

# II-2

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## Modeling the Impact of Environment on Quality of Life

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### 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 ( $\mu\text{g}/\text{m}^3$ ) drop in annual  $\text{PM}_{10}$  (particulate matter with an aerodynamic diameter of 10 microns or less) concentration from an initial value of  $50 \mu\text{g}/\text{m}^3$  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  $\text{PM}_{10}$  concentrations have enormous benefits.

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## Modelado del Impacto Ambiental en la Calidad de Vida

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### 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 proveídos 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 cinco microgramos por metros cúbicos ( $\mu\text{g}/\text{m}^3$ ) caen en concentraciones de  $\text{PM}_{10}$  anuales de un valor inicial de  $50 \mu\text{g}/\text{m}^3$  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  $\text{PM}_{10}$  tienen beneficios enormes.

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## 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.

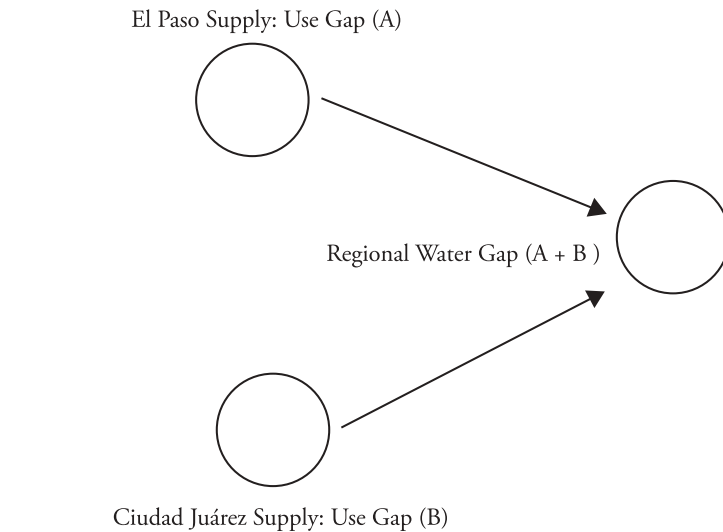
The quality of life sector in the model is an “output” indicator based on the parameters supplied by other sectors of the same model. The definition of quality of life in this case is limited to only those aspects being modeled within the B+20 model structure. In the next phase of model development, 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.

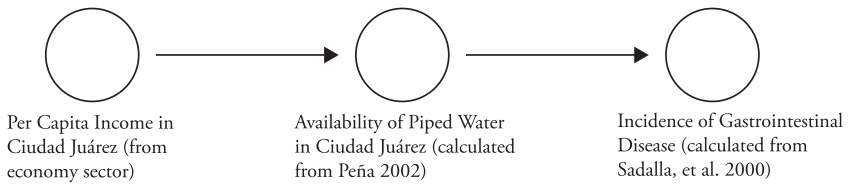
Source: Adapted from Peña forthcoming

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



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 thresh-

olds 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

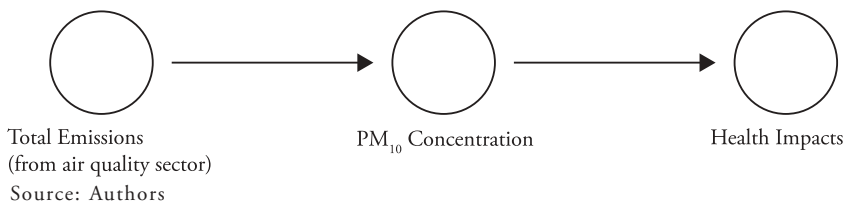
Air quality in the B+20 model is currently represented by a single measure—emissions. A number of sources of emissions are in the air quality model, including households, roads, manufacturing plants,

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



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 ( $\mu\text{g}/\text{m}^3$ ) 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  $\mu\text{g}$  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 health 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  $\mu\text{g}/\text{m}^3$  Increase of  $\text{PM}_{10}$  Concentration

Health Outcomes	Relative Risks	+ Confidence Interval	Percent Increase in Outcome for 10 $\mu\text{g}/\text{m}^3$ Increase in $\text{PM}_{10}$
Long term mortality (adults $\geq 30$ 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 $\geq 25$ 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 $\geq 20$ years) <sup>a</sup>	1.094	1.079–1.109	9.40%
Asthmatics: asthma attacks (children $< 15$ years) <sup>b</sup>	1.044	1.027–1.062	4.40%
Asthmatics: asthma attacks ( $\geq 15$ years) <sup>b</sup>	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  $\mu\text{g}/\text{m}^3$ )

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.

$$D_{10} = 1000000 \times F_p \times P_0 \times (RR - 1)$$

where,

$D_{10}$  = number of additional cases (per million) per 10  $\mu\text{g}/\text{m}^3$  increment of  $\text{PM}_{10}$  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:

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

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  $7.5 \mu\text{g}/\text{m}^3$ )

*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

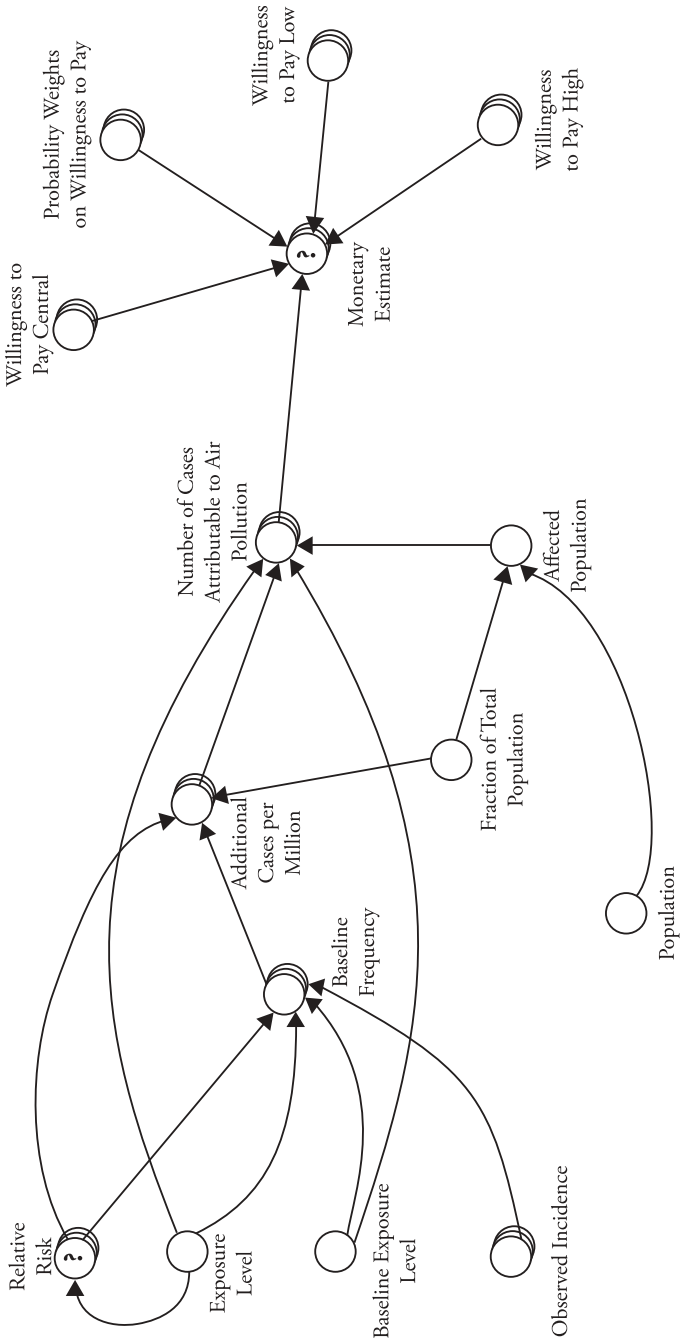
and Chestnut (1998) were applied to the population at risk. These estimates have been adjusted according to the distribution of mortality and morbidity in the population. For example, assuming 85% of the pollution-related mortality occurs in the population age group 65 and over, WTP for reducing mortality 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  $5 \mu\text{g}/\text{m}^3$  change in annual average  $PM_{10}$  concentration from an initial level of  $50 \mu\text{g}/\text{m}^3$  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  $5 \mu\text{g}/\text{m}^3$  drop in annual  $\text{PM}_{10}$  concentration from an initial value of  $50 \mu\text{g}/\text{m}^3$  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  $\text{PM}_{10}$  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  $5 \mu\text{g}/\text{m}^3$  Change in  $\text{PM}_{10}$  Concentration (1995\$billions)

$\text{PM}_{10}$	Monetary Savings for Each $5 \mu\text{g}/\text{m}^3$ Change in $\text{PM}_{10}$ 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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