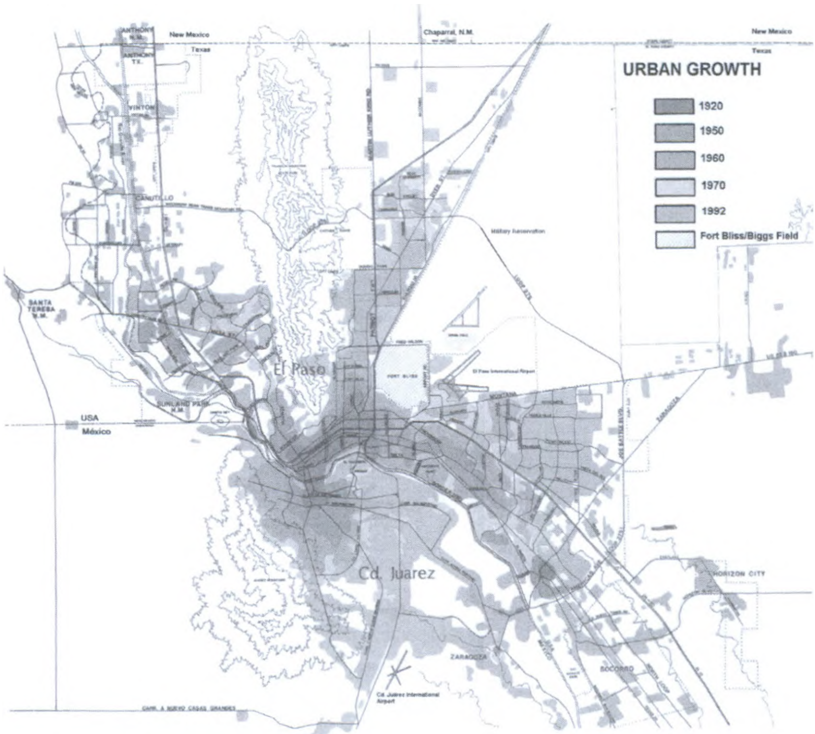
Because of the sprawl induced by these factors, the plan of the Junta Municipal de Agua y Saneamiento (JMAS) notes that the part of the irrigation district closest to Ciudad Juárez has seen a decline of more than 1,000 hectares as a result of conversion to urban use. The Instituto Municipal de Investigación y Planeación (IMIP) (2001) projects the use of urban land in Ciudad Juárez will total 32,421 hectares by 2020. Compared to today's total of 21,572, future expansion will add 10,848 new hectares of land to urban development. IMIP estimates that about one-quarter of that new urban land will be converted from land previously in agricultural use. Figure 1 depicts the spatial distribution of urban growth in Paso del Norte from 1920 to 1992.

Land Use and Water-Related Infrastructure

Understanding trends in land use is crucial to water planning because the water needs of irrigated farmland are different from those of residential and industrial uses. Also, they are affected by different factors. The portion of the city with water service has been declining since 1998 because infrastructure construction cannot maintain pace with the rapid expansion of the city. In 1998, the demand for water in different sections of the city was almost completely satisfied—92% of the urban area and 85% of the population were served. However, just two years later only 88.1% of the urban area and 88.3% of the population were covered by water service.

In 1999, an analysis of water use by different types of users showed that 78.2% of water is used by residential, 9.11% commercial, and 8.38% industrial. Residential users were sub-classified into socioeconomic groups (low, middle/lower, middle, and upper) based on housing type and location within the city. The current domestic population is divided into socioeconomic groups in the following percentages: low (34.6%), middle/lower (41.69%), middle (15.24%), and upper (8.47%). In terms of water use, the low-income group uses 25.36%, middle/lower 32.25%, middle 13.30%, and upper 7.35% (Table 3).

Figure 1. Urban Growth for El Paso-Ciudad Juárez, 1920–1992



Source: Border Environment Cooperation Commission

Table 3. Water Use in Ciudad Juárez by User Type (1999)

User Average Consumption	Registered Accounts	Annual Volume (m^3/yr)	Annual Volume (af/yr)	Average Consumption	
				Liters per Capita per Day	Gallons per Capita per Day
Domestic	232,013	87,373,286	70,835	322	85
• Low	80,275	28,308,600		270	71
• Mid/lower	96,726	36,007,559		339	90
• Middle	35,351	14,851,458		386	102
• Upper	19,660	8,205,669		521	138
User Average Consumption	**Registered Accounts**	**Annual Volume (m^3/yr)**	**Annual Volume (af/yr)**	**Average Consumption (m^3 per User per Month)**	
Commercial	10,533	10,175,108	8,249	88.9	
Industrial	996	9,364,124	7,553	802	
Public	1,087	4,707,198	3,797	402.3	
Subtotal	244,647	111,619,716	90,492		
Unregistered	22,857	20,356,566	16,503		
Losses		18,016,355	14,606		
Total	267,504	149,992,637	121,601		

Source: Paso del Norte Water Task Force 2001

The irregular pattern of per capita water consumption is related to the rate of population growth and territorial expansion. In 1940, per capita water consumption was 1.03 cubic meters per capita per year (cmpcy). However, in 1950, 1960, and 1970, per capita water consumption was reduced to 0.60, 0.78, and 0.71, respectively. In 1980, per capita water consumption began to increase and reached 1.10 cmpcy, and in 1990 the city reached the highest per capita water consumption at 1.37 cmpcy. In 2000, per capita water consumption declined to 1.14 cmpcy.

JMAS's plan notes that these projections do not assume any change in per capita use as a result of conservation programs, nor any improvement in metering or reduction of system losses (currently 15%). The projections do assume an increment in service area coverage, from 82% in 1999 to between 95% and 100% in 2020.

Econometric Estimation of Urban Growth and Water Consumption

The central objective of this section is to estimate the effect of population growth and urban growth on the volume of water extracted. The estimated model includes the natural logarithm of the variables. One regression was estimated for each variable. The results, based

Table 4. Projected Municipal and Industrial Water Demand for Ciudad Juárez by Category (liters per second)

1999	4702.8	362.1	308.2	168.7	5,541.80	141,296
2000	4930.8	472.6	326.1	193.1	5,922.70	151,008
2005	6164.9	590.9	407.8	241.4	7,404.90	188,799
2010	7453.2	714.4	493.0	291.8	8,952.40	228,254
2015	8711.2	834.9	576.2	341.1	10,463.40	266,779
2020	9840.7	943.2	650.9	385.3	11,820.20	301,373

Source: JMAS 1999

on an Ordinary Least Square (OLS) method, are presented in Tables 5 and 6, which summarize the regressions obtained. The following variables were used:

- Natural logarithm of water consumption (dependent variable)
- Natural logarithm of population (LNPOB)
- Natural logarithm of urban area (LNURB)

Table 5. Estimation of Population Growth on the Volume of Water Extracted in Ciudad Juárez (1990–2000) Using LNPOB

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1(Constant)	1.822	1.403	–	1.299	0.251
LNPOB	1.212	0.110	0.980	11.012	0.000

Source: Estimation based on data from JMAS 1999

Table 6. Estimation of Population Growth on the Volume of Water Extracted in Ciudad Juárez

[illegible]	[illegible]	[illegible]	eta	T	Sig.
1(Constant)	9.392	0.572	–	16.411	0.000
LNURB	0.947	0.068	0.987	13.859	0.000

Source: Estimation based on data from JMAS 1999

It is important to emphasize that the transformation of the dependent and independent variables into natural logarithms in the models allows the observation of the parameters as elasticities or percentage changes. For example, a parameter equal to 1 shows that if the independent variable changes 1%, the dependent variable changes 1% as well. The results show that population growth has a greater impact on the volume of water extracted than on urban growth.

The coefficient estimate for population (1.212) is highly significant and indicates that when the population increases by 1%, the volume of water extracted increases by 1.2%. The coefficient estimate for urban growth (0.947) is highly significant and indicates that when the city's size increases by 1%, the volume of water extracted increases almost 1% to 0.947%; that is, the relationship is proportional.

B+20 Land Use Model

Model Assumptions

The Paso del Norte land use model begins with some basic assumptions that take into account how economic and demographic processes trigger the demand for urban land in the form of residential and non-residential uses such as industrial, commercial, and roads, among others. The assumptions are the following:

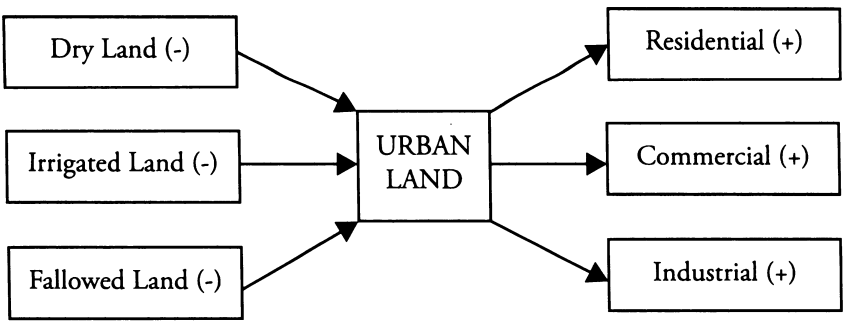
- An increased number of jobs leads to an increased non-residential component of urban land (El Paso and Ciudad Juárez)
- Increased population growth leads to an increase in the number of dwellings, which is synonymous with an increase in the residential component of urban land (the model seeks to quantify this relationship)
- Urban land increases at the expense of irrigated land and/or dry land in El Paso and Ciudad Juárez
- Fallowing irrigated land can lead to increased water availability for urban uses if water transfers are enacted

Model Description

STELLA® software was used to model the dynamics of land use changes in El Paso and Ciudad Juárez (Figure 2). The software allows modeling of a system using four types of relationships. A box represents a stock variable, in this case land is considered a stock that could increase or decrease as a result of endogenous and exogenous factors. There are inflows and outflows represented by arrow icons that feed or drain the stock variable (land), these two flows represent dry and irrigated farm land as inputs that feed the demand for urban land, which in turn is an output transformed to residential, industrial, and commercial use.

The circles with faucets represent rates that convert different inputs into a common denominator or measure. In other words, the stock (land) is a function of several factors or variables that act as inputs. However, since the scale or measurement of the inputs can be different, this rate icon performs the function of transforming or computing different measurements and scales into a common denominator, such as densities or growth factors. Finally, there are auxiliary variables in the form of circles that explain the changes in the stock variable. In sum, the icons allow the modeler to develop a map or conceptual model that links different relationships so the modeler can conceptualize how the system or the "world" operates. The model can be seen as a graphical or conceptual representation of a system of differential equations.

Figure 2. Conceptual Model



Source: Authors

Overview of the Model

The model was initially developed with some basic assumptions. It is assumed that El Paso and Ciudad Juárez are two central places with urban functions surrounded by a hinterland whose main economic activity is farming. Part of the hinterland is dry land unsuitable for farming. Furthermore, El Paso and Ciudad Juárez have politically defined boundaries that may restrict or limit their growth or impose some challenges to the implementation of land use policy. Growth at the urban central place can be accommodated through two, though not mutually exclusive, options: an increase in density through vertical growth or a constant density with an expansion of physical boundaries by transforming farming and dry land into urban land. Data presented previously show that Ciudad Juárez and El Paso have opted for the second option, given the fact that the ratio of urban land change to population change in the last decade is almost equal to 1 for Ciudad Juárez and has fallen to .81 for El Paso.

The Model

The stock variables in the model represent transfers of land from one activity to another. The losses and gains of the stocks should be equal. In other words, the process can be described as a negative sum game where the gains of land in one sector are the losses of land in another. In this particular case in the model, the gains in urban land have been at the expense of dry land and farming land capture; the variables have been denominated as conversion rate to urban land.

A key question remains: What factors have accounted for the conversion of land from farming to urban uses? The answer is that El Paso is no different than any other community that has lost a significant amount of open space and farm land to urban growth. Several authors (Garreau 1991; Gottdiener 1994; Levy 1997; Kelly 1993; Feagin 1988; Orfield 2002) have described a process of suburbanization of the American cities as a result of the desire for affordable, low-density dwellings combined with suburban amenities. Additionally, the ease of obtaining credit for home construction through federal programs such as those by the Federal Housing Administration (FHA) has also contributed substantially.

In the Border Plus Twenty Years (B+20) model, the assumption is that the conversion of farm land is made through market mechanisms; thus, due to the housing demand, it will be more profitable to supply or convert farm land or dry land into urban dwellings. As well, farmers could not only make money by selling land but also by selling the water rights. As long as there exists a differential in what the farmer can get from farming the land and what urban dwellers are willing to pay, urban sprawl will occur.

The system of land use interdependencies in the case of Ciudad Juárez begins with the growth rate of the U.S. gross domestic product (GDP), which affects the rate of foreign direct investment in Ciudad Juárez and, as a consequence, the growth of maquiladora employment. As maquilas locate in a city, the demand for industrial uses increases. Initially local labor is employed, but due to the rapid influx of maquiladora plants, each employing hundreds of workers (on average), additional "outside" labor is needed. This leads to in-migration and overall urban population growth. The inflow of labor increases the demand for residential land as workers and their families seek housing. Vacant housing units are initially filled, but the escalating number of migrants leads to the development of new residential districts. Population growth also inflates the demand for commercial activities, defined broadly to include wholesale, retail, and businesses/personal services.

The demand for commercial activities leads to the expansion of commercial establishments already in place, as well as the formation of new enterprises, so that the amount of commercial land use rises. The expansion of the commercial sector creates more employment and these employees require additional residential land. Most of the land is taken from irrigated land and desert land. Finally, it is important to clarify that in Ciudad Juárez, unlike El Paso, there are both informal and formal housing markets.

The B+20 model implicitly takes into account those factors as the sources that generate the demand for urban land, whereas irrigated and dry land are supplying the land for urban uses. What are the forces behind this conversion process? The model only takes into account conversion rates, fallowed land, and the requirement of crop rates. The rate of conversion implicitly assumes that farmers, when facing the decision to either sell their land to developers or continue farming, realize that they can make a bigger profit selling two important assets—land and water rights—for which urban dwellers are willing to pay.

Links with the Rest of the Model

The land use sector is linked to the rest of the B+20 model through the demographic sector, which is labeled as changing population (Figure 3). In essence, demographic changes in El Paso and Ciudad Juárez are the driving force behind the demand for urban land and, consequently, the transformation of dry land and agricultural land into urban residential uses.

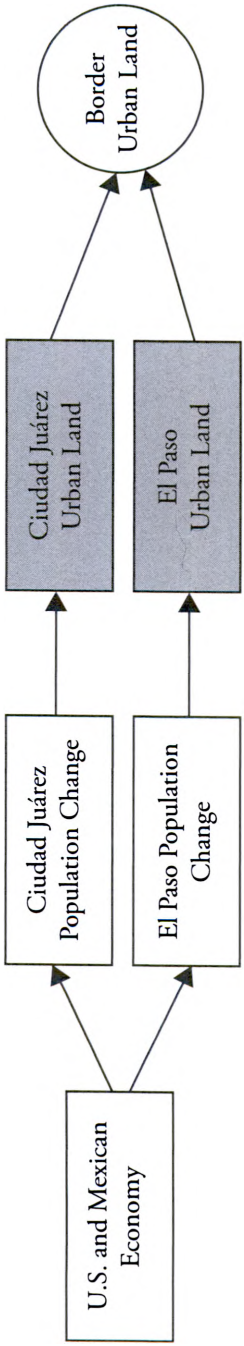
Demographic changes in the B+20 model are a function of employment opportunities. International trade and economic integration have had mixed impacts in the border region. Ciudad Juárez experienced an economic boom from 1980 to 2000. In the same period, El Paso's economy had stagnated and key employers (mainly in the garment and textile industry) left the city. Other employers simply stopped operating, as was the case with the American Smelting and Refining Company's (Asarco) copper mining activities. In recent years, new sectors associated with international trade, such as warehousing and transportation, have experienced employment growth. According to the El Paso Economic Adjustment Strategic Plan (1999), more than 14,500 El Paso workers have been certified as displaced by the North American Free Trade Agreement (NAFTA); overall, El Paso has had a net gain (6,150) in jobs due to NAFTA, but these jobs pay comparatively lower salaries than those lost as a result of NAFTA.

In sum, urban growth in the border region in the last two decades cannot be explained without taking into consideration the impacts employment growth has had on demographic changes, which are the factors behind the expansion of the urban boundary and, consequently, the transformation of dry land and irrigated land into urban uses, as shown in Figure 2. The land use models for El Paso and Ciudad Juárez are shown in Figures 4 and 5.

Endnotes

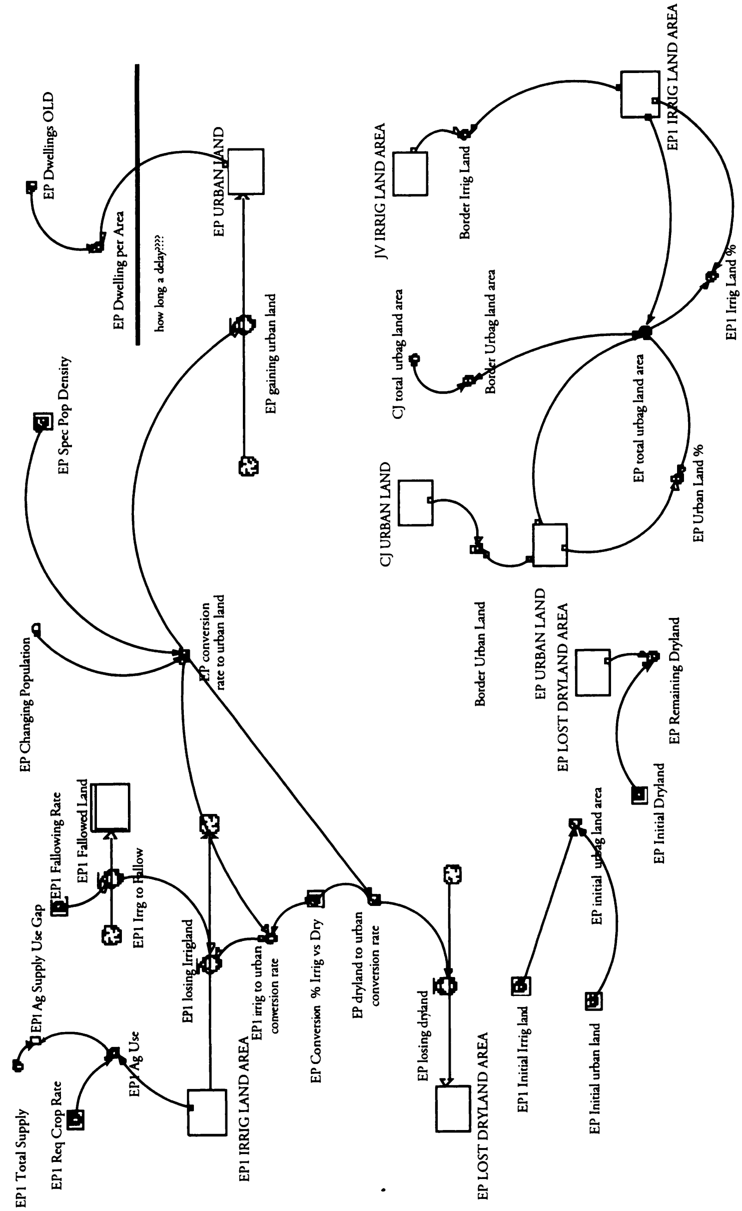
[1] Information comes from The Plan for El Paso, the Municipal Institute for Planning and Research (IMIP) in Ciudad Juárez, and National Institute of Geographic Information and Statistics (INEGI).

Figure 3. Links



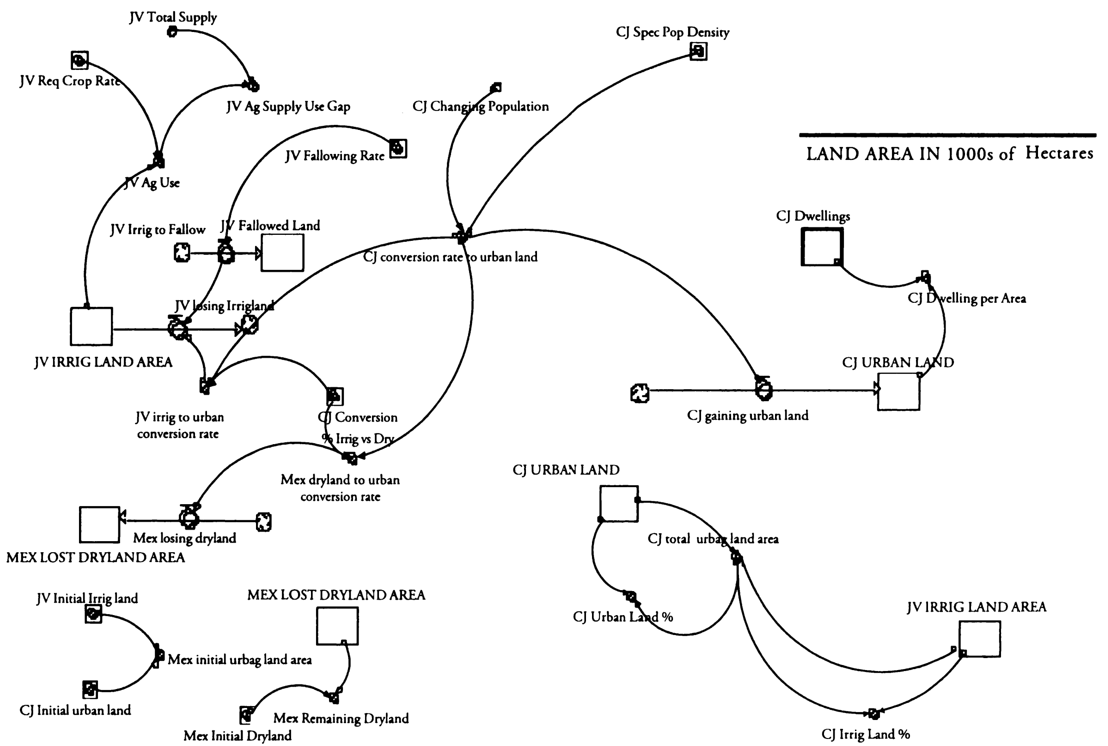
Source: Authors

Figure 4. B+20 Land Use Model for El Paso



Source: Authors

Figure 5. B+20 Land Use Model for Ciudad Juárez



Source: Authors

[2] Data comes from Lorey (1993) and http://www.inegi.gob.mx/estadistica/espanol/economia/feconomia.html.

[3] 1 hectare is 2.47 acres.

[4] The Distrito de Riego 009 has a total area of 61,100 acres.

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Paso del Norte Air Quality

Margarito Quintero Núñez and Craig Forster

ABSTRACT

The Paso del Norte air basin is shared by the communities of El Paso, Tex.; Las Cruces, N.M.; and Ciudad Juárez, Chih. Airborne pollutants emitted from each city mix with emissions from surrounding non-urban land and circulate within a complex transborder air basin. In the United States, El Paso, Tex., is classified by the U.S. Environmental Protection Agency (EPA) as a nonattainment area for particulate matter (PM), carbon monoxide (CO), and ozone (O_3). Pollutant levels in El Paso's twin city, Ciudad Juárez, are no less than those of El Paso (Emerson, et al. 1998; Li, et al. 2001). Nonattainment conditions continue to the present day in Paso del Norte, although air pollutant levels have been declining since the 1980s (Rincón and Emerson 2000). If future population growth is not accompanied by adequate reductions in per capita emissions, pollutant levels could rise. Declining air quality will, in turn, impose constraints on economic development in the border community as air quality mitigation procedures are imposed through regulatory action.

The Border Plus Twenty Years (B+20) Project team used a dynamic simulation model to assess how future air quality conditions might affect economic activity, human health, and quality of life in Paso del Norte. Although it would be desirable to simulate

changes in all pollutants of concern, only variations in PM are considered in this phase of the Paso del Norte modeling activity. This chapter outlines the various factors and issues considered in developing the air quality sector of the Paso del Norte system model. The overall trends in air quality for Paso del Norte are also addressed. The physical and socioeconomic characteristics of the region are described to set the scene for linking air pollution with human health, economy, and quality of life in the model. The few existing studies of air quality effects on human health in Paso del Norte are also summarized. A description of air quality standards, monitoring programs, and approaches to air quality management in the United States, Mexico, and the border region helps outline the regulatory framework for current and future air basin management in the region. The information is incorporated in the air quality sector of the system model, which is being used to explore future air quality scenarios in the Paso del Norte air basin.

La Calidad del Aire en el Paso del Norte

Margarito Quintero Núñez y Craig Forster

Resumen

La cuenca del Paso del Norte es compartida con las comunidades de El Paso, Texas; Las Cruces, Nuevo Mexico; y Ciudad Juárez, Chihuahua. Los contaminantes aerotransportados fueron emitidos de cada mezcla de ciudades vecinas con emisiones de tierras no-urbanas y que circulan dentro de una cuenca transfronteriza compleja. En los Estados Unidos, El Paso es clasificado por la Agencia de Protección Ambiental (EPA) como un área de no logro de materia particulada (PM), monóxido de carbono (CO), y ozono (O_3). Los niveles de contaminantes en Ciudad Juárez, ciudad gemela de El

Paso, son los contaminantes de El Paso (Emerson, et al. 1998; Li, et al. 2001). Las condiciones de no logro hoy en día continúan en el Paso del Norte, aunque los niveles de dichos contaminantes de aire han ido bajando desde 1980 (Rincón y Emerson 2000). Si el futuro crecimiento de la contaminación no es acompañado por reducciones adecuadas de las emisiones per capita, los niveles de contaminantes pudieran subir. La disminución de la calidad del aire puede, a su vez, imponer limitaciones en el desarrollo económico de la comunidad fronteriza mientras que los procedimientos de atenuantes de la calidad del aire son impuestos a través de acciones reglamentarias.

El grupo de trabajo del Proyecto Frontera Más Veinte Años (F+20) utilizó un modelo de simulación de dinámica para evaluar cómo futuras condiciones de la calidad del aire pudieran afectar la actividad económica, salud humana y la calidad de vida en el Paso del Norte.

Aunque lo deseable sería simular cambios en todos los contaminantes de preocupación, sólo variaciones en PM son consideradas en esta fase de la actividad de modelado del Paso del Norte. Este capítulo delimita los diversos factores y temas considerados al desarrollar el sector de la calidad del aire del sistema del Paso del Norte. También son abordadas las tendencias generales en la calidad del aire para el Paso del Norte. Las características físicas y socioeconómicas de la región son descritas para establecer el escenario de unir a la contaminación del aire con la salud humana, economía, y con la calidad de vida en el modelo. También se resumen los pocos estudios existentes de los efectos de la calidad del aire sobre la salud humana. Una descripción de los estándares de la calidad del aire, programas de monitoreo y aproximaciones a la administración de la calidad del aire en los Estados Unidos, México y la región fronteriza ayuda a delimitar el esquema regulatorio para la administración presente y futura de la cuenca de aire en la región. La información está incorporada en el sector de la calidad del aire del sistema de modelo que está siendo usado para explorar futuros escenarios de la calidad del aire en la cuenca de aire en el Paso del Norte.

Physical Characteristics of the Paso del Norte Air Basin

The Paso del Norte air basin is located along the Rio Grande at an elevation of nearly 3,700 feet in basin and range topography typical of the southwest United States and northern Mexico. This natural basin is bounded on the east by the Hueco Mountains of Texas, split on the west by the north-south trending Franklin Mountains of Texas, bounded on the south by the southwest trending Sierra de Juárez Mountains of Chihuahua and defined on the north by topography that rises to the Organ Mountains of New Mexico (Emerson, et al. 1998).

Weather conditions that create unhealthy air quality in the Paso del Norte air basin are typical of those found in high elevation desert basins. In fall and winter, natural temperature inversions develop to trap pollutants in a pool of cold air lying in the bottom of the basin. Because air temperature usually decreases with increasing altitude, a temperature inversion occurs when stable atmospheric conditions cause air temperatures to increase with increasing altitude. In the Paso del Norte air basin, thermal inversions begin in September when the nights grow longer; inversions become increasingly frequent in November, December, and January (TNRCC 1991). During summers, stable atmospheric conditions combined with hot temperatures and abundant sunshine catalyze the photochemical reactions that convert gaseous emissions into ground-level ozone.

Although high winds can clear the air basin of pollutants, low-to-moderate wind speeds lead to mixing within the air basin. El Paso, Tex., and Sunland Park, N.M., are downwind of Ciudad Juárez, Chih., roughly 15% of the time; the reverse is true about 20% of the time. Paso del Norte is located in an arid desert region with annual rainfall varying from five inches to 12 inches (10.8 centimeters [cm] to 30.5 cm). The dry top layers of soil contain fine particles readily entrained by winds that frequently transport airborne dust into the basin from adjacent desert areas.

Socioeconomic Characteristics of the Paso del Norte Air Basin

After the U.S.-Mexican War (1847), in which Texas and New Mexico became part of the United States, the Paso del Norte region became an international border with shared natural resources and the exchange of everything from customs, employment, goods, and services to pollution. El Paso and Ciudad Juárez also became international border cities. This blend of cultures, divided by political and geographic boundaries, has produced an economically viable and dynamic international community. In fact, Paso del Norte is the largest international metroplex in the world (El Paso MPO 1998).

The current population of the combined communities of El Paso, Ciudad Juárez, and Sunland Park exceeds 2 million; about one-third of those residents live in El Paso. It is anticipated that the El Paso population will grow by 18,000 people per year and the Ciudad Juárez population will grow by about 40,000 people per year. The population of Doña Ana County, N.M., is expected to double in the years between 1990 and 2015 (from 135,000 to 332,000), with growth occurring mostly in the southern end of the county as the area around the Santa Teresa Port of Entry is developed. El Paso's population is estimated to increase to 980,000 by 2020 (El Paso MPO 1998).

According to the EL Paso Metropolitan Planning Organization (MPO), approximately 200,000 vehicles are registered in El Paso and 350,000 vehicles are registered in Ciudad Juárez. The older vehicle fleet of Ciudad Juárez means the rate of emissions per vehicle in Ciudad Juárez is greater than that of El Paso (Rincón and Emerson 2000). Meanwhile, active movement of vehicles across the international border (Parks, et al. [2003] estimate about 40,000 vehicles per day) concentrates vehicle emissions at topographically low points in the air basin along the Rio Grande.

The economies of the border communities are intricately interwoven through commercial, industrial, financial, and service activities. Despite this interdependence, there are considerable differences between cities, generated primarily by the unequal distribution of income and the unequal consumption capacity of various social groups in the region. By U.S. standards, El Paso and southern Doña

Ana County are relatively poor, with a per capita income at 59% of U.S. per capita income (El Paso MPO 1998). In Ciudad Juárez, 63% of the population earns less than the Mexican poverty level, which is defined as an income three times the minimum wage (Suarez and Chavez 1996).

A major component of regional trade is found within the maquiladora sector. Maquiladoras are manufacturing facilities set up as "off shore" assembly plants under Mexican law, and under U.S. law they are considered duty-free assembly and cost centers. Companies from the United States, Europe, and Asia operate the facilities directly or in conjunction with Mexican investors to reduce product assembly labor costs. Given specific tariff advantages by the U.S. Department of the Treasury, the maquiladora sector has thrived on inexpensive and plentiful labor from Mexico and easy physical access to the U.S. market. Hundreds of plants that employ thousands of workers in Mexico have accelerated the economic growth of the region as well as its urbanization. This growth and urbanization has led to environmental problems that, like the economic benefits, both communities must share.

The growth of both the maquiladora sector and the population of Ciudad Juárez follow a positive feedback loop. As more companies open facilities in Ciudad Juárez, more workers arrive from other regions in Mexico seeking employment. The population of Ciudad Juárez is estimated to reach 2 million in 2010 (SEMARNAT 1998). In El Paso and Doña Ana Counties, U.S. and multinational corporations are locating production facilities to take advantage of expanding trade under the North American Free Trade Agreement (NAFTA) and convenient access to multi-modal transportation hubs and enterprise zones located in both countries.

The interdependent growth of both population and maquiladoras has occurred at such a rapid rate that growth in border infrastructure has not kept pace with the growth in demand for services. For example, population growth leads to rapid growth in housing needs, which are met by expanding the existing periphery of the Paso del Norte urban area. Roads to the new settlements are frequently unpaved. Roughly 47% of all streets in Ciudad Juárez are unpaved (Velázquez 2002). PM entrained into the air by traffic on unpaved roads creates health, cleanliness, and aesthetic problems for local residents. In El Paso and Doña Ana Counties, low density development associated with suburbanization causes long travel times and travel distances between land uses. The result is an increase in vehicle miles traveled (VMT) and associated difficulties in meeting air quality standards for PM, carbon monoxide, and ozone (El Paso MPO 1998).

Air Quality Issues

Beyond the smoke stacks of the Asarco, Inc. smelters in downtown El Paso and Ciudad Juárez, a monument stands representing Capitan-General Don Juan de Oñate, who led a Spanish colonial expedition across the river in 1598. He named this location "El Paso del Río Norte," which was later shortened to "Paso del Norte." Some 370 years later, in about 1968, the local research community residing in Paso del Norte began to work on air quality issues, stimulated by their observations of poor air quality and the then-recent appearance of the American Association of Science report from its Air Conservation Committee (AAAS 1965).

The National Ambient Air Quality Standards (NAAQS) are promulgated by EPA to measure air quality. NAAQS consists of seven different parameters, six of which are chemical-specific—sulfur dioxide (SO_2), hydrocarbons, ozone, nitrogen oxides (NO_x), carbon monoxide, and lead (Pb); the seventh is a broad measure of the density of suspended particles in the lower atmosphere. This last parameter is the indicator of air quality used in the Border Plus Twenty Years (B+20) model. Particulate matter with a mean aerodynamic diameter of less than 10 microns is referred to as PM_{10}. Because PM_{10} consists of very small particles, it remains suspended in the air for long periods of time and is easily inhaled deep into the lungs. High PM_{10} concentrations have been associated with increased rates of respiratory disease, cardiovascular disease, and mortality.

The most obvious evidence of air quality degradation in Paso del Norte is the frequent, well-defined haze hanging over the region during the morning hours. Parts of El Paso County fail to meet NAAQS for PM_{10}, carbon monoxide, and ozone. Sunland Park exceeds NAAQS for ozone and PM_{10}. Ciudad Juárez air pollution levels exceed the Mexican ambient air quality standards for PM_{10}

(150 micrograms per cubic meter [$\mu g/m^3$] for a 24-hour average and 50 $\mu g/m^3$ for the annual average), ozone (0.11 parts per million [ppm] for a one-hour average), and carbon monoxide (11 ppm for an eight-hour average). The Mexican long-term, averaged standards are comparable to, or more stringent than, those of the United States.

The principal contributors to PM_{10} emissions in border communities are vehicular emissions, dust from unpaved roads, and atmospheric emissions from industrial processes. These contributing factors are different on opposite sides of the border. For example, the issue of dust particles from unpaved roads is important in Mexico but much less so in the United States. The average mass of PM_{10} emitted per VMT is greater in Mexico than in the United States due to the older cars in Mexico, but the car ownership rates and average VMT per car are greater in the United States. Economic expansion has increased traffic between border cities, which causes longer idling times of vehicles in queue to cross the international border from Mexico into the United States, thus aggravating the region's air quality.

A collaboration of El Paso city and county officials and academics led to a summary publication of much of the 1980s air quality effort in the Paso del Norte region (Gray, et al. 1989). This publication includes a wealth of original data and analysis over several years for carbon monoxide, ozone, and total suspended particulates (TSP). El Paso was out of federal compliance during this time and no data existed for Ciudad Juárez. Carbon monoxide, in particular, had been found to have dramatically high values for hourly maxima—nearly 200 ppm at some times, according to measurements taken at inspection stations. This work ultimately led to the redesign of a clean air supply system for inspection booths on international bridges.

Other issues addressed by Gray, et al. (1989) include the subjects of various symposia, proposals for international accords, and impacts on a new treaty, the La Paz Agreement, which was signed in 1983 by Mexican President Miguel de la Madrid and U.S. President Ronald Reagan. The La Paz Agreement and future annexes, which also have the standing of treaty in U.S. law, specify that EPA and the Mexican Secretaría de Desarrollo Urbano y Ecologia (SEDUE) are the designated federal agencies and that local officials are to be included. This agreement permitted EPA to spend money for air pollution studies or abatement programs that would take place in the border area. At the time, the Mexican government considered the border's air quality to be of lower priority than the markedly more serious air quality problems of Mexico City. In the 1990s, the La Paz Agreement expedited the process for acquiring air pollution data by the various responsible Mexican agencies in the Paso del Norte region. Today, carbon monoxide, ozone, NO_x, and PM_{10} levels are routinely measured on both sides of the border.

Air Quality Standards, Monitoring, and Emissions Inventory

Mexico and the United States have both established health-based air quality standards. When air quality concentrations exceed these proscribed levels, both governments mandate that local agencies use control programs to take action to improve air quality. Table 1 shows U.S. and Mexican air quality standards. In some cases, the standards differ between the two countries. Most notably, the recently adopted eight-hour ozone and $PM_{2.5}$ (particulate matter less than 2.5 microns in diameter) standards do not currently exist in Mexico. Air quality monitoring networks have been deployed throughout the air basin to measure human exposure to these pollutants. There are nine monitoring sites operated by the Texas Commission on Environmental Quality (TCEQ) in El Paso, 11 stations in Doña Ana County operated by the New Mexico Environment Department (NMED), and six monitoring sites in El Paso operated by El Paso City County Health and Environmental District (EPCCHED). The Ciudad Juárez Dirección General de Ecología y Protección Civil (General Directorate of Ecology and Public Safety, in Spanish DGEPC) obtains daily air quality data from equipment at five Ciudad Juárez air quality monitoring sites. EPCCHED provides maintenance, quality control, and technical support for these stations.

Table 1. U.S. and Mexican Air Quality Standards

Pollutant	Mexico		U.S.	
	Units	Average	Units	Average
Ozone	0.11 ppm	1 hour	0.12 ppm	1 hour
Sulfur dioxide	0.13 ppm	24 hours	0.14 ppm	24 hours
	0.03 ppm	Annual arthimetic mean	.03 ppm	Annual arthimetic mean
Nitrogen dioxide	0.21 ppm	1 hour	0.25 ppm	1 hour
			0.053 ppm	Annual arthimetic mean
Carbon monoxide	11 ppm	8 hours	9 ppm	8 hours
			35 ppm	1 hour
Total suspended particles	260 µg/m³	24 hours	n/a	n/a
	75 µg/m³	Annual geometric mean	n/a	n/a
PM_{10}	150 µg/m³	24 hours	150 µg/m³	24 hours
	50 µg/m³	Annual arthimetic mean	50 µg/m³	Annual arthimetic average
Lead	1.5 µg/m³	3 months arthimetic mean	1.5 µg/m³	3 months arthimetic mean

Source: EPA and SEMARNAT 1996

The United States and Mexico have established air quality monitoring networks for the Paso del Norte air basin to measure ambient concentrations of particulate pollution, ozone and its precursors (volatile organic compounds [VOCs] and NO_x), carbon monoxide, SO_2, lead, and air toxics. TCEQ, the city and county of El Paso, Ciudad Juárez's municipal government, and NMED operate Paso del

Norte air monitoring stations. Most stations include PM_{10}, carbon monoxide, and NO_x monitoring. Non-methane hydrocarbons are monitored at the Chamizal site in El Paso.

The total number of monitoring stations, exclusive of EPA's new $PM_{2.5}$ program, are 13 in the United States and six in Ciudad Juárez. Because new monitors are required to measure $PM_{2.5}$ under the new U.S. fine particle standards, TCEQ and NMED are in the process of establishing a new $PM_{2.5}$ monitoring network for El Paso and Doña Ana Counties. Once the networks are completely deployed and three years of data are collected, EPA will make nonattainment designations, likely sometime between 2003 and 2005. EPA and Mexico's Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) are working on a proposal to deploy $PM_{2.5}$ monitors in Ciudad Juárez.

There are eight $PM_{2.5}$ monitoring stations running or being made operational in Texas and two in New Mexico, for a total of 10 stations in the U.S. portion of Paso del Norte. It is expected that the fine fraction of PM_{10} may be more important for health risk assessment. The first report of $PM_{2.5}$ sampling in Texas, including one sample in downtown El Paso at the Tillman Health Center, appeared in December 1998 (Tropp 1998). The proposed regulation is that the 24-hour average $PM_{2.5}$ level should not exceed 65 $\mu g/m^3$ for a three-year average of annual 98th percentiles at any population-oriented monitoring site. The El Paso preliminary results show maxima above this level.

The severity of air quality problems in the Paso del Norte area have caused the federal governments of both the United States and Mexico to mandate that air quality control programs be implemented to attain health-based air quality standards. Through the U.S. Clean Air Act, TCEQ and NMED are required to submit State Implementation Plans (SIPs) to EPA that outline air pollution control programs for nonattainment areas. SEMARNAT worked with the state of Chihuahua and the municipal government of Ciudad Juárez to develop and implement the *Air Quality Management Program for the Improvement of Air Quality in Cd. Juárez 1998–2002* (SEMARNAT 1998).

Air quality planning and assessment are the first steps in the air quality management process. Monitoring, characterizing air quality, and developing and maintaining an emissions inventory, in conjunction with air quality modeling, are indispensable tools for the design and implementation of strategies that will achieve air quality standards established by both nations.

Emissions inventories allow for analysis of major emissions contributions and make it possible to determine the source categories for emissions control. Accurate emissions inventories in conjunction with air quality modeling are the tools employed to develop appropriate control strategies for attainment of air quality standards. Under the U.S. Clean Air Act, nonattainment areas must develop emissions inventories, conduct air quality modeling, and develop control strategies to achieve air quality standards. These analyses are submitted to EPA in the SIP. For Mexico, such tools constitute the methodological foundation of the air quality programs relying on environmental operating permits and statements of operation (for the industrial sector), Mexican official *norms,* emission factors, and mass balance modeling (Rincón 2002).

Emissions inventories and models have been more intensely examined in the 1990s than ever before. TCEQ periodically produces the El Paso Industrial Emissions Inventory. The most recent monitoring data are available at http://www.tceq.state.tx.us/index.html. This information, and the hydrocarbon source apportionment section of the 1996 Paso del Norte Ozone Study (Fujita 1998), was combined with the development of a grid map emission inventory for the entire Paso del Norte region (Haste, et. al. 1998).

Impact of Air Quality on Health in the Paso del Norte Air Basin

Although recognized to be important, the impact of air quality on human health in the Paso del Norte air basin has received only limited study. As a consequence, Paso del Norte-specific relationships between particulate concentrations and human health conditions are difficult to define. For example, particulates in the Paso del Norte air basin often include both urban and non-urban material that falls within the respirable size range. Although substantial literature documents the negative effects of dust on human health, few data exist concerning the degree to which the undisturbed desert lands contribute to particulate matter entrained in the air basin. In other areas of the western United States (Hefflin 1994; Schwartz 1999), the urban particle fraction (the amount of PM_{10}, $PM_{2.5}$, and total suspended particles in the air) alone has been shown to increase the mortality rate (Pope 1999).

Studies of the adverse effects of inhaled fine particles in Paso del Norte have appeared only recently. Hart, et al. (1999) report that the first medical studies to clearly relate contaminated air at El Paso and Ciudad Juárez to a broad range of respiratory problems, such as asthma, bronchitis, lung cancer, and emphysema, predated by 26 years the first study in 1991 of pediatric asthma by VanDerslice, et al. Hart, et al. (1999) modeled pediatric emergency room admissions in 1994 and 1995 for respiratory illness as a function of PM_{10} and ozone. In Paso del Norte, an increase in asthma-related emergency room visits was found to be associated with a decrease in dew point temperature on the same day and an increase in PM_{10} two days before. Risk assessment of exposure to fine particles in the Paso del Norte air basin has received little attention. Adverse health effects are commonly anticipated after exposure to inhalable fine particles produced by urban air pollutant sources, sandstorms, or a combination of the two (Hefflin 1994; Pope 1996). During the 1980s, attention focused on the air quality consequences of vehicles waiting to cross international bridges. Research explored such variables as numbers of vehicles in queue, waiting time, vehicle emissions, general air pollution, and health consequences for people living in and around the international bridges.

Roumiue, et al. (2003) studied the impact of PM_{10} and ozone on children's health in Ciudad Juárez. A relationship between ozone levels and emergency room visits by children for treatment of asthma and for treatment of respiratory infections has been identified. In children up to 5 years of age, the exposure to ozone is also related to infection in the lower respiratory tract with a late manifestation of four days. An increase of 20 ppm in the maximum eight-hour moving average prior to medical consultation is related to an increase of 12.7% in the risk of infection in the lower respiratory tract. The risk of infection is increased by 15% subsequent to an increase of 20 ppm in the one-hour daily maximum during the five days prior to medical consultation. No correlation is found between children's health and ambient PM_{10}. Multi-pollutant modeling with ozone yields a similar lack of correlation. In general, the air pollutants bear little relationship to respiratory-related mortality in the children sampled. Nevertheless, there are indications that elevated ambient PM_{10} could increase the risk of respiratory-related mortality in children aged one month to one year.

Air Quality Institutions in Paso del Norte

The 1990s in Paso del Norte were characterized both by more research and a much higher level of citizen and non-governmental organization (NGO) participation in air quality issues. For several years the Paso del Norte Air Quality Task Force has been active as a forum for debate and presentation of issues on both sides of the border. Meeting locales typically alternated between El Paso and Ciudad Juárez, with some meetings in Sunland Park, N.M. The meetings were attended by representatives of all local, state, and federal agencies having a vested interest on both sides of the border. The academic research community has been well-represented by local NGOs such as the Clean Cities Coalition and by international NGOs such as Environmental Defense.

The Paso del Norte Air Quality Task Force supported the formation of an International Joint Advisory Committee for the improvement of air quality in the air basin that covers Ciudad Juárez, El Paso, and Doña Ana County. The International Joint Advisory Committee now meets regularly to address air issues in the basin. The meeting notification and minutes distribution are managed through TCEQ's Region 6 office in El Paso (Valenzuela 1999).

One issue the task force lobbied for was commuter lanes to speed up bridge crossing and reduce transborder traffic waiting times. Various "fast identification" methods for pre-registered drivers and the commuter lane have been developed, according to a report to the Joint Air Quality Advisory Committee. Another issue addressed involves the export to Ciudad Juárez of U.S. automobiles that fail U.S. emissions tests. These issues cause a conflict between the economic gain from exportation of the vehicles versus efforts to reduce mobile source emissions. Other issues involve whether U.S. oxygenated fuels should be exported to Ciudad Juárez and what will replace MTBE (methyl-tertiary-butyl-ether) in the United States if this gasoline oxygenator is banned. Grassroots political action and citizen participation in ad hoc groups concerned about air quality have been important in raising public awareness about air quality in Paso del Norte.

A variety of public and private groups and organizations are now involved in air quality issues within Paso del Norte (Parks, et al. 2003). Some companies and utilities, through their environmental divisions, have participated in ways that have both present and future value. Two organizations with facilities on the Rio Grande have made their engineers available to display the most sophisticated modern air pollution control equipment to students in the area. One such company is Asarco, Inc. Its facilities essentially eliminated the hundreds of tons per day of sulfur oxides flowing from its smoke stack with "ConTop" smelting reactors, installed in 1993. The former waste product was then marketed as sulfuric acid. This facility is presently idle as a consequence of low copper prices and thus, for the first time in 100 years, is not contributing to air pollution. El Paso Electric Company has two plants in Paso del Norte that burn clean natural gas and have sophisticated temperature feedback controls to prevent NO_x emissions from exceeding regulatory limits. This utility has a pro-active environmental education program and successfully interacts with academic institutions in the area. The various public institutions involved in air quality in Paso del Norte are listed in Table 2.

Table 2. Institutions Involved in Air Quality in Paso del Norte

Local governments	Air Group, El Paso City-County Health Department Dirección de Desarrollo Urbano y Ecología del Gobierno del Municipio de Juárez
State governments	Dirección General de Desarrollo Urbano y Ecología del Gobierno del Estado de Chihuahua New Mexico Environment Department Texas Commission for Environmental Quality Western Governors' Association
Federal government	Instituto Nacional de Ecología Secretaría de Medio Ambiente y Recursos Naturales U.S. Environmental Protection Agency U.S. Centers for Disease Control and Prevention
International; U.S.-Mexico	Joint Advisory Committee for the Improvement of Air Quality in the Ciudad Juárez, Chihuahua; El Paso, Texas; Doña Ana County, New Mexico Air Basin
Academic institutions	Arizona State University New Mexico Institute of Technology New Mexico State University University of Texas at El Paso University of Utah San Diego State University Universidad Autónoma de Ciudad Juárez Southwest Consortium for Environmental Research & Policy
Non-governmental organizations	Border Health Research Center of the Paso del Norte Health Foundation Environmental Defense Clean Cities Coalition Physicians for Social Responsibility Paso del Norte Air Task Force

Source: Parks, et al. 2003

Future Issues of Air Quality Policy and Research

Uni-Basin Concept

Air pollution knows no political boundaries and travels across both state lines and the international border. El Paso, Ciudad Juárez, and Doña Ana County share a common air basin. Both policymaking and research would benefit from increased coordination between agencies with different local jurisdictions. Because of the international and state borders that lie within the air basin, binational, tri-state cooperation is an element critical to solving the area's air quality problems. Cooperation will be needed in the implementation of an area-wide strategic plan (Rincón 2002).

Pollutant Credit Reduction Exchange

Emission trading is an innovative U.S. environmental policy designed to control air pollution through the exercise of free market forces. Currently, the United States has a viable market in permits for SO_2 traded at the Chicago Mercantile Exchange. Permit trading is currently used to allocate SO_2 emissions for coal-fired electric generating plants in the United States, and is gaining ground between U.S. and Canadian firms through a Pilot Emission Reduction Trading (PERT) program. Such a program has yet to be tried in the border area between the United States and Mexico. One idea is to develop a program for international exchange between the United States and Mexico in the El Paso-Ciudad Juárez air basin. Due to recent decentralization of air quality management efforts in Mexico, the Mexican government has established, under the overall supervision of the Instituto Nacional de Ecología (INE), a framework for a collective implementation action plan for air quality improvement. Under this new scenario, INE and SEMARNAT could examine the possibilities of a border emission permit trading mechanism (Ghosh 2001).

Environmental Impact Assessment

Transboundary Environmental Impact Assessments (TEIAs) are an important emerging approach intended to address transboundary environmental impacts of border industrial projects. Because there are fewer environmental regulations and construction permits are easier to obtain than on the U.S. side of the border, border industrial projects are located in Mexico rather than the United States (Rohy and Sweedler 2002).

Pollutant Emissions Inventory

An emissions inventory project for the entire country of Mexico has been initiated in the six Mexican border states and has recently included the four American border states (Fields 2003). On the Mexican side, INE is conducting an emissions inventory with technical assistance from EPA, the Western Governor's Association, and support from the Commission for Environmental Cooperation of North America.

Air Quality Sector of the Paso del Norte System Model

The air quality sector of the Paso del Norte system model captures a highly simplified version of how particulates are emitted and transported in the Paso del Norte air basin. Airborne particulates are generated by a mix of mobile sources (vehicle exhaust and traffic on unpaved roads), stationary urban sources (brick kilns, industrial activity, commercial activity, residences, and urban land), and stationary non-urban sources (irrigated land and dry land). Because there are important differences in the magnitude and frequency of particulate emissions on each side of the border, emissions from El Paso and Ciudad Juárez are computed separately before total particulate contributions to the air basin are computed. This approach enables the presentation of the possibility that emissions generated on either side of the border are transferred across the border. In static air conditions, particulate-laden air will tend to flow down slope to the Rio Grande from sources located within each community. At the Rio Grande, airborne particulates mix with those generated by vehicular traffic at border crossing bridges. During windy periods, particulates may be transported from one community to the other, blown completely out of the air basin, or transported into the air basin from adjacent dry land.

Explicit estimates of annual particulate emissions from mobile sources in both El Paso and Ciudad Juárez are based on computed vehicle kilometers traveled annually by a representative mix of vehicles (gasoline and diesel). Growth in vehicle kilometers traveled is linked directly to growth in urban land area computed in the land use sector of this volume (Chapter II-6).

Particulates generated by traffic on unpaved roads are estimated by computing the total length of all roads, estimating the portion that remains unpaved, and multiplying by the mean annual particulate mass emitted per kilometer. A portion of the new roads constructed in response to urban growth is assumed to remain unpaved unless a commitment is made to pave existing roads to reduce particulate emissions. The dynamic interaction between land use change and growth in road lane miles is described in more detail by Emmi (2003).

Implicit estimates of mobile emissions are included as part of the total emissions per employee working in manufacturing, trade, and other sectors of the economy such as commercial, retail, and service. The number of employees working in each sector of the economy is tracked in the economy model sector of this volume (Chapter II-4). The total emissions per employee also includes estimated contributions from localized stationary sources associated with each sector of the economy.

The brick kiln industry of Ciudad Juárez, however, is considered separately because this is a potential area for policy action to reduce particulate emissions. The number of kilns operating in the air basin is assumed to increase as new dwellings are added in response to population growth in Ciudad Juárez. Emissions per brick kiln are estimated from the results of research aimed at assessing strategies for reducing kiln emissions (Lara 2000).

Although it is relatively straightforward to estimate annualized patterns of particulate emissions within the air basin, it is much more difficult to compute aggregate, annualized particulate concentrations that can be effectively used in the quality of life model sector (Chapter II-1). Comparing historical emissions rates to records of particulate concentrations (Li, et al. 2000) provides a crude empirical basis for converting particulate emissions to particulate concentrations. Embedded in the calculation is an option to transfer a portion of the particulates generated in one city to the other city. Ultimately, mean annual particulate concentrations are computed separately for both El Paso and Ciudad Juárez. Although not fully implemented, options are also made available to adjust the way that a drier (or wetter) future climate might modify the relationship between emissions rate and mean annual concentration.

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Afterword

Interdisciplinary and Team Dynamics

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Introduction

The U.S. National Science Foundation (NSF) has been attempting to foster the formation of interdisciplinary teams by funding research projects under the Biocomplexity in the Environment Competition (NSF 2003). The goal of NSF's program overlaps with the Border Plus Twenty Years (B+20) Project. That goal is to understand "...the complex interdependencies among living organisms (including humans) and the environments that affect, sustain, and are modified by them" (NSF 2003). Environmental biocomplexity research requires that the following be recognized:

- The high degree of complexity and uncertainty associated with human-environment interactions
- The interplay of interactions within and between different environmental systems
- That regulatory and management decisions must be made regarding systems where data and functional relationships are both uncertain and sparse
- The broad range of spatial and temporal scales
- The multiple levels of biological organization

Because many problems currently facing humanity bear these attributes (including human-environment interactions at the U.S.-Mexican border), NSF wants to improve the ability to perform biocomplexity research by developing ways to improve interdisciplinary research strategies, guide interdisciplinary team building, and foster the development of interdisciplinary skills in young researchers. The B+20 project team provides one example of the formation and function of an interdisciplinary team.

NSF (2003) recognizes that "[a]dvancing our understanding of the nature and role of biological complexity demands increased attention and new collaborations of scientists from a broad spectrum of fields—biology, physics, chemistry, geology, hydrology, statistics, engineering, computation, social sciences." It is becoming increasingly clear, however, that the academic researchers currently applying for, and winning, the research funds can benefit from learning how to frame, plan, and perform interdisciplinary research that integrates knowledge across a broad range of disciplines. For example, Salter and Hearn (1996) note that interdisciplinary projects may fail by evolving toward a group of loosely connected monodisciplinary studies that fail to achieve the intended interdisciplinary goals. One factor that inhibits interdisciplinary research is the lack of well-prepared interdisciplinarians. Klein (1990) suggests that the personality traits of such team members might include "...reliability, flexibility, patience, resilience, sensitivity to others, risk-taking, a thick skin, and a preference for diversity and new social roles." Thus, it is increasingly apparent that team members require fundamentally appropriate personality traits, in addition to both discipline-specific and interdisciplinary training, if interdisciplinary teams are to be successful.

The authors posit that various factors inhibiting the success of interdisciplinary projects can be captured in the concept of "interdisciplinary overhead." This concept is analogous to the "transaction costs" or effort incurred in choosing, organizing, negotiating, and entering into business contracts (Williamson 1985). Research projects with intrinsically high interdisciplinary overhead require a carefully planned and facilitated process that helps dissipate the overhead while projects with intrinsically low overhead are more likely to succeed with much less cost in terms of financial expense, personal energy, and human resources. Obtaining a better understanding of the interplay between factors that contribute to interdisciplinary overhead help frame, plan, and complete successful interdisciplinary research projects. Factors that lead to high interdisciplinary overhead in the B+20 project include the following team attributes:

- Wide geographic distribution
- Drawn from multiple institutions
- Broad cultural diversity
- Differing native languages
- Multinational context
- Monodisciplinary personalities and foci
- Inexperienced in interdisciplinary research
- Selection by project administration that is external to the team
- Lack of full control over project planning and direction

Having defined the concept of interdisciplinary overhead, the authors suggest that high interdisciplinary overhead leads to low levels of "interdisciplinarity"—a non-measurable quantity that influences the likelihood for success of an interdisciplinary project. For example, low overhead leads to high levels of interdisciplinarity within the project team and greater likelihood for project success. A project with low overhead is initiated with a high degree of interdisciplinarity because the project team is self-selected through an intense proposal-writing process. By developing a strategy that counters the factors previously listed, the resulting low interdisciplinary overhead enables a team to rapidly build interdisciplinarity and deliver an integrated research product. At the other end of the spectrum, a project team with high overhead takes longer to build even a moderate degree of interdisciplinarity. By failing to overcome the interdisciplinary overhead, the high-overhead project team devolves to a group of monodisciplinarians involved in a loosely connected group of monodisciplinary projects. An intermediate case might represent the interdisciplinarity trajectory of a project team that employs a variety of good strategies for reducing interdisciplinary overhead, but cannot fully overcome the limitations imposed by the complexity of the project and the characteristics of the team members. The B+20 project team likely fits in the intermediate category, having declined from a very high value in the early stages of the project to a current low-to-moderate value.

To develop its modeling framework, the team has attempted to work across at least three significant boundaries: disciplinary, institutional, and sectoral. Each of these exchanges brings additional complications. In order to model the U.S.-Mexican border region, the team requires technical expertise from a variety of scientific disciplines. Developing an integrated model requires epistemological assumptions and activities that do not always match disciplinary expectations. Ultimately, the final product is unlikely to match the disciplinary demands faced by any team member. Team members also are drawn from multiple institutions, each with different governance structures and mandates. Finally, because the model is intended as a decision-support tool for use in this region, the team must cross from the academic sector into the infrastructure sector.

One approach to dealing with this complexity is to identify potential flashpoints (challenges associated with crossing traditional boundaries) and assign one person to coordinate each flashpoint. If possible, the person's technical expertise should match their assigned role. Key roles (in addition to a project leader) for this project include:

- Model Coordinator
- Team Process Facilitator
- Outreach Facilitator

It is generally not productive for one person to coordinate multiple flashpoints. It is reasonable to expect the project leader to facilitate one of the potential flashpoints. For example, in this case the project leader could serve as the model coordinator, team process facilitator, or outreach facilitator, as indicated by individual expertise. The project leader should not attempt to play all of these roles, however. If desired, facilitators/coordinators may be part of the research team unless the level of conflict among team members is such that it requires an outside party to facilitate productive interaction. The three or four people playing these roles must work together to ensure that they do not undermine each other's tasks. It is generally best if the people playing these roles remain stable over the course of the project. Because the B+20 project has multiple study locales, however, it may be more reasonable to work with a different outreach facilitator for each locale.

Ultimately, the B+20 project is focused on developing a better understanding of border urban ecosystems that include the human decision-makers, managers, and citizens that influence how the community nested within the ecosystem operates. Nilon, et al. (2003) suggest that to be effective, this understanding must be gained by not only the members of the project team, but by those living in, and making decisions about, the community. Furthermore, Harisson and Burgess (1994) suggest that developing an understanding of urban ecosystems requires the recognition that "understanding" is a participatory and deliberative process, not just a one-way exchange of facts and information about ecological, physical, and social systems between experts and the public. Although the B+20 project team has engaged stakeholders and decision-makers in several discussions that have influenced project framing and direction, team members have been slow to build a coherent process for fully engaging stakeholders and decision-makers in defining attributes of, and questions to be explored with, the system model. The project team's early tentativeness in developing the modeling concept, the lengthy period required to develop team interdisciplinarity, and their lack of experience in community engagement are key factors that have inhibited productive community engagement. Lessons learned from this experience, however, are leading the team to begin their focused work in the Mexicali-Imperial Valley community (located on the border of California and Baja California) by quickly building on existing community partnerships established by the B+20 outreach coordinator.

Stakeholder Engagement

The project team has struggled with the issue of how and when to engage with individuals, communities, businesses, and agencies holding a vested interest in and concern about the future of the border. For this project to make an impact on quality of life on the U.S.-Mexican border, models of the borderland human-environment dynamic must be accepted, viewed as useful, and exercised by stakeholders who have participated to varying degrees in model development. To date, the project team has worked largely in isolation as members developed their systems thinking and modeling capacity in an interdisciplinary team context.

The first stakeholder meeting was held at the Hilton Hotel in El Paso, Tex., on May 15, 2001. This meeting coincided with a working meeting of the project development team. It was not originally intended to be a stakeholder meeting so much as an opportunity for the project team to meet with a select group of community representatives to plan the stakeholder involvement process. Instead, the invitation list was expanded to include a broader group of community leaders and the meeting evolved into a *de facto* stakeholder meeting. Twenty-four individuals, in addition to the members of the project team, participated in the meeting.

The meeting began with a luncheon, during which a presentation was made to introduce attendees to the project. Following the luncheon, participants were invited to a separate workroom and introduced to the STELLA® program through an example from the land use and transportation sector that illustrated the effect of feedback loops. Subsequent discussion was prompted using three questions:

- Who could use this model?
- How do we involve stakeholders?
- What should we include or not include in the model?

Users of the Model

Initially, responses to the question about who could use this model generated the expected list of utility agencies, irrigation districts, resource management agencies, regional planning agencies, municipal land use and transportation planners, foundations, business advocacy organizations, and non-governmental organizations (NGOs). One person suggested that the research team might develop a matrix of potential users for dissemination. Although participants were intrigued by the possibility that B+20 could be a tool to break down institutional barriers within the community and thereby promote political understanding, participants were doubtful that lawmakers and other high-level policymakers would directly use the model. Rather, if the B+20 model is to become a viable decision-support tool, participants suggested that the emphasis should be placed on making the model available to support staff of policymakers.

One participant suggested that the B+20 model might find value not as a decision-support tool but as an educational support tool. The potential value of the model for educational purposes was previously unrecognized. If this option is pursued, it will influence the nature of the model and the types of user interfaces provided in the computer program.

Some participants voiced concerns that the value and application of the model would be limited if direct access to it were restricted to the research team. Instead, participants advocated for the B+20 model to be designed to enable individual users to modify program parameters to meet their needs and interests. This generated further discussion of the workability of this approach—it was determined that it would limit users to those entities that were able to procure the software program.

Involving Stakeholders

Participants expressed the opinion that the model's acceptance requires active involvement of people and organizations, and thus they emphasized the need for more outreach efforts. Three general principles were suggested as a result of the discussion:

- The research team should seek a "buy-in" of the B+20 modeling effort from the intended users of the model, from the inception of the model development process
- The model's subsequent development should be influenced by the needs and potential applications of the stakeholders
- Stakeholders must have both an active and continuing involvement in the model's development to establish and maintain their trust

Several participants expressed opposition to the creation of a new group to provide stakeholder feedback. Instead, they suggested that the B+20 research team use existing organizations to promote stakeholder involvement. A concern was raised that fewer organizations might be available on the Mexican side of the border, but another stakeholder observed that increasing levels of community involvement have changed the political landscape in Mexico. One participant stated that formal stakeholder meetings might be premature; he suggested that the research team first have one-on-one meetings with potential stakeholders and then bring the different stakeholders together in a formal meeting. He further noted that outreach efforts might involve a large number of participants, but input regarding individual sectors should be limited to small groups. Different applications of the B+20 model will require different approaches to stakeholder involvement. For example, if the educational support potential of the model is to be realized, an effort should be made to identify users in local universities and high schools.

Elements to Include in the Model

The ultimate development of the B+20 model will depend on the types of questions addressed by the model. Thus, identifying the necessary model elements and their relationships to each other is of importance only relative to the intended uses of the model. Despite this seemingly straightforward logic, the types of issues that might be analyzed by the model cannot be anticipated without first being assured that the basic model structure encompasses topics important to community leaders. Therefore, a final portion of the stakeholder discussion focused on the completeness of the list of elements previously identified by the research team, because this list forms the backbone structure of the model. The question put to stakeholders was simply stated as, What should we include or not include in the model?

The discussion of additional elements that might be included in the model actually commenced prior to the workroom discussion session. During the luncheon portion of the meeting, a participant made an impassioned plea to expand the model to include a separate housing sector. Comments from other participants indicated a broad consensus that housing quality is directly related to the quality of life of border inhabitants. Issues of concern include both the adequacy of supply and the quality of housing. Conceptually, inadequate housing supply results in overcrowding, whereas excessive supply may cause abandonment and have a blighting influence on a community. Housing quality might be quantified by classifying housing either as meeting standards or as substandard. This simple division, however, may not be adequate to determine the magnitude of investment required to rehabilitate substandard housing if a significant percentage of a community's housing is severely substandard. Integrating housing with other sectors of the model poses different challenges. Housing demand is a factor of population change, but, more directly, the number of housing units required depends on a community's social composition, as this determines average household size. This level of detail is not currently built into the population sector. Similarly, housing demand is influenced by economic conditions. If new employment opportunities are predominantly low-wage, a growing community is more likely to have a lack of affordable housing, and this, in turn, could lead to an increase in substandard housing and overcrowding. The economy sector may not be sufficiently developed to project wage levels.

During the workroom discussion, participants expressed interest in better identifying crossborder links. They noted that investment in a city on one side of the border has an effect on its twin city on the other side, and thus an important, though seldom acknowledged, functional integration exists. The nature and, more importantly magnitude, of such economic links are neither well understood nor broadly appreciated. In this same regard, participants expressed interest in using the model to better identify transborder links on environmental issues such as air quality and water supply, and the implications of continued manufacturing growth on the region's energy demands. The economic future of the region will be affected by expected increases in north-south and east-west commerce, and therefore the regional economy is highly subject to external influences. Participants suggested that such external drivers be built into the model.

Several participants expressed a desire for a spatial element in the B+20 model. Initially this question was framed simply as, "What will El Paso look like in 20 years?" One individual commented that even energy issues might have a spatial component. During this portion of the discussion, the research team articulated the limitations of the current modeling approach. Because it lacks an explicit spatial component, the first version of the model will not be able to address issues such as the distribution of poverty-stricken neighborhoods or the potential expansion of city limit boundaries. The research team offered that a spatial component might be incorporated if the project were funded for a second phase of development.

Another subject of discussion was the need to include cost parameters in the model. For example, participants stated that future sources of water would depend, in part, on the cost of water. One participant observed that identifying water sources alone would not account for cost implications because significant delivery infrastructure enhancements would be required if Ciudad Juárez, Chih., opted for a centralized water treatment system. Other participants voiced the opinion that the substantial subsidizing of water infrastructure in the region results in economic inefficiencies; this led to a discussion about using the model to project economic dislocations if water were to be priced based on its true cost. This concept, by itself, has no meaning unless significant institutional changes were adopted to create an open water market.

One of the concerns expressed by meeting participants was that the model should account for cultural differences between the United States and Mexico. This general need was expressed without being well-articulated. System dynamics can be used to model so-called soft variables, but doing so requires an explicit understanding of the nature and effect of such variables. In subsequent discussions, a member of the research team noted that some elements, such as legal implications, might not be capable of being modeled.

Climate change may affect the border region. One participant speculated that more water might be lost to evaporation and that prolonged periods of high temperatures could result in increased energy consumption by air conditioners. Another participant suggested that changes in the level of precipitation could alter daytime humidity, thereby lessening the efficiency of evaporative air conditioners. This would force a change in the type of air conditioning technology commonly employed in the region, with implications for both water use and energy demand.

A participant noted that the model was missing a rural sector. Rural elements include agriculture and potential sources of groundwater. In the latter instance, outlying rural communities have already begun to express concerns over the effect of proposed groundwater import schemes by the large urban areas. The lack of a rural component, if deemed a significant deficiency, could challenge the basic structure of the model, as it has been fundamentally conceived of as a series of urban models.

The proposed 20-year timeframe may not be appropriate for all sectors of the model. The kinds of capital-intensive improvements required to meet the region's water needs may require adopting a 50-year timeframe to be consistent with the time horizon of current water plans.

The second stakeholder meeting was conducted at the offices of the Instituto Municipal de Investigación y Planeación (IMIP) in Ciudad Juárez on October 10, 2001. The meeting at IMIP coincided with a change of administration in Ciudad Juárez, and this conflict decreased the number of participants. Nonetheless, 27 people participated in the meeting and a number of different ideas were generated by the discussion. Participants were challenged to identify potential applications for the B+20 model and to speculate about the kinds of risks that might be involved in using it. Key issues discussed are detailed below.

Accessibility of the Model

One of the first questions raised concerned gaining access to the model once developed. Some participants expressed interest in having direct access to the model rather than having to go through the research team. Other participants suggested that complete copies of the model might be available to some key stakeholders, and a more limited version of the model might be available to the general public via the Internet. Both suggestions raise issues about software-licensing requirements and challenge the modeling team to develop a user-friendly interface to simplify the use of the model by local stakeholders.

Beyond gaining access to the model, participants expressed the desire that it be adaptable for a wide variety of potential users. Anticipating the needs of different kinds of organizations requires that flexibility be built into the model so that different users can adapt it for different applications. Another participant observed that one benefit of the model was its use as a mechanism to prompt discussion among different agencies. This participant speculated that such a mix of agencies might include the Comisión Federal de Electricidad (CFE), the Junta Municipal de Aguas y Saneamiento (JMAS), and U.S. and Mexican environmental regulators.

Risks in Using the Model

Challenged with articulating their reservations about the potential misuse of the B+20 model, participants identified the following concerns:

- It will be challenging to create a model that is, at once, pertinent to real needs and issues, practically feasible to develop, and accurate and reliable in its projections
- If the model is to be accepted, all assumptions about the relationships of different elements must be clearly communicated and made available to prospective users
- There is a risk that some factors that exert a strong influence on the system may be omitted; for example, participants noted that none of the sectors included wastewater collection, treatment, and disposal options (i.e., agricultural use versus municipal reuse)
- The model should not promise more than it can deliver, or the expectations of prospective users will not be met; this may damage the credibility of the modeling effort
- The model may become too theoretical and thus lack any practical application

Model Validity Concerns

One of the concerns expressed during the meeting involved reliability. Similar kinds of information might be obtained from different sources but differences in the data should be reconciled before being included in the model. The formulae that connect different elements should be validated through some process, perhaps using historical data. Stakeholders offered that the relationship between different elements is likely to be complicated and non-linear.

Standardization of information on the two sides of the border is going to be a significant challenge. Stakeholders noted that some critical data might be unobtainable because they are deemed classified by the agency that possesses it. Because access to information from government agencies is different in Mexico than in the United States, stakeholders expressed concern that the lack of compatible information may make it difficult to create a symmetrical model that captures the dynamics of both communities with equal accuracy.

Land Use Concerns

Urban planners expressed interest in being able to use the model to test assumptions about the impact of different densities of development and different patterns of urban land use. In particular, one stakeholder suggested that, if new development could be guided to promote village-like nodes of commercial activity interspersed in the community and linked by mass transit, it could reduce traffic congestion and promote stronger neighborhood identity, thereby decreasing crime. Another stakeholder, who suggested the model be used to evaluate alternative scenarios about the direction of urban expansion, posed a similar challenge. These levels of analysis may be beyond the capabilities of the model currently under development. If the model is ultimately expanded to address such issues, it will have to incorporate a spatial aspect, perhaps by linking it to a geographic information system (GIS) program.

Economic Concerns

Stakeholders suggested that a structural analysis of the regional, binational economy was needed to determine the relative importance of different economic sectors. Such an analysis might document the relationship of different kinds of business activities to the number of people employed and the total employee payroll. In particular, some stakeholders were interested in identifying the levels of income associated with different types of businesses and industries.

One of the stakeholders maintained that the economy of Ciudad Juárez was too dependent on maquiladoras, and that this has created economic vulnerability. Further, the economic downturn in the United States resulted in the loss of approximately 60,000 maquiladora jobs in Ciudad Juárez in as many months. (Between January 2001 and November 2001, industrial employment in maquiladoras throughout Mexico declined by 206,636 people, representing a nearly 16% reduction [INEGI 2002]). Another stakeholder suggested that the layoffs at maquiladoras were responsible for a recent increase in the city's crime rate. To diminish the vulnerability of the local economy, programs are needed to diversify the region's economy. Stakeholders suggested that the model be designed to allow analysis of the broader implications of different economic diversification schemes.

One stakeholder posed the rhetorical question, What if there were no border? This generated subsequent discussion of incorporating features into the model that could explore the implications of changes in the operations at the international ports of entry. Potential issues that were suggested included altering waiting times, changing immigration policies, and modifying import restrictions.

Qualitative Data Concerns

Several stakeholders expressed a desire for more social elements in the model. Specific suggestions included:

- Public health indicators, such as the incidence of different types of disease
- Public service availability, such as the extent of coverage of water service, wastewater service, health service, and variable levels of hygiene
- Education, such as the level of educational attainment of the existing population and the adequacy of the two communities' educational facilities and programs
- Crime rates, especially when variations in crime rates can be associated with economic perturbation, or with recentness of household tenure (such as when neighborhoods have a large percentage of recent in-migrants)

Stakeholders also challenged the modeling team to incorporate differences, on either side of the border, of political and economic systems, as well as the subtler cultural differences. Because cultural issues are inherently qualitative, it will be difficult to integrate such elements into the model. In subsequent discussions, stakeholders speculated that if the criteria used to select qualitative information were not carefully chosen, it could alter the model's operation, color the interpretation of its results, and ultimately influence the types of users.

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THE SCERP MISSION

The Southwest Consortium for Environmental Research and Policy (SCERP) was established by the U.S. Congress in October 1990 to "initiate a comprehensive analysis of possible solutions to the acute air, water quality, and hazardous waste problems that plague the United States-Mexico border region." SCERP is a consortium of five U.S. universities (Arizona State University, New Mexico State University, San Diego State University, University of Texas at El Paso, and University of Utah) and five Mexican universities (Colegio de la Frontera Norte, Instituto Tecnológico de Ciudad Juárez, Instituto Tecnológico y de Estudios Superiores de Monterrey, Universidad Autónoma de Baja California, and Universidad Autónoma de Ciudad Juárez). SCERP carries out its mission through a cooperative agreement with the U.S. Environmental Protection Agency. A permanent administration office is maintained by the consortium in San Diego.

ENVIRONMENTAL PROBLEMS OF THE U.S.-MEXICAN BORDER REGION

The border region lies 100 kilometers, or 60 miles, on each side of the U.S.-Mexican political boundary and encompasses parts of four states in the United States—Texas, New Mexico, Arizona, and California—and six Mexican states—Baja California, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas. Approximately 13 million people live in the U.S. counties and Mexican *municipios* on the border. The high density of people and increased industrialization since the passage of the North American Free Trade Agreement (NAFTA) have placed an even greater burden on the inadequate infrastructure and environmental resources of the region. Exacerbating the problem is the fact that many U.S. counties along the border are categorized as "economically distressed," and few communities possess the resources needed to address their environmental concerns. Some of the critical border environmental issues include:

- Rapid urbanization and lack of adequate infrastructure
- Air pollution from open burning, vehicle emissions, and industrial operations
- Contamination of surface water and groundwater from open sewers and industrial waste
- Overuse of aquifers and surface streams
- Transportation and illegal dumping of hazardous wastes
- Destruction of natural resources

THE SCERP SOLUTION

SCERP uses a broad, integrated, multidisciplinary approach to address the issues of the border. SCERP researchers collaborate with the U.S. Environmental Protection Agency (EPA) and Mexico's Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), as well as local and state governments, tribal nations, business and industry, nongovernmental organizations, and communities of the border region. SCERP organizes research, outreach, and training programs devoted to improving environmental conditions and building capacity in the border region for resolving critical environmental problems. SCERP is pioneering a model of binational cooperation that brings U.S. and Mexican researchers together and introduces new skills and perspectives in binational environmental problem solving.

CONSORCIO DE INVESTIGACION Y POLITICA AMBIENTAL DEL SUROESTE

SOUTHWEST CONSORTIUM FOR ENVIRONMENTAL RESEARCH & POLICY