AN ANALYSIS OF THE EFFECTS OF ENVIRONMENTAL CONTAMINATION ON RESPIRATORY ILLNESSES IN THE IMPERIAL AND MEXICALI VALLEYS

PROJECT NUMBER: EH-01-02

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NARRATIVE SUMMARY

Mexicali is the third most contaminated city in Mexico and the second city in the country with the highest level of particles smaller than 10 micrometers in diameter (PM_{10}). It continuously fails to meet annual air quality standards (50 µg/m^3). Mexicali's U.S. neighbor, the Imperial County, has the same geographical characteristics, and is in non-attainment for PM_{10}, ozone, and carbon monoxide. One health condition associated with PM_{10} levels is asthma, and both Imperial Valley and Mexicali have the highest child asthma indices for their respective states of California and Baja California. PM_{10} is primarily formed naturally, from dust and pollen, but the anthropogenic sources are gaining importance due to an accelerated growth in this binational basin. The thermoelectric plants recently constructed are an example of this accelerated growth and their construction prompts binational concern in a basin with an already deteriorated air quality.

With the limited published documents focusing on Mexicali's and Imperial County's health or environment, only a few contain data on PM_{10} levels or respiratory illnesses (including asthma), and even fewer jointly report on health conditions and the environment. This lack of information produces flawed and unproductive environmental policy in the U.S.-Mexican border region.

A model based on the Poisson regression was used to study the impact PM_{10} may have had on primary respiratory diseases given the temperature and relative humidity in the Imperial Valley-Mexicali basin. Data for the years 1997 through 2000 was measured in series by seasons. The PM_{10} data were taken from six environmental monitoring stations in Mexicali and the data for asthma, acute respiratory infections, and pneumonia were obtained from Baja California public health centers.

The primary pollutants caused by PM_{10} and the percentages that they contribute to overall contamination are identified. Also, dispersion graphs and cross correlation coefficients between the series are shown for respiratory illnesses and environmental markers, including PM_{10}.

The ARI/bronchitis model maintained the R^2 value of 0.83 when relative humidity was omitted, and decreased slightly from 0.83 to 0.79 when PM_{10} was omitted. When temperature was omitted in this model, the R^2 value decreased from 0.83 to 0.37. This indicates that ARI/bronchitis is highly sensitive to temperature, less sensitive to PM_{10}, and has no relationship to relative humidity.

To date, three publications have been generated from this study. Two journal articles have been submitted, one already accepted to be published in Spanish by the R*evista Mexicana de Ingenieria Biomedica*. A second article written in English has been sent the *Journal of Environmental Health*, but the authors are still awaiting word whether it has been accepted or not. Finally, the data development from this research was put in an easy-to-read pamphlet, published in English and Spanish.

The second benefit has been a clearer understanding of the correlation between air quality and respiratory illnesses in the Imperial and Mexicali valleys. This benefit is tied with the first as this information is only productive if we communicate the results. The pamphlet was sent to approximately 500 stakeholders in the region. Also, copies have been made available to faculty and students at the Imperial Valley Campus and Universidad Autónoma de Baja California.

The third benefit to the region was the building of human capacity and understanding of the environmental health concerns. In addition to the researcher's growth, two students who still work in the region were involved in the project.

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INTRODUCTION

The first evidence suggesting that air pollution was related to illness and death was recorded in England in 1880. It was in this year that a large, dark cloud appeared in the London sky and subsequently, nearly 2,200 people died. Almost three-quarters of a century later, a similar situation occurred in the same city in which 4,000 people died. This event is well known as the London Fog of 1952 (United Kingdom Ministry of Public Health 1954).

After these and numerous other comparable events took place, scientists became more involved in the study of air pollution and its effects on health. In the 21st century, the relationship between breathable suspended particles and mortality and morbidity is further elucidated. The issue of environmental health is gaining importance and continues to be a subject of profound interest all across the world (Borja 2000; Díaz, et al. 1999; Ostro 1998; Pajares, et al. 1997; Pope, Dockery, Spengler, and Raizenne 1991; Pope, et al. 1995; Schenker, Gold, Lopez, and Beaumont 1993).

The most serious threats to the respiratory system are particulates suspended in the atmosphere for long periods of time at the height at which most people breathe. Perhaps the most dangerous of these materials is Total Suspended Particles (TSP). The particles in this classification that have the greatest impact on the respiratory system range from 10 microns in diameter (PM_{10}) to smaller than 2.5 microns in diameter ($PM_{2.5}$). The particles that measure between five and 10 microns do not reach the deepest tissues of the respiratory system because they are caught by mucous in the nose, larynx, pharynx, and trachea. Even though these particles are caught before reaching the depths of the respiratory system, they can still have harmful effects on the body by inducing sneezing. If the sneezing becomes severe, it could lead to chronic illnesses such as otitis, depending on the composition of the particles.

The smaller the diameter of the particle, the more harmful it becomes, since these smaller particles are able to penetrate deeper areas of the respiratory track containing the internal tissues. Two of these areas, the bronchus and the alveolus, are particularly dangerous as reactions may take place that could bring about serious complications, including premature death; grave respiratory symptoms; irritation of the eyes, ears and nose; an increased risk of developing lung cancer; more acute asthma cases; and a worsening of cardiovascular diseases (Mariéthoz E, et al. 1999).

The suspended particles originate in either natural or anthropogenic sources. When they mix with the air, they become more complex. For larger particles with diameters between 2.5 and 10 microns, the principal sources of anthropogenic origination are factory smoke (such as cement kilns), dust from lime and other minerals, agricultural practices such as emissions from burning of agricultural residues and pesticide use, and dust from construction sites and unpaved streets. The majority of the naturally produced particles in this group come from the pollen of several plants. The finest particles, those that measure less than 2.5 microns in diameter, come mainly from the emissions from fossil fuel combustion motors (such as those found in automobiles) and from nitrates and sulphates in the form of aerosols.

In order to prevent the harmful impacts of suspended particles on the health of the community, there are regulations that establish maximum permissible amounts in the concentration of particles in the air. Both the Mexican and U.S. regulatory standards for PM_{10} should not exceed 150 $\mu g/m^3$ (micrograms per cubic meter) for the 24 hour average and 50 $\mu g/m^3$ for the annual average.

RESEARCH OBJECTIVES

The municipality of Mexicali, the capital of the state of Baja California, Mexico, is located in the farthest northwest state of the country. It shares the border with the Imperial County, Calif., in the United States. Imperial County is also known as the Imperial Valley. Mexicali and Imperial Valley share the same physical, geographical, and meteorological conditions. These common characteristics provide a situation in which contamination or pollution is shared through a binational airshed and watershed. For these purposes here, the impacts of air pollution on the airshed will be analyzed. As seen in Table 1, both Mexicali and the Imperial Valley have non-attainment standards for PM_{10}.

Air pollution has been blamed for the high rates of asthma, bronchitis, pneumonia, and allergies in this region, especially among children between the ages of 1 and 14 years (California Department of Health Services 2000; IseSalud 1998). In fact, the rates of respiratory diseases have been worsening in both valleys as the concentrations of suspended micro particles continue to increase (Reyna and Alvarez 2001). The Secretariat of the Environment and Natural Resources (in Spanish, Secretaría de Medio Ambiente y Recursos Naturales, or SEMARNAT, formally known as SEMARNAP [Secretaría de Medio Ambiente, Recursos Naturales y Pesca]), in its second report, classified Mexicali's air quality as seriously dangerous (Figure 1). Mexicali is the second city in the country after Mexico City that continuously exceeds the permitted annual averages of PM_{10} (150 $\mu g/m^3$) (INE-SEMARNAT 1998). Additionally, the two newly constructed thermoelectric plants in Mexicali, La Rosita and La Termoelectrica Mexicali, have created concerns that the air quality in the two valleys will diminish once the plants begin operations (Cornejo 2002a; 2002b).

Interesting data on concentrations of various pollutants and respiratory diseases are found in Mexicali's emissions inventory (Ingeniería en Control Ambiental y Riesgo Industrial, S. de R. L. M. I. 1999) and in a presentation by IseSalud (IseSalud 1998) at the Forum on Environmental Health at the California-Baja California Border, which was held in Mexicali in April 2002 (Collins, Dowling, and Reyna 2002). The graphs of these reports show a systematic increase in respiratory diseases from 1998 to 2001.

In 1991, an article was published in the *Journal of Environmental Research* (Alvaro R. et al. 1991) detailing the results of a series of experiments in which rats were used to determine the degree of toxicity of the inorganic particles in the dust produced in the city of Mexicali. It found that samples of Mexicali dust are a mixture of 75% potassium aluminum silicates (illite) and 20% silica. The rats exposed to this dust developed a multifocal interstitial lung disease associated with deposits of the aluminum silicates. Mexicali dust induced biological activities and lung changes similar to those of asbestos and silica, suggesting that this material could be an etiologic agent of pulmonary fibrosis in exposed individuals.

In 1997, a study was conducted by the U.S. Environmental Protection Agency (EPA), Region IX to more precisely determine the sources and types of micro fractionated materials suspended in the air in the bordering valleys (Chow and Watson 1995). The samples determined that annual averages for PM_{10} were exceeded on both sides of the border. On average, the greatest component of PM_{10} was geological material (50% to 60%). Soot was second, comprising approximately 25% of total PM_{10}. Sulfates, nitrates, ammonium, aluminum, silica, titanium, calcium, and iron were other components, comprising between 1% and 4% of total PM_{10}.

The California Center for Border and Regional Economic Studies (CCBRES), located at the San Diego State University Imperial Valley Campus, reported that the PM_{10} levels in Imperial Valley were 80,414 tons per year and 71,323 tons per year for the city of Mexicali, according to the California Air Resources Board (CCBRES 2001). It should be noted that the data for Mexicali is somewhat misleading as it only accounts for the urban areas and does not include data for the whole valley.

The problem of air contamination in both valleys has created an alarming reaction—an increase in the number of cases of asthma and cardio-respiratory illnesses. These health conditions are so alarming that the former president of Mexico, Ernesto Zedillo, mandated the Program to Improve the Quality of the Air of Mexicali 2000-2005 during his time in office (SEMARNAT, Gobierno del Estado de Baja California, Gobierno Municipal de Mexicali, and Secretaría de Salud 1999). The program intends to abate air pollution due to PM_{10} by 30% through the implementation of several regulations. These include vigilant enforcement of the inspection of industrial and service establishments, vehicular inspection, sanctions of highly polluting vehicles, urban and transportation management, reforestation, an increase in the number of paved streets, adequate use of soil, and the promotion of an environmental education program. This environmental education program is intended to be promoted through the signing of border agreements, and is designed to encourage civic participation in environmental matters. Implementation of this program has been slow as financial support was not included. It will be necessary, though, to analyze the individual initiatives to determine the actual degree of progress.

Paul B. English et al. (1998) did a comparative study of asthma rates between Imperial and San Diego Counties. Imperial County had the highest rate for asthma hospitalizations for children under 14 years in the entire state of California. From 1983 to 1994, there was a 59% increase in the hospitalization rates in Imperial County, compared to a reduction of 9% in hospitalizations in San Diego County.

Each of the above studies provides references to the correlation between PM_{10} and respiratory illnesses in the Imperial-Mexicali valleys. It is clearly important, though, to carry out additional binational studies that analyze the existing relationship between respiratory illnesses and the levels of air pollution to accurately understand the situation in the region.

Research Methodology/Approaches

A clinical and environmental database for Mexicali and the Imperial Valley was generated. The time series included weekly data for the years 1997 through 2000. The original environmental series was in 24-hour intervals, but only weekly hospitalization data were available. For Mexicali, the clinical database contained time series data of asthma, pneumonia, and acute respiratory illnesses (ARI). These data were collected from the clinical files supplied by Official Public Health Centers in Mexicali. For the Imperial Valley, the clinical database included time series data of asthma, bronchitis, and pneumonia. This data was supplied by the State of California Health and Human Services Agency, Office of Statewide Health Planning and Development.

The environmental database included the same time series for temperature, relative humidity, and PM_{10}. All of the environmental data was supplied by the California Air Resources Board (CARB), which manages six air monitoring stations in the city of Mexicali and eight stations in Imperial Valley. Both the environmental time series and clinical data varies between Mexicali and the Imperial Valley, as seen in Figures 2 and 3.

Problems/Issues Encountered

The collection of the health data in the region was the most complex and difficult task in this project. In Mexicali, the data was available, but not digital. Therefore, all of the data had to be inputted into the database. Furthermore, the respiratory diagnoses by doctors in Mexico are grouped into one category called “acute respiratory illnesses.” This includes acute bronchitis, acute bronchiolitis, acute rinofaringitis, acute faringitis due to other specific organisms, acute infections of the superior respiratory pathways, and acute amigdalitis due to other specific organisms.

In the Imperial Valley, the data was limited by only including hospitalizations in the region. Clearly, these data do not collect all of the cases in the valley. There is the added complication that many individuals in the region either self-medicate or visit doctors in

Mexicali for monetary or cultural reasons. It could therefore be assumed that the number of asthma cases in the region is higher than reported in the data collected. These factors (along with other possible factors) show that this analysis is limited in developing an absolute understanding of the impacts of PM_{10} on respiratory illnesses.

RESEARCH FINDINGS

Analysis by Years

The PM_{10} annual standard of 50 µg/m^3 was exceeded every year in Mexicali, but only in 2000 in the Imperial Valley (see Figure 2f and 3f). The annual average of 50 µg/m^3 was exceeded for all years under study in both valleys, with the exception of 1998, in which the level in Imperial Valley only reached the maximum permissible level (Figure 4).

Figure 5 displays the number of weeks that the PM_{10} standard was exceeded for the 24-hour norm of 150 µg/m^3 and provides the average PM_{10} levels for each week of the exceedances. In Mexicali (Figure 5a), the PM_{10} standard was exceeded more than three weeks in 1997, and continued to rise each year thereafter. In Imperial County, the PM_{10} 24-hour standard was exceeded for only three weeks in 2000 (Figure 5b).

Figure 6 provides the number of hospitalizations for each selected pathology under study by year in Mexicali and Imperial Valley. Figure 7 gives the total hospitalizations for each pathology in both Imperial Valley and Mexicali for the years studied. This data makes it possible to determine the years with the highest and lowest hospitalization rates, to establish a visual association between the atmospheric and meteorological variables, and to create a correlation between the Imperial and Mexicali valleys. For example, it was possible to determine that on average, Mexicali had more cases of asthma than bronchitis and that if indices were calculated as a function of the population, Mexicali has a higher index of asthma than Imperial. Imperial and Mexicali have the same indices in the case of pneumonia.

Seasonal Analysis

Table 2 displays the average atmospheric variables by season for the respective years analyzed. Table 3 provides the hospitalization rates for asthma and pneumonia in both areas, along with bronchitis in the Imperial Valley and acute respiratory illness in Mexicali by season of years under analysis.

These tables make it possible to determine which season of the year had the highest hospitalization rate and also what effect different atmospheric variables had on those hospitalizations. Fewer hospitalizations occurred during the summer season, in which the highest temperature and the lowest PM_{10} value were recorded. It is important to note that the average atmospheric-meteorological variables and clinical variables that correspond to winter 1997 consist of data for the months of January and February as the monitoring stations only began to operate adequately in January 1997. This explains why the average values for those dates are lower in comparison with later years.

Figure 8 is the dispersion graphs and r value of the simple regression analysis of the atmospheric and clinical variables. Note that when the dispersion graphs show a linear tendency behavior, the r values are larger. An example of this phenomenon is the correlation of temperature with each illness. Another interesting observation is that the weakest correlation is seen between relative humidity and asthma with a value of 0.11, followed by PM_{10} and pneumonia with a value of 0.15, and finally, relative humidity and pneumonia with 0.23.

Poisson regressions that combined the temperature, relative humidity, and PM_{10} variables were used to obtain different models for asthma, pneumonia, and ARI in Mexicali. For the Imperial Valley, the same models were used, but bronchitis was analyzed instead of ARI.

The R^2 value for the predictions obtained from the models for both valleys are seen in Tables 4 and 5. The highest R^2 value is found in the model that included all three variables—temperature, relative humidity, and PM_{10}. The R^2 value in the correlation of asthma with temperature, relative humidity, and PM_{10} for Mexicali was 0.80. In the Imperial Valley for the same correlation, it was 0.70. In the asthma model, the R^2 value remained high with the removal of the relative humidity variable—indicating that relative humidity is not an important variable in the analysis of respiratory illnesses and PM_{10} levels. On the other hand, PM_{10} and temperature have stronger connections to the levels of asthma in the region as seen in R^2 values of 0.65 and 0.43 for Mexicali. In Imperial Valley, the R^2 was 0.55 in the correlation of temperature and relative humidity with asthma and 0.31 for the correlation of PM_{10}, relative humidity, and asthma. The other R^2 values for pneumonia, ARI, and bronchitis are seen in Tables 4 and 5.

With these Poisson regression models, a number of experiments were conducted to determine the number of hospitalizations that would occur for asthma, ARI, and pneumonia in Mexicali if the levels of PM_{10} were zero during the same time period. Similar calculations were also done for the Imperial Valley. The results of these calculations are provided in Tables 6 and 7 for Mexicali and Imperial Valley, respectively. As seen in Table 6, in 1997 the number of asthma cases would have been 15.4% less in Mexicali if the PM_{10} levels had been 0. In the Imperial Valley, as seen in Table 7, the number of asthma hospitalizations in 1997 would have been 4.16% less if the PM_{10} values were 0.

Through the exploratory analysis of the time series of the atmospheric variables (temperature, relative humidity, and PM_{10}) and the clinical variables (asthma, pneumonia and bronchitis/ARI), it was possible to determine that the average annual air quality standard of 50 $\mu g/m^3$ for PM_{10} was exceeded during the four years studied. It was also possible to locate the number of weeks per year that exceeded the 150 $\mu g/m^3$ standard for PM_{10}. Furthermore, it was possible to determine the number of hospitalizations for asthma, pneumonia, and bronchitis/acute respiratory infections that occur during the four seasons of the year.

With the initial analysis, it can be concluded that temperature and PM_{10} levels have a greater impact on the clinical variables than relative humidity. However, such a conclusion cannot be supported quantitatively. For this reason, dispersion graphs and correlation coefficients were obtained. Under the Colton lineament, it was determined that the degree of correlation among variables was highest for the temperature variable. The coefficient between temperature and ARI was the strongest, with a value -0.79 (considered excellent); this was followed by pneumonia, with a good correlation of -0.66; and finally, asthma, with a moderate correlation of -0.48. Relative humidity showed a relatively low correlation of 0.39 for ARI, and null correlations between pneumonia and asthma of 0.23 and 0.11, respectively. The correlations of PM_{10} on asthma, pneumonia, and ARI/bronchitis were 0.35, 0.15, and 0.39, respectively, indicating a moderate effect on asthma and ARI/bronchitis and a null effect on pneumonia.

With this new information, it was possible to determine that:

- Temperature has an important impact on the three pathologies studied
- Relative humidity does not have a linear affect on pneumonia, asthma, ARI in Mexicali and on bronchitis in Imperial
- PM_{10} has an affect only on asthma and ARI

Determining the type of distribution for each variable provides insight to the type of model or models that may be used in a regression exercise. In this case, as often happens with this type of data, the majority of temporary series that were analyzed followed a Poisson distribution, and these were used to derive the models for each illness.

In the case of asthma, the model lowered its confidence from 86% to 70% when relative humidity was not considered, from 86% to 65% when PM_{10} was omitted, and from 86% to 43% when temperature was disregarded. These omissions show that temperature and PM_{10} have a greater influence on asthma than relative humidity.

For the pneumonia model, the R^2 value stayed nearly the same, 0.67 to 0.67 for Mexicali, and 0.68 to 0.58 when relative humidity and then PM_{10} were eliminated. However, it went down dramatically from 0.67 to 0.22 for Mexicali and from 0.68 to 0.20 for Imperial when temperature was omitted. This demonstrates that pneumonia is more sensitive to temperature, and less sensitive to relative humidity and PM_{10}.

The ARI/bronchitis model maintained the R^2 value of 0.83 when relative humidity was omitted, and decreased slightly from 0.83 to 0.79 when PM_{10} was omitted. When temperature was omitted in this model, the R^2 value decreased from 0.83 to 0.37. This indicates that ARI/bronchitis is highly sensitive to temperature, less sensitive to PM_{10}, and has no relationship to relative humidity.

Once these three models were derived, they were used to determine the number of hospitalizations from 1997 to 2000 that could have been avoided if the PM_{10} levels could have been 0. For the asthma model, it was found that there could have been 15.4% fewer hospitalizations in 1997, 14.4% fewer in 1998, 17.7% fewer in 1999, and 19.9% fewer in 2000. The pneumonia model concluded that there could have been 2.3% fewer hospitalizations in 1997, 2.1% fewer in 1998, 2.7% fewer in 1999, and 3.2% fewer in 2000. In the ARI/bronchitis model, there could have been 14.5% fewer hospitalizations in 1997, 13.7% fewer in 1998, 16.9% fewer in 1999, and 19% fewer in 2000.

CONCLUSIONS

Making the correct decision related to the environment, or at least with the lowest degree of error possible, depends principally on the information that is available and the reliability of this information. Intuition, for example, that air pollution in a city causes illness in people is not enough. It needs to be demonstrated, but this is not a trivial task as there are many different aspects from anthropogenic to natural that enter the equation. Therefore, it is necessary to try and understand all of the aspects that are part of this equation along with which are the most important to consider and how one considers them in a synergetic way. Clearly, environmental concerns are one of the most important elements in the equation and need to be included in the decision-making process. This project provides additional information about the environment in the Imperial-Mexicali valleys that can help decision-makers in the region take actions to improve the quality of air in the binational airshed.

This work considered only PM_{10} as a factor of pollution, and temperature and relative humidity as meteorological variables. It studied the how meteorological variables impact PM_{10}. Also, it analyzed how PM_{10} influences asthma, pneumonia, and ARI/bronchitis. The experiments demonstrated that temperature has a greater impact on the respiratory diseases studied than relative humidity and PM_{10}. This is shown in the fact that not all of the respiratory diseases responded in the same level when correlated with PM_{10} and the meteorological variables.

The Poisson regression models predicted that asthma, pneumonia, and ARI are much more sensitive to temperature than to PM_{10}, and have a very low relationship to relative humidity. Pneumonia, for example, shows null sensitivity to PM_{10}; on the other hand, asthma shows more sensitivity to PM_{10} than ARI. The fact that pneumonia and ARI/bronchitis are not as sensitive to PM_{10} does not mean that other atmospheric pollutants like carbon monoxide (CO) or ozone (O_3) are not harmful; in fact, the standards of these elements are also frequently exceeded in Mexicali. The confidence percentage in the predictions could have been improved if these elements were included when the models were designed.

These results were derived from the analysis of clinical and atmospheric-meteorological data done on a weekly basis. However, sometimes it is necessary to conduct studies with more in-depth analysis or for a shorter period of time, such as for a 24-hour period or by geographical areas in the cities. These types of tests are being explored and call for further work within this line of research.

RECOMMENDATIONS FOR FUTURE RESEARCH

Access to accurate data is the main challenge in the region. Many studies and analyses could be conducted if the data existed. This is particularly true when working with health indicators. The main source of information on the U.S. side with any consistency is from the Office of Statewide Health Planning and Development. These data consist of hospital emissions. Therefore, all patients that self-medicate, go across the border for health services, or just go to their local doctor for health services are not included. On the Mexican side of the border, the data is collected mainly by hand and therefore, problems of accuracy could be an issue without a strong quality assurance program in place.

A number of studies that collect data for specific periods have been helpful but do not provide a consistent database on health issues in the region. Therefore, it is highly recommended that a binational system to collect health data be designed and implemented. A pilot program could be held in the Imperial-Mexicali region.

Additionally, research that examines the local environmental values of the community should be conducted. This research will help in the implementation of projects to improve the environment. A challenge that was encountered in the project is the disconnect between air quality and public health issues. Because it is so difficult to absolutely pinpoint environmental contamination to a specific health issue, it is even more difficult to get local community members actively involved. With a clearer understanding of the environmental culture in the region, specific outreach projects could be designed to educate the community further and hopefully, get them more involved in the decision-making process.

Finally, other research that would be helpful in the region includes conducting the same correlations with carbon monoxide and modeling the binational airshed.

RESEARCH BENEFITS

This research provided a number of benefits to the region. First, to date three publications have been generated from this study. Two journal articles have been submitted, one already accepted to be published in Spanish by the R*evista Mexicana de Ingenieria Biomedica*. A second article written in English has been sent the *Journal of Environmental Health*, but the authors are still awaiting word whether it has been accepted or not. Finally, the data development from this research was put in an easy-to-read pamphlet, published in English and Spanish.

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The third benefit to the region was the building of human capacity and understanding of the environmental health concerns. In addition to the researcher's growth, two students who still work in the region were involved in the project. Clearly, the building of local capacity is the key to sustainable development and improving the environment in the Imperial and Mexicali valleys. Both students have graduated and are working in other positions, but this knowledge has gone with them. A strong example is a student that previously worked for CCBRES, and indirectly worked on the project, is now the director of the Imperial Valley Community Health Organization. He worked on a number of environment and health projects with CCBRES and has taken that knowledge to obtain other positions in the Imperial Valley.

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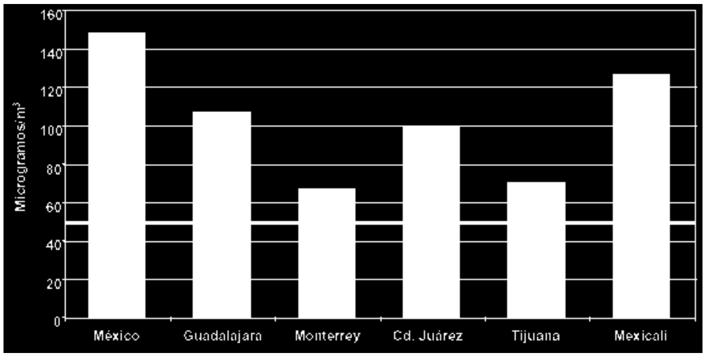

Figure 1. Average Annual PM10 Levels in Major Mexican Cities, 1997

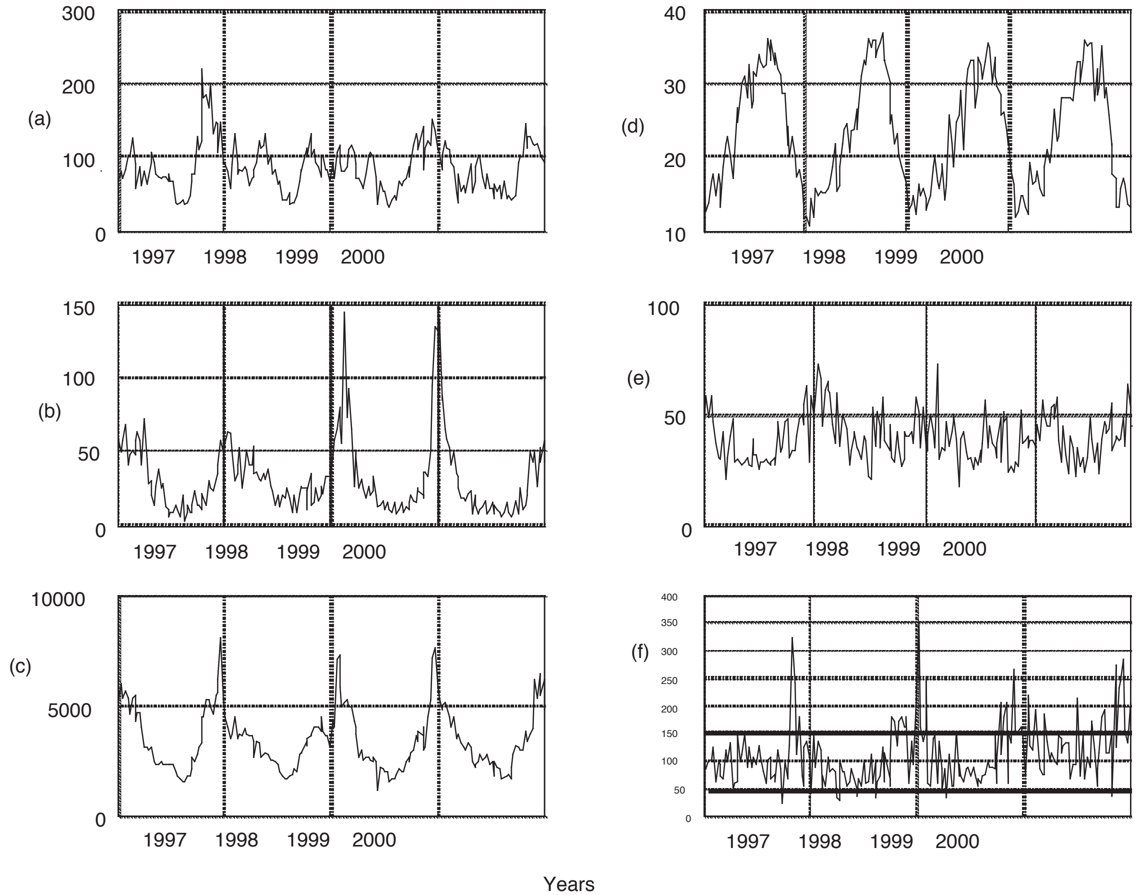

Figure 2. Hospitalizations from 1997 to 2000 in Mexicali for: (a) Asthma, (b) Pneumonia, (c) Acute Respiratory Infections (ARI); Atmospheric Variables: (d) Temperature, (e) Relative Humidity (f) PM10 (thick dotted line indicates the 50mg/m3 annual air quality standard; solid thick line indicates the 150 mg/m3 standard for a 24 hour period)

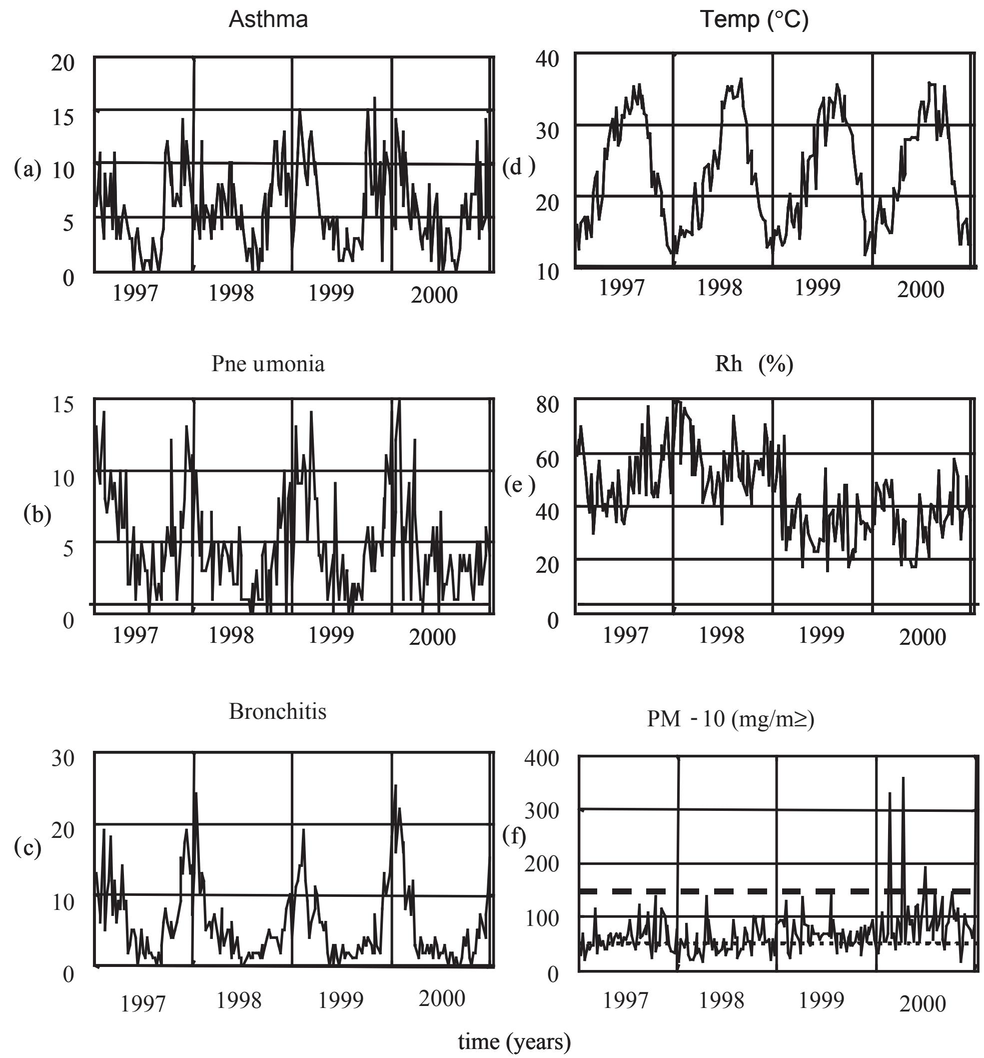

Figure 3. Hospitalizations from 1997 to 2000 in Imperial Valley for: (a) Asthma, (b) Pneumonia, (c) Bronchitis; Atmospheric Variables for: (d) Temperature, (e) Relative Humidity (f) PM10 (thick dotted line shows the 50mg/m3 annual air quality standard; solid thick line shows the 150 mg/m3 standard for a 24-hour period)

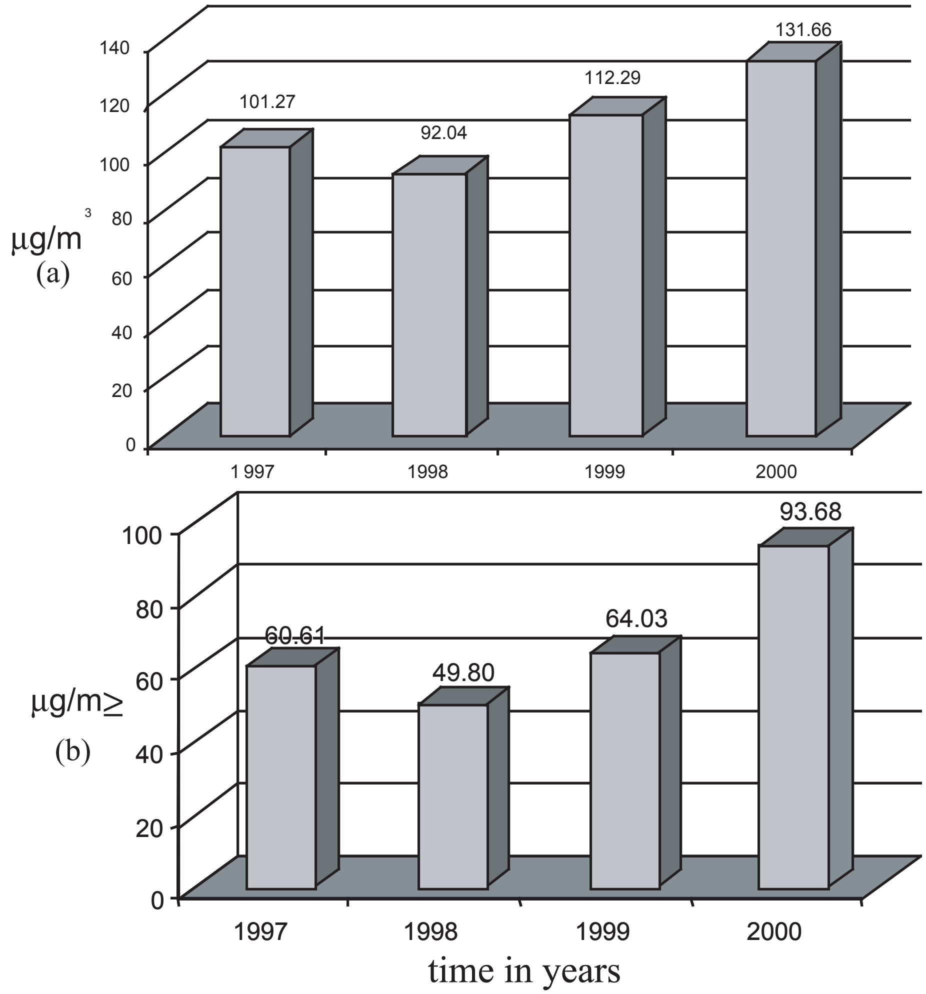

Figure 4. Annual PM10 Averages for Mexicali (a) and Imperial County (b)

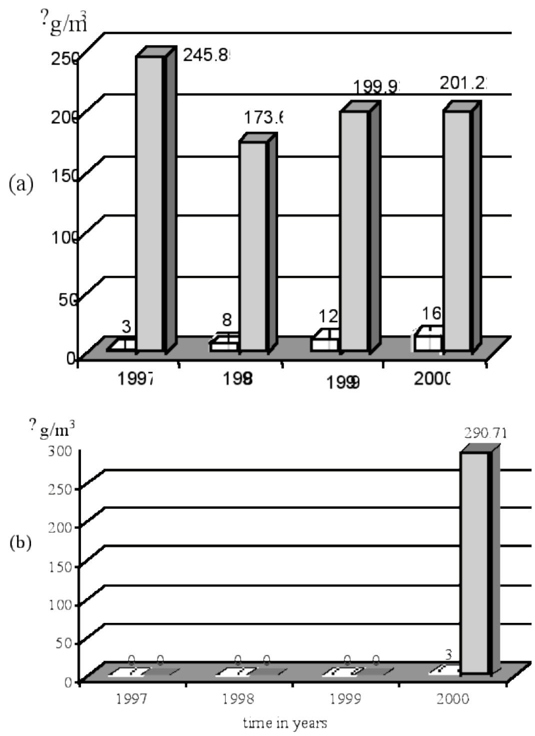

Figure 5. Number of Weeks that Exceeded the 150μg/m^3 Air Quality Standards in Mexico and the United States and the PM10 Averages for Those Weeks in the Year; (a) Mexicali (b) Imperial

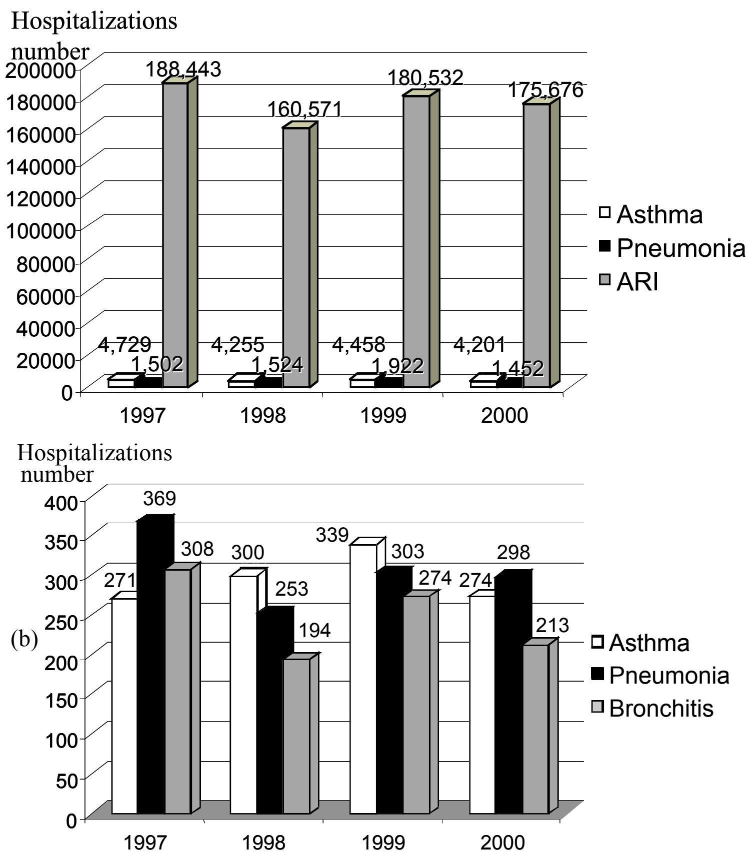

Figure 6. (a) Number of Hospitalizations due to Asthma, Pneumonia, and ARI in Mexicali, 1997 to 2000; (b) Number of Hospitalizations from Asthma, Pneumonia, and Bronchitis in Imperial County, 1997 to 2000

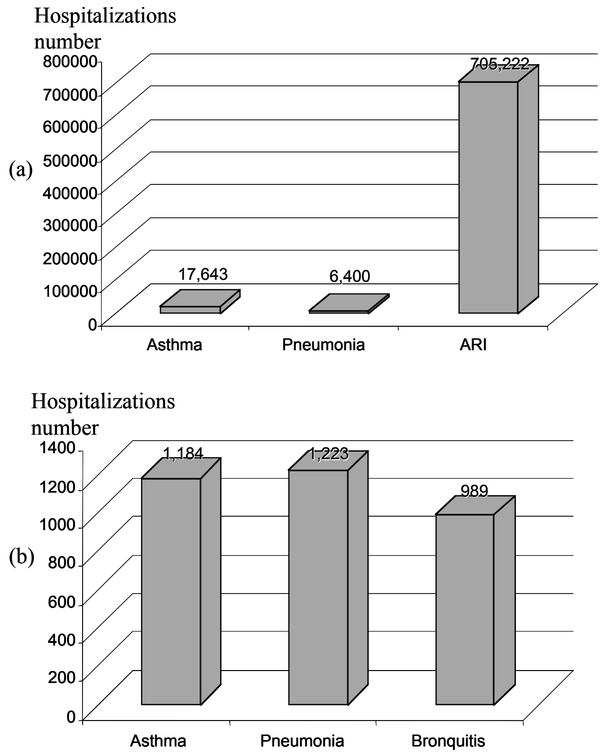

Figure 7. Total Hospitalizations During 1997 to 2000 in (a) Mexicali and (b) Imperial

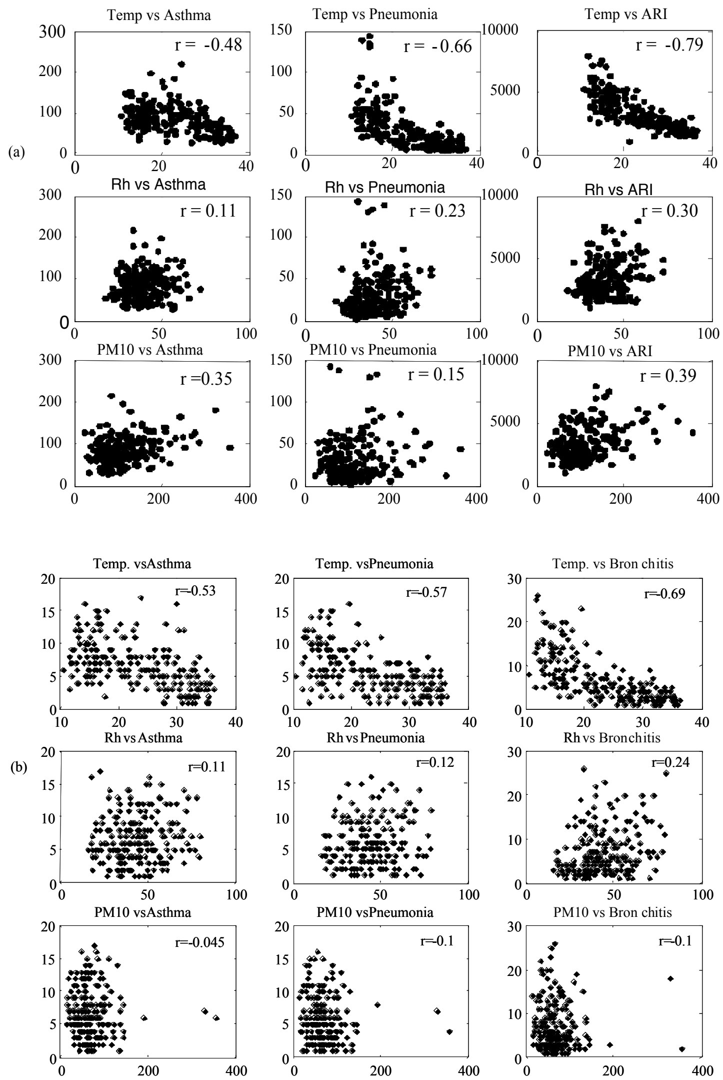

Figure 8. Dispersion Graphs Depicting the Association between Atmospheric Variables with Clinical Variables in Mexicali (a) and Imperial (b)

Table 1. Border Counties and Municipalities that Do Not Meet U.S. and Mexican National Air Quality

U.S. Counties	PM10	S02	CO	O3
El Paso, TX	X		X	X
Doña Ana, NM	X			X
Imperial, CA	X		X	X
San Diego, CA			X	X
Douglas, AZ	X	X		
Nogales, AZ	X			
Mexican Municipalities	PM10	S02	CO	O3
Tijuana, BC	X			
Mexicali, BC	X		X	X
San Luis Río Colorado, SON	X			
Nogales, SON	X			
Agua Prieta, SON	X	X		
Cuidad Juárez, CHIH	X		X	X

Table 2. Average Temperature, Relative Humidty, and Particulate Matter Smaller than 10 Microns by Season of the Year, 1997 to 2000

Mexicali Atmospheric Variables												
Season	Average Temperature				Average Relative Humidity				Average PM10			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	9.57*	13.77	14.73	14.99	27.25*	55.65	41.66	44.35	57.39*	92.82	148.21	139.88
Spring	24.81	20.87	20.73	23.50	30.03	39.28	36.41	33.41	98.51	67.44	79.59	121.43
Summer	32.21	32.98	31.22	32.11	30.03	38.87	36.85	38.28	90.50	71.39	74.82	103.77
Fall	24.23	23.52	25.92	22.77	41.51	37.93	35.91	42.11	121.46	131.46	136.95	149.05

Imperial County Atmospheric Variables												
Season	Average Temperature				Average Relative Humidity				Average PM10			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	12.11*	17.82	18.64	19.64	43.69*	88.90	65.05	49.80	33.69*	56.38	85.25	110.20
Spring	30.40	25.55	26.05	29.17	56.09	68.85	43.07	38.96	75.87	67.79	73.21	132.03
Summer	41.49	41.38	40.04	41.38	58.96	66.99	39.51	40.97	86.95	60.37	89.38	134.61
Fall	32.73	32.37	35.53	31.22	73.81	67.46	42.31	51.59	95.40	73.09	76.85	105.72

*Winter 1997 data is for only two months as the monitoring stations began operation in January 1997.

Table 3. Number of Hospitalizations for Asthma, Pneumonia, Acute Respiratory Illness/Bronchitis by Season, 1997 to 2000

Mexicali												
Season	Asthma				Pneumonia				Acute Respiratory Illness			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	712*	1262	1165	1376	417*	590	793	1019	43113*	59391	62863	67820
Spring	1005	1223	1120	901	481	482	406	225	40355	40721	40242	37207
Summer	646	700	629	702	126	232	154	131	24913	25855	23630	27076
Fall	1815	1233	1361	1290	243	280	278	293	50590	45818	41760	46643

Imperial County												
Season	Asthma				Pneumonia				Acute Respiratory Illness			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	56*	76	130	101	82*	164	135	210	79*	88	100	105
Spring	61	83	51	51	106	61	74	56	85	54	74	56
Summer	19	32	46	35	26	19	18	22	34	24	29	39
Fall	83	109	112	87	85	43	46	34	64	45	52	40

*For the Winter 1997 season, data from December 1996 is not available as the data series began in January 1997.

Table 4. R2 for Mexicali for Asthma, Pneumonia, and Acute Respiratory Diseases, Each Correlated wtih Temperature, Relative Humidity, and PM10

Asthma Model	R2
Temp, Rh, PM10	80%
Temp, PM10	75%
Temp, RH	65%
Rh, PM10	43%

Pneumonia Model	R2
Temp, Rh, PM10	66.90%
Temp, PM10	66.80%
Temp, RH	66.80%
Rh, PM10	21.70%

ARI Model	R2
Temp, Rh, PM10	83.30%
Temp, PM10	83.30%
Temp, RH	79.30%
Rh, PM10	36.70%

Table 5. R2 for Imperial Valley for Asthma, Pneumonia, and Acute Respiratory Diseases, Each Correlated wtih Temperature, Relative Humidity, and PM10

Asthma Model	R2
Temp, Rh, PM10	70.0%
Temp, PM10	60.9%
Temp, RH	55.1%
Rh, PM10	31.3%

Pneumonia Model	R2
Temp, Rh, PM10	68.30%
Temp, PM10	60.60%
Temp, RH	58.20%
Rh, PM10	19.70%

Bronchitis Model	R2
Temp, Rh, PM10	80.00%
Temp, PM10	78.10%
Temp, RH	65.90%
Rh, PM10	22.20%

Table 6. Estimated Percentage of Hospitalizations Per Year in Mexicali Calculated from the Models for Asthma, Pneumonia, and Acute Respiratory Infections (ARI)

Asthma Model	Year				
	1997	1998	1999	2000	1997-2000
Model (T, Rh, PM10)	4089	4084	4282	4326	16,781
*Expected (PM10=0)	15.4% less	14.4% less	17.7% less	19.9% less	16.9% less

Pneumonia Model	Year				
	1997	1998	1999	2000	1997-2000
Model (T, Rh, PM10)	1389	1465	1438	1393	5,685
*Expected (PM10=0)	2.3% less	2.1% less	2.7% less	3.2% less	2.6% less

*Exected hospitalizations for each model assume the value for PM10 is equal to µg/m

Table 7. Expected Number of Hospitalizations in Imperial for Asthma Model, Pneumonia Model, and Bronchitis Model

Asthma Model	Year				
	1997	1998	1999	2000	1997-2000
Model (T, Rh, PM10)	338	355	347	345	1,385
*Expected (PM10=0)	4.16% less	4.0% less	4.6% less	5.43% less	4.5% less

Pneumonia Model	Year				
	1997	1998	1999	2000	1997-2000
Model (T, Rh, PM10)	265	288	277	275	1,105
*Expected (PM10=0)	6.7% less	6.5% less	8.0% less	9.6% less	7.7% less

Bronchitis Model	Year				
	1997	1998	1999	2000	1997-2000
Model (T, Rh, PM10)	301	318	311	310	1,240
*Expected (PM10=0)	4.16% less	4.0% less	4.5% less	5.4% less	6.5% less

*Exected hospitalizations for each model assume the value for PM10 is equal to µg/m