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Back-of-the-Envelope Estimates of Environmental Damage Costs in Mexico

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Developing countries cannot afford an in-depth study of every environmental issue. Policymakers must be given rough, "back-of-the-envelope" estimates of the economic costs of various environmental problems if they are to rank the issues and act. Here is one such estimate — for Mexico.

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This paper — a product of the Agriculture Operations Division, Country Department II, Latin America and the Caribbean Regional Office — is part of a larger effort in the Bank to define a strategy for the environment in Mexico. Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact Josie Arevalo, room I7-100, extension 30745 (29 pages). January 1992.

For developing countries, budget constraints help set the agenda on mitigating environmental damage, one of the indelible marks of our era. And political considerations often dictate the measures taken. There are no firm analytical formulas to help even environmentally conscious policymakers rank needs and remedies.

A developing country such as Mexico — the focus of this paper — cannot afford an in-depth study of every environmental issue. Policymakers need to be provided with rough, "back-of-the-envelope" estimates of the economic costs of various environmental problems. This allows them to rank the issues and act.

In this paper Margulis applied existing methods to estimate the costs stemming from different environmental problems in Mexico. Although the examples are from Mexico, the method can be useful in other developing countries as well.

Margulis shows how creative use of U.S. and other data can help provide simple estimates of the likely costs of soil erosion, air pollution, mining of underground waters, and estimates of the health effects of water and solid waste polluton, lack of sanitation, and the ingestion of food contaminated by polluted irrigation. The assumptions underlying all calculations are conservative. Some environmental damage issues, such as loss of biodiversity, were too complex to permit quantification.

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I. INTRODUCTION AND CONCLUSIONS

For developing countries budget constraints help set the agenda on mitigating environmental damage, one of the indelible marks of our era. Political considerations often dictate the measures taken. There are no firm analytical formulae to help even environment-conscious policy makers to rank needs and remedies.

A developing country like Mexico--the focus of this paper--cannot afford an in-depth study of every environmental issue. Policy makers need to be provided with rough, "back-of-the-envelope" estimates of the economic costs of various environmental problems. This will allow them to rank the issues--and to act.

In this paper, the outcome of an exercise in LA2AG, I applied existing method to estimate the costs stemming from different environmental problems in Mexico. Although the examples are Mexican, the method can be relevant in other developing countries as well. The paper shows how creative use of U.S. and other data can help provide simple estimates of likely costs of soil erosion, air pollution, mining of underground waters, and estimates of the health effects of water and solid waste pollution, lack of sanitation, and ingestion of food contaminated by polluted irrigation. The assumptions in all calculations are conservative.

Table 1 summarizes the major problems analyzed, their potential effects, the costs involved, and a summary of the equations and calculations. Chapter II describes the method and its limitations. Chapter III gives details on the cost estimates. (Some environmental damage issues, such as loss of biodiversity, were too complex to permit quantification).

TABLE 1

SUMMARY OF MAJOR ENVIRONMENTAL COSTS IN MEXICO (*)

Problems	Potential effects production/health	Method/formula	Annual costs (US$ billions)	Built-in assumptions
SOIL EROSION	Loss of agricultural output	Average productivity loss x output (soybeans, maize, sorghum, and wheat)	1.00	Application of projected tendency losses in U.S. to perpetuity.
HEALTH EFFECTS FROM AIR POLLUTION (MEXICO CITY ONLY)	Particulates: Morbidity (respiratory restricted activity days - RRAD)	ΔRRAD = 0.0114 x baseline RRAD x (conc. fine particulates - legislation standard)	0.36	Day Lost=US$32. Conc.FP=119 μg/m3. FP Standard=50 μg/m3. Baseline RRAD=3.
	Particulates: Mortality (MR)	ΔMR = 1.69/million x concent. suspended particles	0.48	Conc.SP = 298 μg/m3. 1 Statistical life = US$75,000.
	Ozone: Morbidity	ΔRRAD = baseline x adult population x exp [(6.88 x Δozone) - 1]	0.10	50% productivity loss other assumptions as above.
	Lead: Children's treatment for high blood lead levels (BLL)	Population affected x average estimated treatment costs	0.06	Screening if>25μg/dl. EDTA test if>35μg/dl. 1% require chelation. Hospital cost = 1/15 of U.S. cost.
	Lead: Children's compensatory education	Population affected x education costs	0.02	20% of those>40μg/dl. Average education expenditure per child
	Lead: Hypertension in adults	Population affected x average estimated treatment costs	0.01	Δ1μg/m3 lead in air = Δ3μg/dl in blood. Δ1% BLL = Δ0.8% prob. of hypertension. Lead conc.air = 1.4 μg/m3. Average BLL 15μg/dl.
	Lead: Myocardial infarctions	As above	0.04	60% occur in hypertense. Costs=1/2 as in U.S.
EXCESS USE OF UNDERGROUND WATER DUE TO POOR PRICING (not social costs)	Subsidies to supply water to Mexico City	(Marg.cost - charge) x consumption	1.00	Average price P$2900. Marginal Cost P$4500. Average consumption = 1.8 billion m3.
	Subsidies to irrigation	As above	0.16	Implicit subsidy of US$82/ha/year to 2 million ha.
DIARRHEAL DISEASES FROM WATER AND SOLID WASTE POLLUTION, LACK OF SANITATION AND FOODSTUFF POISONING	Morbidity	Incidence x average treatment costs	0.03	Children and elderly require treatment, 50% ORT, 20% lab analysis. Adults require treatment and 20% ORT.
	Mortality: Scenario 1 - current situation	No.of lives x life expectancy x value	3.60	1 Statistical life = US$75,000.
	Mortality: Scenario 2 - with oral rehydrat. therapy (ORT)	Incidence x average treatment costs	0.00 (US$450,000)	Treatment = US$3, ORT = US$1 + 12 administration.

(*) - In all cases, the rate of discount is 5%.

The estimates presented here are conservative estimates of the likely environmental costs of the problems analyzed. Policy recommendations based on these estimates have to be made with extreme caution. A much more detailed analysis of the data provided, as well as of the applicability of the U.S. experience to the Mexican conditions, would have to be made. From the calculations, we draw the following conclusions.

(1) Where human lives are at risk, the costs of environmental problems rise sharply, even attributing the most conservative values to them.

(2) Water- and solid-waste related health problems are significant only if one assumes current diarrheal disease mortality rates, without reference to the potential benefits of oral rehydration therapy (ORT). Guaranteeing water supply, sewage supply, water treatment, and solid and toxic waste disposal are all vital. But given the potential benefits of ORT, the government should urgently promote campaigns to advertise ORT, its proper administration, and its benefits, and attempt to guarantee access of all those at risk to serum ingredients or laboratory compounds.

(3) If diarrheal infant mortality were controlled or significantly reduced, air pollution in Mexico City would be the country's major environmental problem. This would reflect both the large urban population and the incredibly high pollution level.

(4) Particulate matter is Mexico's most damaging pollutant, more dangerous than ozone and lead. Lead should soon cease to be a major health hazard--although the issue of use of leaded and unleaded gasoline in MCMA, their prices and effects on the use of catalytic converters are still critical issues for government.

(5) Water supply to both Mexico City and to irrigation in agriculture are rarely mentioned as major Mexican environmental problems. But underpricing water has led to overuse. We calculated only the subsidies implicit in the charging systems. Massive pumping underground waters is also causing the terrain to sink, threatening infrastructure. Although the effects of subsidence in Mexico City were not even calculated, the cost estimates here suggest that adjustment of pricing is urgent.

(6) Soil erosion is often considered the major environmental problem in Mexico and some Central American countries. The calculations suggest that after water pollution and related problems this could well be the case. We only considered on-farm costs (impaired crop yields), but off-farm costs (siltation of dams, for example) must eventually be taken into account. We also could not estimate the costs from increased fertilizer applications. Estimation based on applying U.S. parameters to Mexican soil data may be particularly invalid because the effects of soil erosion are very site specific. Such issues deserve much further analysis.

II. METHOD AND LIMITATIONS

Ranking Environmental Problems

No unambiguous criterion ranks one environmental problem over another--for instance, making urban water pollution more critical than air pollution, loss of biodiversity, or soil erosion. The issue is complicated by the different nature and effects of the problems. One criterion would be to consider more severe the problem that implies the highest costs--but this would not necessarily indicate which problem must be addressed first. Given the budgetary constraint, even though the costs of water pollution may be higher than those caused by air pollution, it may be more cost effective to control air pollution first, if the control costs are lower.

On a practical level, the above limitation may not be so serious. There is a significant lack of information on the extent of physical problems, on the damages, and on the costs of control. Thus, it would be too grand a goal to make a full benefit/cost analysis of every major environmental problem in a country such as Mexico. This is probably true in most nations. Making rough estimates of damages may be a realistic, less ambitious way to indicate to environmental authorities the relative severity of national environmental problems. This is a necessary first step to defining priorities. The exercise here demonstrates to policy makers that benefits can be estimated with currently available information, so that when full cost-benefit analyses are performed, they already have a place to start, i.e., a very practical (back-of-the-envelope) guide for first cut benefit estimation.

An important additional benefit derives from the quantification of the environmental costs of different problems. Under the laws of most countries, and under the Bank's lending conditionalities, environmental impact assessments (EIA) are now required for different types of investment projects. But economic decisions on the viability of projects are usually independent of EIA; since a number of environmental costs are direct costs, there is clear scope for estimates of such costs to be made based on EIA and then incorporated in the economic evaluation of projects. This would allow for EIA to become a more integral part of project preparation. The economic evaluation would give a more rational ranking of alternatives.

Method

Three basic steps help estimate the costs associated with environmental degradation. The first is to measure the level of environmental quality (or degradation). The second is to relate such level of quality to damages--health, productivity, materials. This depends on knowledge of the "dose-response" function, the relationship that associates the incidence of health problems (or other effects) to different levels of environmental quality.[1] The last step then assigns costs to the predicted incidence of health problems (or loss of agricultural production, or damage to materials). In the case of the health effects, we tried to assess both direct costs (hospital and treatment costs, for example) and indirect costs (a mother's time).

This paper does not discuss the pros and cons of assigning monetary values to physical or to health effects from environmental degradation. There is a fairly vast literature on this issue. What is missing are applications of theory, particularly in the context of developing countries. The existing applications have been made almost exclusively for the U.S. and some European countries. Some methodologies used in the U.S. studies are not readily applicable elsewhere, because of geographic and socioeconomic differences. Even so, in some situations, simple first order estimates of the damage costs can be made by "direct" application of the U.S. experience; that procedure is not new here.

Limitations

This study is limited in several respects. As indicated, dose-response curves are not necessarily applicable to all populations and all regions. In addition, (1) quantification methodologies are still subject to much debate. (2) Not all major problems have been considered in this study, and for those problems analyzed, not all the effects have been estimated and a great deal of uncertainty is involved. (3) In the case of Mexico, there is a paucity of information on parameters. We have additionally opted for a conservative approach, so that estimates tend to be underestimates of the true costs of each problem.

(1) Estimating the economic effect of environmental improvement (or degradation) has been controversial. In some environmental problems, society incurs in "direct" costs--material damage, loss of agricultural production, and so on. It is necessary to incorporate these costs into decisions on investment projects. The costs associated to the health effects of pollution involve subjective pain, which cannot be readily quantified, as well as direct costs (hospital and treatment cost, loss of productivity). "Much research has been devoted to the area and several health benefit studies on the acute effects and the mortality effects [of air pollution] are now available" (Krupnick and Alicbusan 1990).

Cost studies on the mortality effects of environmental degradation involve estimating the "value of life" (premature death). This cannot be thought of in terms of willingness to pay by any

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1. In the case of health effects, the incidence of problems is related to the exposure rather than to ambient concentration of pollutants. Models that attempt to determine exposure of individuals to pollutants require a considerably larger volume of information. For the population at large, it is questionable whether the results differ significantly.

particular individual; instead, it must be measured in statistical terms--as the costs incurred by society to avoid a greater probability of a deadly accident or as an individual's willingness to accept a risky activity at a higher payment. The human capital approach, which values an individual's life according to the net present value of his/her productivity, is subject to wider technical and ethical criticism but requires substantially less data.

(2) Though the conceptual framework exists to evaluate in money terms the consequences of loss of biodiversity, this aspect is not included in the analyses. The main reason is lack of knowledge on the effects of loss of biodiversity (loss of known and unknown pharmaceutical products, soil erosion and so on). Economic valuations thus involve many subjective considerations and great uncertainty. The information available is extremely limited, even for developed countries.

As to uncertainties, "they range from questions about the existence of an effect, to statistical uncertainties about the values of coefficients, to issues about what dollar values should be assigned to various benefit categories" (NERA, 1990). "Currently, the usual technique for dealing with uncertainty is sensitivity testing" (Bojo et al., 1990). We think that addressing uncertainties more rigorously would be beyond the purpose here. Most references present sensitivity analyses for major parameters and assumptions. We make a few sensitivity exercises for the discount rate.

(3) Because it is not possible to make an assessment of environmental costs without information on the levels of environmental degradation, the estimates here are restricted to those problems where data are known or reasonably estimated. Coastal management and deforestation--major environmental problems in Mexico--are not included. And because the effects are largely the same, the environmental costs of water pollution and of solid and toxic waste disposal are not analyzed individually, but together.

We describe in some detail the steps taken in applying the U.S. methodology to the Mexican data. Because data are limited, a few assumptions and simplifications had to be made, and they are explicitly mentioned. We are convinced that the exercise provides a guide for prioritization and could be replicated elsewhere.

III. COST ESTIMATES OF MAJOR PROBLEMS

Damage and Control Costs. In estimating the benefits of improving the level of environmental quality, it is important to distinguish between damage and control costs. In the case of pollution, control costs are located at the source (typically a filter); in the case of erosion, they are the costs of soil conservation practices. Damage includes both mitigation (preventive) costs and costs from the impacts remaining after mitigation and control (typically, the costs from pollution after filters have been installed and medication has been used to treat pollution-related diseases; in the case of erosion, the yield losses after both soil conservation measures have been implemented and compensatory fertilizers have been applied). As discussed previously, we concentrate on damage costs in this exercise.

The estimation of such costs, however, presents complications. For instance, how to estimate the benefits associated with the control of air pollution--which will avoid some cases of asthma? The benefits measured in terms of damages avoided are large, say US$50 per case per day (suffering and pain, work loss days, and loss of productivity); however, if measured in terms of control costs they may be extremely low, say US$1 per case (as low as medication costs). So in this case, what is the economic benefit associated with the elimination of pollution and reduction in the incidence of asthma?

The damage should be given by the opportunity cost of controlling pollution by the least cost alternative, in this case medication. However, in measuring such opportunity cost, both direct and indirect costs must be taken into account. Thus, along with medication, the opportunity cost of time (work loss days) is also included. Indirect costs more difficult to assess, such as suffering and pain, are not estimated. The same argument applies to control of water pollution. The procedure adopted for soil erosion is discussed below.

Soil Erosion

Soil degradation and its negative impact on water retention, runoff, and aquifer recharge is one of the most serious environmental problems confronting Mexico. A 1988 Bank study stated that 66 percent of the national area (112.8 million hectares) had moderate erosion and 13 percent (22.4 million hectares) severe erosion. Comparisons with limited but more detailed aerial photographic coverage indicate that the situation may well be even worse, with some 42 percent of land totally or severely eroded. At "moderate" levels (in Mexico), losses may be as much as 10 tons of soil per hectare per year; at "severe" levels, such losses are from 10 to 15 tons.

On-farm erosion costs are impaired crop yields, land removed from crop production or used in less productive enterprises, and additional production costs, notably fertilizers to replace lost nutrients. Non-farm losses to erosion are siltation of waterways, dams, and other collection sites. No good evidence exists on these effects in Mexico. Estimates of non-farm costs from research done in other countries are subject to uncertainty because of the local specific interactions between erosion and land use. There is disagreement on the magnitudes of these costs relative to on-farm costs. The estimates here of the total costs of erosion are based exclusively on reduced yields, thus are clear underestimates.

In order to estimate the change in yield in the U.S. due to erosion, a regression of yield trend values on annual erosion rates was made (Crosson & Stout 1983, using county level data). For the U.S. yield losses to erosion estimated this way range from 1% to 18% of maize yield, with an average loss of 4%; from 2% to 22% of soybean yields, with an average of 4%; and 1% of wheat[2]. These crops represent roughly 65 percent of the area of annual agricultural crops in Mexico.

Application to the Mexican case was made by estimating the 1965-85 Mexican yield trends and then applying the average U.S. erosion effects above; the resulting estimated yields (with and without erosion) were then compared.[3] The results were the following: losses in wheat on the order of 1% of the value of 1990 output, or US$4.6 million at international prices; average losses to maize 2.9%, or US$38 million, and 0.4% to soybean, or US$0.5 million in 1990. Sorghum, beans, and cotton would be the other annual crops where erosion is intense (the area occupied by these crops is roughly 25% of the total agricultural area), but no studies are available relating erosion rates to yield losses. Only sorghum has shown a decrease in productivity in the last five years; for this crop we assumed that the effects of erosion on yields are the same as for wheat --only 1%-- which lead to an estimated loss of US$6 million in 1990.

Total annual estimated losses to erosion were US$50 million. "However, erosion-induced productivity losses are not confined to a terminal year, but accumulate over much or all of the intervening period. Consequently, knowledge of the effect of erosion on costs in a terminal year is incomplete. ... The way to compensate (for these deficiencies) is to calculate the present value of the annual productivity loss" (Crosson and Stout, op.cit.). To illustrate this aspect, suppose we have

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2. The regression coefficient for maize was -0.0091, with the rate of erosion of 8.48 ton/acre; this lead to an average yield loss of 0.077 bushels/ acre, which represented 4% of the average yield of 1.97 bushels/acre/year. The same procedure was applied to the other crops.

3. The trend yield growth (with erosion), which is observable, was 3.45% for maize, -0.52% for soybeans, and 10.95% for wheat. The trend yield growth without erosion is equal to (1 + loss from trend yield growth) x (trend yield growth with erosion), where the losses from trend yield growth are the percentages observed in the U.S. As acknowledged, the figures of the Mexican case were provided by John McIntire, personal communication, and McIntire and Shaw 1991).

a .op yield of 10 tons/ha without erosion, and that with erosion there will be a yield loss of 1 ton/ha. This means that yield in year 2 will be 9 ton/ha. If, again, on year 3 no preventive measures are taken, productivity will further decline to 8 ton/ha. This could be repeated for 10 years, when productivity would eventually drop to zero. Whichever the decision on year 2, the productivity loss of 1 ton/ha in the first year is perpetual, assuming it is irreversible. Therefore, irrespective of actions taken on subsequent years, the loss per hectare due to erosion on the first year alone is the discounted value of 1 ton of the crop to perpetuity.

The procedure above assumes that losses to erosion are irreversible. Applying the procedure using a 5 percent value for the discount rate, the estimated net present value of yield losses caused by one year of erosion in Mexico is roughly US$1 billion.[4] Such cost, however, does not include the increased application of fertilizers to compensate for the loss of nutrients caused by erosion. Such "compensatory" use of fertilizers represents a mitigation cost of the environmental problem (equivalent to the medication costs in the case of pollution previously discussed). It is, however, very difficult to assess which percentage of fertilizer applications are used to compensate for erosion, and no works are known estimating such parameter. We do not pursue the issue further here, assuming that such costs are not significant in comparison to the present value of yield losses.

Air Pollution in MCMA

Several studies have analyzed air pollution health effects on humans. The costs of such health effects are of three types: medical expenses (prevention and treatment), lost wages, and individual disutility (discomfort, suffering and the opportunity cost of time). Monetary estimates of the first two types of costs are fairly straightforward and are the only costs estimated here. While information on willingness to pay or willingness to accept changes in health status could identify the third type of costs, such data are beyond the scope of this exercise. For the U.S., it has been estimated that the ratio between willingness to pay and the costs of illness (in medical expenses and lost wages) is roughly two (Chestnut and Rowe 1988). Additionally, damage costs to material and loss of (agricultural) productivity are not considered here due to lack of information. In the U.S., these two types of costs have been estimated to represent up to 40 percent of total damage costs. The numbers presented here are underestimates of the total costs of air pollution.

Exposure to different air pollutants causes different health effects. This means that the dose-response curves differ between pollutants and that analyses must be made for each pollutant. Moreover, the combined effects of two or more pollutants are usually greater than the "sum" of their contributions. This synergistic effect is complicated and not well understood, mainly because so many

4. *US$500 million if the discount rate were 10 percent.*

factors of atmosphere's chemistry are involved. Such effects are not considered here, again giving conservative estimates.

The three basic procedures in quantifying the health effects of a pollutant are: (1) to determine the ambient concentrations; (2) given the concentration levels and the population age distribution, to use a specified dose-response curve to determine the (incremental[5]) incidence of diseases in the population; and (3) based on the costs associated with each disease (treatment, lost wages or life), to determine the overall costs.

Two brief qualifications

Data on air pollution in MCMA. All data on air quality was provided by the Departamento del Distrito Federal and by the air pollution unit of Mexico's environmental agency SEDUE. Since October 1989 SEDUE has been monitoring every major pollutant daily in different areas of the city, providing results grouped into five regions. For most stations, there is available the annual number of readings, the daily average, and the daily maximum. Scattered more specific data are also available for specific regions and periods (maximum-maximorum readings, number of days above standard, and so on).

Dose-response curves. Relations between concentration of pollutants and effects on health are based on both laboratory experiments and epidemiological studies. The references used here usually balance the results obtained by the two approaches.

Two aspects are more difficult to address, however. One aspect is the possibility of threshold levels below which some health effects cease to occur; this would directly affect the benefits (or costs) associated with a change in pollution. There is insufficient evidence for the pollutants analyzed here, except for lead. Thus, the procedure adopted was to consider the legislation standard as the level of air quality associated to "no" deleterious health effects, and zero concentration level in the case of lead. The second aspect relates to potential differences in pollution-related health effects due to the high altitude of Mexico City, in contrast to the sea-level cities where dose-response studies are typically made. Again, there is little evidence on such differences. Similar estimates for

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5. The benefits (or costs) associated with different levels of pollution--typically, the incidence of diseases--are a function of the desired change in the level of pollution. To estimate the costs stemming from a certain level of pollution, it is therefore necessary to consider the difference between that level and the one that causes no health effects. Such level of air quality may be zero pollutant concentration level (in the case of lead) or the legislation environmental standard (all other pollutants).

Denver, Colorado (Chestnut and Rowe 1988), whose conditions resemble Mexico City's, did not incorporate any factors to account for the altitude effect. This is also the procedure here.

In the case of MCMA, the major health impacts originate from three major pollutants, namely suspended particulate matter (SPM), ozone, and lead. The effects of carbon monoxide and sulphur dioxide are not analyzed here. Oxides of nitrogen and hydrocarbons are precursors in the formation of ozone, so their effects are "captured" in the analysis of the latter.

Suspended Particulate Matter

Morbidity. The major health effects from exposure to particulates are restricted activity and increase in overall mortality rates. Restricted activity means acute morbidity that, in the case of particulates, can be measured in terms of restricted activity days (RAD days when a respondent was forced to alter his/her normal activity), work loss days (WLD), visits to emergency rooms, minor respiratory disease, and children's chronic cough.

The most relevant (highest cost) morbidity effect from suspended particles relates to respiratory related restricted activity days (RRAD). The dose-response equation used is the following (based in Ostro, 1987, and Chestnut and Rowe, 1988):[6]

(1) (Δ RRAD)/person/year = 0.0114 x baseline RRAD x (Δ Annual FP)[7], where (Δ RRAD) is change in respiratory related restricted activity days, baseline RRAD is the average current level of restricted activity days due to respiratory diseases per person per year, and (Δ Annual FP) stands for a change in annual average arithmetic mean concentration of fine particulates[8] ; fine particulates are the smaller suspended particles that penetrate deeper into the respiratory tract and cause harm. In Mexico this fraction is estimated at between 40 and 65 percent (Secretaria de Salud

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6. *Controlled variables used in the reference are sex, age, education, chronic health condition, race, marital status, income, annual mean temperature, occupational status, and number of sick paid days. Coefficients for WLD is 0.004 and for RAD is 0.009 (average of six years of observations).*

7. *A more recent result by Ostro has been used in NERA (1990), where a 1 µg/m3 change in FP yields a 0.028 change in RRADs per person, irrespective of baseline RRAD. In the Mexican case, this would lead to a 0.034 change in RRAD (3 x 0.0114), which is NERA's high range estimate. We attain to the original work, even though it produces a 20% higher estimate.*

8. *Change in relation to the point where there are no health effects. As discussed earlier, this is the concentration legislation standard for fine particles.*

1991); in Denver between 30 and 45 percent (Chestnut and Rowe 1988) and in California 61 percent (Kleinman et al. 1989).[9]

The two parameters needed to apply equation (1) to the Mexican conditions are baseline RRAD, which is 3 (Secretaria de Salud 1991, and personal information), and the change in the annual concentration of FP. If the purpose is to achieve the legislation standard, we have to substitute (Δ Annual FP) for the difference between the current average levels of FP (119 μg/m3) and the legislation standard (50 μg/m3). Substitution of these values in equation (1) leads to a change in RRAD of 2.4. This is almost the baseline value of RRAD (3 in Mexico), suggesting that most RRAD would disappear if FP were controlled in Mexico City.[10] The population in the metropolitan area of Mexico City is not precisely known. We used the round estimate of 17 million in 1990, of which 55 percent were adults.[11] In estimating the monetary value of saving 2.4 restricted activity days per person per year, we assumed that half the cases of RRAD implied a work loss day (this is based on the fact that the elasticity of WLD to pollution was roughly half of that for RAD).[12] The total number of work loss days saved by bringing the current levels of FP pollution to the legislation standards is thus 11.2 million (17 million x 0.55 x 0.50 x 2.4).

We took the average wage in industry in Mexico City-- US$4 per hour-- to value each day lost. Excluding all suffering and eventual medication to treat minor RRAD, the morbidity benefits associated with the reduction of the current levels of FP pollution to the legislation standard are estimated at US$358 million.

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9. *If the data available is concentration of total suspended particles (TSP - the most common measure of particulate matter pollution) rather than FP, the same equation should be used, with the right hand term being multiplied by the percentage of FP in TSP; in the case of Mexico, this fraction would be from 0.4 to 0.65.*

10. *If instead of attaining legislation levels the purpose were to eliminate completely FP (if possible), the reduction in RRAD would be greater than 3, the current levels of RRAD. This may strengthen the argument that there are indeed threshold levels below which further reduction in the concentration of FP leads to no extra health benefits.*

11. *Demographic estimates were based on Sistema Nacional de Salud (1988) and on the Encuesta Nacional de Salud (Secretaria de Salud 1988).*

12. *An alternative approach would be to use the data presented in the Encuesta Nacional de Salud, which indicates that 76 percent of the cases of acute diseases did not imply WLD (dias de incapacidad), while the remaining 24 percent implied one or more days. The expected number of dias de incapacidad was 1.13, meaning that on average all cases of RAD implied a WLD (in fact 1.1 WLD); we used the more conservative approach.*

Dose-response curves for other effects from concentrations ` total suspended particles or TSP (children's cough, emergency room visits, and changes in the number of chronic respiratory disease incidents) are provided in the annex. In the case of Mexico the first two effects did not account for significant costs compared with RADs, while there was no data to evaluate the third effect.

Mortality. Several studies suggest that there is a significant relation between TSP and mortality rates. The regression estimates of changes in mortality rates (ΔMR) as a function of changes in the concentration of TSP (ΔTSP) are all linear ($\Delta MR = b \times \Delta TSP$), with coefficient b varying from 2 to 4.46 per 1 million people (Oskaynak 1985 [apud USAID 1990] and Schwartz and Marcus 1986). We used the value 1.69 per 1 million people (NERA, 1990 and Evans et al. 1984). Based on the current levels of TSP pollution in Mexico City (annual average concentration of 297.8 μg/m3 in 1990, while the standard is 75 μg/m3; ΔTSP is thus 222.8 μg/m3), the estimated total number of (statistical) lives saved would be 6,400--equivalent to 3.8 lives per 10,000 people.

Since older people and those who already have respiratory diseases are more likely to die from pollution-related problems, we assumed an expected life of those who die prematurely from TSP of only 12.5 years (NERA 1990). As discussed previously, in order to place a value on human life we should use willingness to pay. This is impossible to be performed in the case of Mexico due to lack of data. An alternative would be to multiply U.S. figures by the two countries GDP ratio. We use the human capital approach which provides a first cut estimate, which is the purpose here. Based on the hourly wage, the annual salary is US$7,700. Discounting at 5 percent per year gives a value of US$75,000.[13] Multiplying the 6,400 lives saved by the value of each gives an estimated saving of US$480 million.

The total annual estimated cost related to particulate matter pollution in Mexico City is US$850 million.

Ozone

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13. American estimates based on willingness to pay place such values between US$500 thousand and US$10 million; using the ratio between the two countries' per capita GNPs -- roughly 10 -- to compare U.S. and Mexico figures, our estimate appears conservative. We can also compare our estimates for Mexico with equivalent U.S. figures by applying the same human capital approach to the U.S., and this can be simply obtained by dividing wages in the two countries. Since the typical hourly wage in metropolitan areas in the U.S. is roughly US$100 and in Mexico US$20, we see again that our estimates are on the conservative side.

Ozone is a pollutant formed in the atmosphere in the presence of hydrocarbons, nitrogen oxides, and sunlight. It is the primary component of photochemical smog and is believed to be irritating to the human respiratory system (Chestnut and Rowe 1988). The major health cost from ozone pollution in Mexico City relates to RRAD. Specific effects such as asthma attacks, eye irritation, mild cough, sore throat, headache, and chest discomfort have been examined in the literature. Because the values obtained were too small compared to those for RRAD--and also due to lack of data--such effects were not considered individually here. The relationship between these effects and RRAD is not clear. Dose-response curves are provided in the annex, with the results of some applications to the Mexican case.

The major study relating RRAD and ozone levels is Portney and Mullahy (1986). It provides a number of alternative specifications that have been adopted throughout the literature. The general specification is the following:

(2) $\underline{\text{No.RRAD/adult} = \exp(\text{Az} + \text{b(ozone)}^c)}$,

where Z stands for other independent variables, ozone stands for the maximum daily hour concentration of ozone, measured in PPM, a and b are estimated parameters, and c varies from 0.5 to 2. Variables are measured over a period of two weeks, so that the annual estimate is obtained by summing up 26 parcels, corresponding to the 26 two-week periods in the year.

The annual baseline RRAD is 3 in MCMA, or an average of 0.115 every two-week period. Data were only available for 7.5 months in 1990, so we multiplied the estimates obtained for this period by (12/7.5). Concentration levels were provided by SEDUE (the observed average was 0.14 [14], while the maximum one-hour standard is 0.11 PPM). Using the specification of equation (2) assuming c = 1, b equals 6.883 so that the expected annual change in the number of RRAD is ΔRRAD = 3 x {exp [6.883 x 0.03] - 1} x 0.55 x 17 million = 6.4 million, or 0.69 per adult, which corresponds to 23 percent of the present level of RRAD.

In equation (2) RRAD is measured in terms of bed-disability days, school loss days, and just restriction of activity that does not fully impair the two above. Since it is not possible to determine the percentage of each of these in the regression analyses, we assume that there is a

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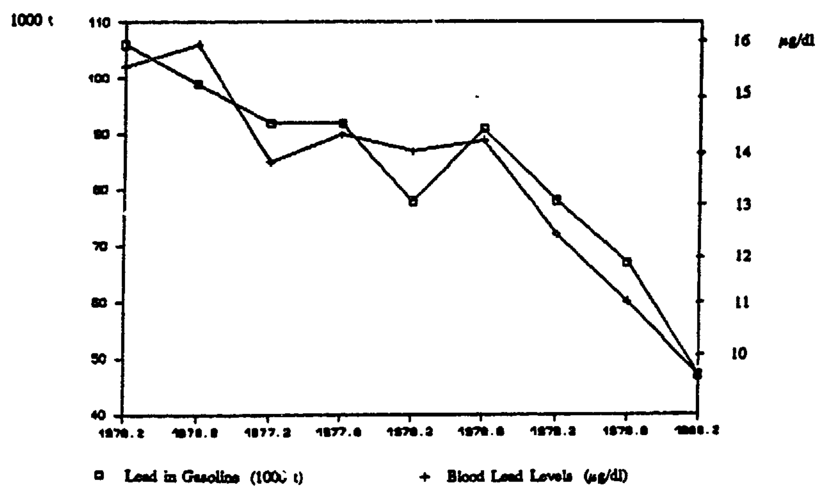
14. We had data for the June/90 - February/91 period, thus 15 2-week periods. For every period, we took the difference between the average concentration (measured in daily 1-hour maximum) and the standard to evaluate the expected number of RRAD lost. Additionally, if the average were below the standard there would be a decrease in the number of RRAD, so that in such cases we considered the observed average equal to the standard, leading to no change in RRAD.

productivity loss of 50 percent.[15] Excluding suffering and medication to treat minor RRAD, the estimated annual benefits associated with reduction of current average levels of ozone pollution to the legislation standard in MCMA are US$102 million.

Lead

Lead in air has been shown to have a strong correlation with blood lead levels associated with neurological damage in children and with high blood pressure in adults (see figure 1). In infants and children, absorption of lead can be via mouthing, air inhalation, and ingestion of food. Almost all the lead deposited in the respiratory tract is absorbed. Because children inhale a proportionally higher daily volume of air per weight measure than adults, they are more susceptible to lead in ambient air. In a population sample of children in Mexico City, the main determinant of blood lead level (BLL) was the place of residency, suggesting that lead absorption through air inhalation is the major source of poisoning (Secretaria de Salud 1991). Nearly 95 percent of the gasoline in MCMA still contains lead.

Figure 1. Total Lead Used in Gasoline, per Six Month Period, and Blood Levels (U.S.NHANES II Survey), After EPA (1985)



15. *This may be a large estimate, but it partly compensates for the benefits arising for asthmatics, which are not included here (see appendix for estimates on asthma effects).*

One difficulty in studying the effects of lead on health is that progress has in fact been made. Even though lead is still one of the six criteria pollutants in the U.S., it is no longer a real major problem; in most metropolitan areas gasoline is lead-free. The estimates here thus had to be almost entirely based on EPA (1985), considered the major publication on the issue, but with some estimates and parameters out of date. Additionally, dose-response relations between lead concentration in air and health effects are not straightforward with simple econometric representations. They often involve thresholds and have not been quantified in a rigorous manner.

Children's treatment. We assumed that all children with BLL above 25 μg/dl require a screening test. Those with BLL above 35 μg/dl have to undertake an EDTA testing, which requires a day in hospital plus follow-up tests and physicians' visits. According to EPA (1985), the most serious cases require an expensive treatment -- chelation. The estimated population of children (under 18 years old) in MCMA is 7.65 million. According to Secretaria de Salud (1991), 29 percent of children have BLL above 25 μg/dl, and 3 percent above 35 μg/dl. Thus 2.25 million screening tests and 230,000 EDTA tests are required. Chelation therapy is only required for approximately 1 percent of all children (also based on EPA 1985).

Data on hospital, medication, and treatment costs are unavailable in Mexico. We had to adjust the information of these costs in the U.S. to Mexican conditions. The only survey comparing treatment costs in the two countries was made for AIDS and indicated that they were 30 times higher in the U.S. (Secretaria de Salud, personal communication). Because AIDS treatment is so technology intensive, and also because treatment conditions in the two countries are very different, we assumed that for other diseases the ratio between treatment costs would be half as high as for AIDS, thus 15 times higher in the U.S. We adjusted the cost estimates presented in EPA (1985) from 1985 US$ to 1990 US$ using CPIs. The estimated costs are as follows: (a) each screening test costs US$131 in the U.S., thus US$8.7 in Mexico; since 2.5 million tests are required, total costs are US$19.6 million;[16] (b) each EDTA is estimated to cost US$655 in the U.S., thus US$44 in Mexico, including one day in hospital; since 230,000 tests are required, total costs are US$10 million; (c) three follow-up visits are required for those children subjected to EDTA test. For this item there are some data suggesting a lower bound for doctor's visit around US$20, so that the total costs would be US$13.8 million; (d) finally, the chelation therapy is supposed to cost US$3,250 in the U.S., or US$220 in Mexico. Since 76,500 cases require chelation, total costs are US$17 million. Total estimated costs for children's treatment is US$60 million.[17]

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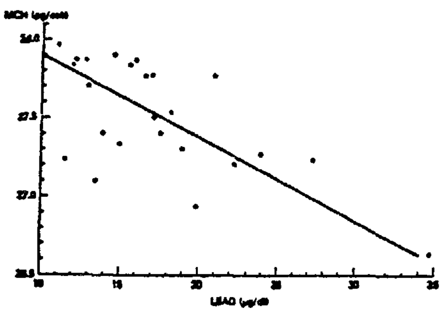
16. It is unlikely that so many children call in hospitals to make such tests. This certainly does not mean that there are no costs involved. We thus assume other children to have the same or higher costs.

17. As noted earlier, since there is indication that even minimal concentrations cause harmful health effects, the estimates do not relate to legislation standards, but to zero concentration levels.

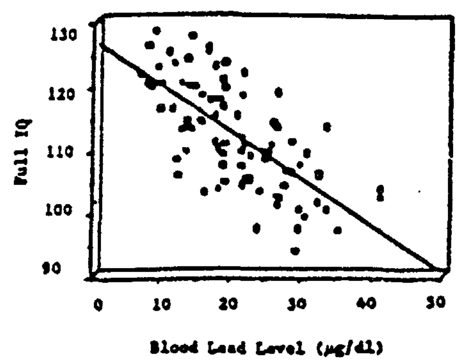
Compensatory education. Studies show that 20 percent of children with BLL above 25 μg/dl have lower cognitive development and require supplemental education for an average period of three years. This applies particularly to those children with BLL above 40 μg/dl. There is also evidence suggesting that, "on average, BLL of 30 to 50 μg/dl result in a 4 point decrement in IQ, and that lead levels of 50 to 70 μg/dl would reduce IQ by roughly 5 points" (EPA 1985 apud De la Burde and Choate 1975 and Rummo et al. 1979). Figures 2, 3, and 4 show, respectively, the relationships between mean cell hemoglobin (MCH) and BLL after being adjusted for a number of significant variables,[18] and the correlations between BLL, (full) IQ, and agility, the latter two having been made in Mexico City. All relationships apply only to children.

Figure 2. Relationship between MCH and BLL (after EPA 1985)



For ease of display, each point represents an average of about 100 children with consecutive BLL.

Figure 3. Correlation of BLL and (Full) I.Q. in 109 Children in Mexico City (after Secretaria de Salud 1991)



We made the conservative assumption that a three year supplemental education would be required for those children with BLL above 40 μg/dl (140,365 children in Mexico City fall in this group). Using the average annual cost of education per child in Mexico City of US$153 produces a total cost in compensatory education of US$21.5 million.[19]

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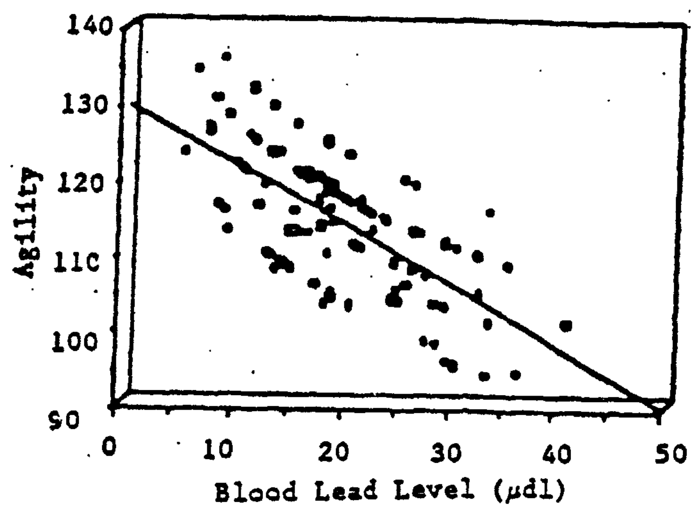
18. The variables were age (under 2, 2-4, and 4-6), race, sex, degree of urbanization, family income, serum albumin, dietary calcium, dietary calories, serum copper, dietary carbohydrates, dietary fat, serum iron, blood lead, dietary phosphorous, dietary protein, transferrin saturation, dietary vitamin C, and serum zinc. Sample size was 1,967 children.

19. The total expenditure in education for children in Mexico was US$5.5 billion in 1990. Assuming that expenditures were uniformly distributed throughout the country, the estimated expenditure in Mexico City was US$5.5 billion multiplied by the population of Mexico City in relation to the rest of the country, which is roughly 17 million over 80 million, or 21 percent. Thus the estimated annual cost of education per child in Mexico City is US$153. Multiplying by three years (discounting at 5 percent p.a.) and multiplying by the 140,365 cases gives the figure presented in the text -- US$21.5 million.

Figure 4. Correlation of BLL and Agility in 109 Children in Mexico City (after Secretaria de Salud 1990)



Hypertension in adults. A relationship that a 1 μg/m3 increase in the concentration of lead in the air will result in an average increase of 2 μg/dl in BLL of adults (and between 3 and 5 μg/dl in children) has been proposed in USAID (1990) apud EPA (1986). In a study recently made in Mexico (Rothenberg et al. 1990), estimates of such elasticity are not explicitly provided, but running a regression on the data presented lead to an estimated relation coefficient of over 6. We assumed that a change of 1 μg/m3 in lead concentration in the air leads to a 3 μg/dl change in BLL. It has also been proposed that a 1 percent change in BLL leads to a 0.8 percent change in the probability of blood pressure being greater than 90 mm Hg (above which the person is considered to be hypertense) (EPA 1985). This means that the elasticity of the probability of being hypertense to the lead concentration in air can be determined if the average BLL in the population is known.

Between 1989 and 1990 there has been a significant decrease from 1.98 to 1.37 μg/m3 in the average concentration of lead in the air of Mexico City (the legislation standard is 1.5 μg/m3). Because the harmful effects from lead on blood appear not to present threshold levels (that is, even below legislation standards there are negative health effects), in order to compute the costs associated to lead levels in the air we considered the effects of 1.37 μg/m3 (the 1990 average concentration). This corresponds to a 4.11 μg/dl decrease in average BLL of the population. The average BLL of the population of Mexico City is not known, but there are scattered samples (Secretaria de Salud 1991 and Rothenberg et al. 1990). We made the conservative assumption (in this case by increasing it) that the average male adult population BLL was 15 μg/dl. This means that eliminating the 1.37 μg/m3 of lead concentration in the air would mean a 27.4 percent change in BLL (4.11 divided by 15). Using the 0.8 elasticity, there would be a 21.9 percent reduction in the probability of blood pressure being greater than 90 (that is, of hypertension). Finally, according to the Encuesta Nacional de Salud, there were 1,460,700 cases of hypertension in the country in 1988. Assuming that all cases were uniformly distributed in the country (this is conservative since urban areas, and specially Mexico City, tend to have a higher incidence of the disease), there should have been 321,270 cases of hypertension in Mexico City in 1990. The elimination of lead in Mexico City's air (from 1,37 μg/m3 to zero) would thus lead to a reduction of 70,422 cases of hypertension in MCMA.

According to EPA (1985), people with hypertension see a physician because of high blood pressure an average of 3.27 times per year. Using the estimate of US$20 per visit gives a total annual cost in Mexico City of US$4.6 million. The same population is forced to remain in bed an average of 0.41 days per year; considering the daily wage of US$32 gives a total cost of US$925,000. Additionally, 30 percent of the hypertense population needs medication; assuming an annual cost of US$100 (half that in the U.S.) gives a total cost of US$2.1 million. Finally, for the U.S. there was a relation between the number of hospital bed-days of 0.058 per person per year due to hypertension alone. Using this same statistic to the Mexican case would give 4,084 hospital bed-days per year in Mexico City which, for a daily cost of US$50, gives a total value of only US$205,000. Adding up all components, the total estimated costs due to hypertension morbidity in Mexico City is US$7.85 million.

Myocardial infarctions (MI). The reduction of hypertension is less important than the indirect benefits in the form of reduced cardiovascular disease associated with elevated blood pressure levels. It is estimated that 60 percent of MI occur in people with blood pressure greater than 90 (based on Framingham Study, McGee el al. 1976 apud EPA 1985, plus some simple adjustments and estimates). Since the elimination of lead from air would lead to a 21.9 percent reduction in the probability of blood pressure being greater than 90, there would be an expected reduction of 13.1 percent in the number of MI (0.219 x 0.6). According to the Anuario Estadistico (Secretaria de Salud 1988) there were 3,794 MI in Mexico City in 1990. Thus an estimated 498 cases of MI would be eliminated.

The costs associated with treatment of MI are also based on EPA (1985). In the U.S., they amount to US$18,000 per case. Assuming that the costs of treatment of MI are half those observed in the U.S. (rather than 1/15, because of intense technology requirements), the overall costs would be US$4.5 million. Additionally, there are lost earnings because of reduced workdays. Using the same values and procedures as with particulates and applying such foregone earnings to all 498 cases gives an additional cost of US$31.1 million. The treatment costs of MI would be US$36.5 million. However, still based on EPA 1985, of all cases of MI, 22.5 percent are sudden deaths, while the remaining 77.5 percent were fatal or nonfatal MIs. We assume that 50 percent were nonfatal MI. Therefore, the costs of treatment are only US$18.25 million (36.5 million x 50%). The fatal cases (498 x 27.5% = 137 cases) cost US$1.25 million (treatment cost = US$9,000 x 137) plus US$10 million (value of lives = 137 x US$75,000). And the sudden death cases cost US$8.4 million (112 cases x US$75,000). The total estimated costs associated to myocardial infarctions is thus US$40 million.

The total annual estimated health costs associated to lead atmospheric pollution in Mexico City are US$125 million.

Adding up the costs associated to the three major air pollutants, the total estimated health costs from atmospheric pollution in MCMA is roughly US$1.1 billion.

Mining[20] of Underground Waters and Pricing

Water Supply to Mexico City Metropolitan Area (MCMA). Since the middle of the past century, water supply to MCMA has partly relied on pumping underground waters. In the 1960s, in order to reduce the effects of mining of these waters, alternative sources were sought, particularly surface waters outside the valley. The most important source was the waters from the Rio Lerma basin, which is 200 meters below MCMA. Attempts to prohibit the opening of new wells failed, and the city's water supply could not match the massive growth of the city's population. In the 1980s, the formidable amount of 4 m3/sec began to be pumped from the Cutzaman region, 1,000 meters below MCMA. The pumping requirements are 86 GWh per year; Tecoluca, the next site, will demand 120 Gwh.

The current total demand for water in MCMA is 56 m3/sec. About 15 percent of consumption comes from surface waters, with the remaining 85 percent from underground waters. The current deficit is 20 to 27 m3/sec, which corresponds to roughly 500 million cubic meters per year. These 500 million m3 correspond approximately to an additional average height of 0.5 meter per year. The average pumping height today is 80 meters.

One of the most dramatic effects from lowering the water table is the potential subsidence of terrain, which has been eight meters or more in the historical part of town. The costs implied by harm to infrastructure (pipes, building structures, sewage, electricity cables), as well as the preventive costs of potential future subsidence, particularly aggravated by earthquakes, are formidable. They may well be the largest component of the costs associated to the mining of underground waters in MCMA. However, the information available on these effects is limited and not well catalogued and published. These costs are not accounted for in this exercise.

The other type of cost is the long-run opportunity cost of water in MCMA. Rather than attempting to estimate these costs, however, a more elementary calculation is necessary, and that is the difference between the marginal social and private costs of supplying water in MCMA. "This is a typical developing country phenomenon where many prices are administered for social and

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20. Mining the resource here means exploiting it in an unsustainable basis, so that the amount pumped out is larger than the recharge.

economic purposes. Conspicuous examples are the pricing of energy and extractive water below market prices. Underpricing tends also to increase the scale of the externality, e.g. excessive irrigation water use can cause waterlogging and salinization of soils" (Pearce 1990). The estimates here are not social cost estimates.

In the Valley of Mexico, marginal cost of water supply is Mex$4,500 (all costs on a per cubic meter basis). On a volume basis, 82 percent of water goes to households for domestic consumption, 10 percent to industry, and the remaining 8 percent to agriculture for irrigation. Average prices are Mex$2,850 for households, Mex$4,000 for industry, and zero for agriculture. Sixty percent of households pay according to their consumption (that is, have a meter); the remaining 40 percent pay on average a little more (15-20 percent; CNA, personal information). The average price is thus Mex$2,900, so that the difference between marginal social cost and price is Mex$1,600/m3. Multiplying by the annual consumption of 1.8 billion m3 gives an annual subsidy of Mex$2.88 trillion or US$1 billion.

Irrigation Waters. The subsidies to water consumption in MCMA can be compared to those given to farmers for irrigation in agriculture. There are three major potential environmental effects from such subsidies, all applying to the case of groundwaters. The first is when the amount pumped is greater than the average recharge of the aquifer. This leads to an irreversible reduction of reservoirs, since water mines cannot be "refilled". Bajio, Central, and North-Central Mexico present this problem. The second is the intrusion of salty waters in the interface of the coastal aquifers, due to a lowering water table. This implies an irreversible lack of sweet water in the coastal aquifer. This may be the case in both North and South Baja California. Finally, excessive irrigation water use can cause waterlogging and salinization of soils: subsidies clearly provide an incentive to such excessive use. This applies to all regions in Mexico. An estimated 100,000 hectares of agricultural land in Mexico are saline due to excessive use of irrigation waters (out of a total of 600,000 hectares of soils affected by some kind of salinity effects).

Information is scarce for most parameters. The irrigated area in Mexico is 6 million hectares; 2 million hectares are irrigated with underground waters. Based on a few standard parameters,[21] the implicit subsidy of US$82/hectares/year multiplied by the 2 million hectares gives a total annual subsidy of US$164 million. These subsidies refer to provision of water; the costs of bringing water from alternative sites are not estimated here. For the purpose of illustration, we present estimates of the costs of reclamation of saline soils : 465,000 hectares need reclamation

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21. Average water diversion 9,000 m3/hectare/year, average pumping depth 50 meters, an energy cost to farmers of US$28 mills/kwh and a marginal cost of US$61 mills/kwh. Such estimated parameters lead to a power demand of 1 Kw per hectare and of 2,500 kwh of energy per hectare per year. Thus the marginal cost of irrigation is US$152/hectare/year, while the average cost to farmers is US$70/hectare/year.

(Comision Nacional de Aguas, personal communication). The estimated cost of reclamation is US$1,333 per hectare. Assuming that only 100,000 hectares which correspond to the area affected by human activity, are reclaimed, the total estimated reclamation costs are US$133 million, roughly the same as the implicit subsidies in the charging system.

Health Impacts From Water and Solid Waste Pollution, from Lack of Sanitation, and from Ingestion of Foodstuff Contaminated by Untreated Wastewaters Used for Irrigation.

Gastrointestinal diseases--namely enteric and diarrheal diseases--represent one of the most serious health problems in developing countries and still are the number one cause of infant mortality in many of them, including Mexico. Such health problems are essentially a consequence of interrelated environmental and socioeconomic problems, such as lack of sanitation, ingestion of contaminated foodstuff, and lack of education, which leads to poor hygienic practices.

The original intention here was to quantify the health costs associated to water pollution in both urban and rural areas and, independently, the health costs associated with the disposal of solid and toxic waste. To a large extent the two problems are linked because both surface and underground waters can be contaminated if rain waters percolate through residues. The fact that the major health effect from the two problems is the same--gastrointestinal diseases--makes it extremely difficult to determine the origin of a particular disease. It is impossible to attribute a child's case of diarrhea to either contact and mouthing of solid wastes or to drinking of contaminated waters. Thus the health effect, rather than the environmental problem, is analyzed here.

Water pollution. In the 1970s, 11 surface water basins classified as the most polluted served 59 percent of population, while the 164 least polluted served only 6 percent of the population. In 1985, the total flow rate of municipal and industrial effluent was approximately 160 m3/sec. Water treatment capacity covers 17.5 percent of total discharges from point sources (28 m3/sec), in 60 industrial plants and 193 municipalities. However, only 15 m3/sec (9 percent) were actually treated. Out of 30 locations identified in the Plan Nacional Hidraulico, 19 had coliform contamination.

By 1986, 72 percent of the total population had access to water supply--82 percent in urban areas and 49 percent in rural areas. As to sewage system, 65 percent had access to these facilities in urban areas and only 11 percent in rural areas. In total, 22.5 million people had no access to safe water and about 40.7 million lacked sewerage services. Even for those who have access to piped water, the quality is not always satisfactory: only 20 percent of the municipal systems (for medium and large cities) have a reliable chlorination system.

Solid waste disposal. In 1986, total municipal wastes amounted to 32.5 million tons; one third of this amount were not properly disposed of. Production of waste in MCMA is around

11 million tons/day of which 80 percent was collected (60 percent in other urban areas). Industrial wastes total 133 million tons, of which 5 million tons are hazardous and 15 million tons require special disposal. Most are mining residues. Toxic wastes are indiscriminately mixed with municipal wastes, and operation of solid waste disposal systems is deficient in most municipalities.

Contamination of irrigation waters. The large-scale reuse of untreated domestic sewage waters for irrigation has been commonplace in Mexico since the early 1900s, and often occurs without effective sanitary controls. This practice may pose substantial health risks for farm workers and for the population consuming agricultural products from such areas. Lago Texcoco and the irrigation districts surrounding Mexico City--Tula valley, where wastewaters irrigate some 90,000 hectares, are the major areas with contamination (there are plans to extend such irrigated area to 250,000 hectares in the next few years). Edible crops from these reuse sites have been found to be contaminated with fecal coliform, and evidence from toxic contamination of groundwater has recently been identified. High rates of parasitosis tend to be associated with uncontrolled reuse, and outbreaks of enteritis, other diarrheal diseases, typhoid, and hepatitis are suspected to have been caused by raw sewage irrigation of vegetables.

Cost estimates: mortality. According to Secretaria de Salud (1990), intestinal diseases (infeccion intestinal mal definida) are still the number one cause of mortality in Mexico, with a rate of 32.8 per 100,000 people in 1990 (total 28,000 deaths). The same rate for children under age 1 is roughly 500 (12,500 deaths), while for children between 1 and 4 it is 70 (5,600 deaths). Death rates for the other age groups were estimated proportionally to the number of cases of the disease in each group (the incidence of diarrheas is essentially the same for the other age groups--Secretaria de Salud 1990).

We considered two alternative scenarios. The first is based on current mortality rates: we applied the same criterion as for air pollution, namely an annual salary of US$7,700 and a 5 percent annual discount rate. As to life expectancy, we used 40 years for children below age 19, 30 years for people in age group 20-39, 20 years for those in age group 40-50, and 10 years for the others. Total estimated costs would be US$3.6 billion. This excludes all suffering and pain and any tentative treatment (mitigation) cost.

The other scenario assumes that oral rehydration therapy (ORT) will completely eliminate deaths from diarrhea. This scenario essentially estimates the mitigation costs associated to such deaths. However, it does not include the costs of ensuring such universal use of ORT, namely the educational effort: such costs are almost impossible to be estimated. It is also not possible to compare them with the costs of control (water treatment costs). Nevertheless, the estimate gives an indication of the benefits associated with the mitigation effort. Health costs associated to scenarios in which oral therapy produces intermediate effects can be evaluated based on the two scenarios presented here.

The possibility that ORT could completely eliminate deaths from diarrhea does not appear unrealistic. Countries where conditions are likely to be worse than in Mexico have shown dramatic reductions in the rates of diarrhea-related child mortality. "An estimated 4 million youngsters under age 5 worldwide succumb to the disease each year, accounting for more than a quarter of the 14 million annual deaths in that age group. ORT now saves a million small children annually. No one, adult or child, would die of diarrhea if only every family in the world knew how to prepare and deliver some form of ORT. The ingredients needed for an adequate formulation can be found in virtually every household" (Hirschhorn and Greenough III 1991).

In the case of Mexico, ORT has not proved so effective, probably because of inadequate administration coupled with lack of knowledge on the beneficial effects of the therapy, or even its own existence (Latorre et al. 1990). The costs of the therapy are approximately US$1 [22] plus administration. "A child with diarrhea may need to be spoon fed more than half a liter of solution each day, in sessions spaced as little as three minutes apart, for five to seven days" (Hirschhorn and Greenough III op.cit.). Administration is estimated at US$12 (average of three daily wages of US$4, which is more than the minimum wage in Mexico, assuming that ORT administration does not require any qualification of the person administering the serum). Additionally, since ORT does not stop diarrhea, but only prevents dehydration, we added an estimated treatment cost of US$3 per case. Applying the figures (US$16 per case) to all 28,000 annual lethal cases would lead to an estimated cost of US$448,000.

Morbidity. In 1990, the number of non-lethal cases of diarrhea in Mexico was 3.36 million (Secretaria de Salud 1991). Sixty percent of these cases were children under age 14 and adults over age 65. For both these age groups we assumed: (a) the necessity to treat all cases and to (b) apply ORT to 50 percent of the total number of cases (both costs described above); and, (c) that 5 percent of all cases require laboratory analyses at an average cost of US$20 each. Total costs for those age groups are estimated at US$20 million. For the other age groups we assumed the necessity to treat all cases and to apply ORT to 20 percent of the cases. We additionally assumed that productivity effects are not significant. Total treatment costs are estimated at US$8.5 million. Total morbidity costs associated to diarrheal diseases in Mexico are estimated at US$30 million.

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22. *Estimated costs vary between US$0.17 to more than US$10. The US$1 estimate used here may still be an overestimate (Martines et al. 1991).*

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ANNEX

DOSE-RESPONSE RELATIONS NOT ESTIMATED IN THE MEXICAN CASE

PARTICULATES

(1) A relation between the expected change in the number of emergency room visits (ERV) per person per year and the average concentration of TSP has been provided in Samet et al.(1981), apud Chestnut and Rowe (1988).

$(\Delta ERV) = 0.000129 \times (\Delta TSP)$, where ($\Delta$ TSP) stands for the change in the annual arithmetic mean concentration of total suspended particles, measured in $\mu g/m3$.

(2) A relation between the percent change in chronic cough in children under 14 years of age (% ΔCC) due to a percent change in TSP concentration has been estimated for the U.S. (Ware et al. 1986, apud Secretaria de Salud 1991).

$\% \Delta CC = 0.0101 \times P \times (1-P) \times (\Delta PST)$, where P is the probability of a child having chronic cough, and TSP is measured in $\mu g/m3$.

(3) Finally, a relation between change in number of chronic respiratory disease incidents per person per year (Δ CRD) and concentration of total suspended particles (TSP) has been proposed (Ferris 1978).

$(\Delta CRD) = b \times (\Delta TSP) \times A$, where A is the annual average rate of chronic respiratory disease incidents per person per year, TSP is measured in $\mu g/m3$, and b is 0.0027 for males and 0.0019 for females.

OZONE

Relationships between five different health effects and concentrations of ozone have been proposed or quoted in Kleinman et al. (1989). Other studies present alternative specifications for these same effects. They are the following (all variables on the left hand side of the equations are the percentage of the population suffering the corresponding health effect, and dose is the concentration of ozone measured in $\mu g/m3$).

(1) Mild cough: i) $\% MC = 5.25 + 0.017 (dose)$. An alternative estimate is (Schwarz et al. (1987) ii) $PC = (1 + \exp (a.Z + b(Ozone))^{-1} + c.V$, where PC stands for the probability of a person incurring a cough in one day, Z for other variables, ozone for the maximum 1-hour

concentration of ozone measured in parts per hundred million, V for lagged error variables, and a, b, and c are estimated coefficients, with b = 0.61.

(2) Chest discomfort: (a) % CD = -0.64 + 0.009 (dose). An alternative estimate is (Hammer 1974 and Hasselbald and Svensgaard 1975) (b) PCD = a + [1 -a] / [(1 + exp (b - c(ozone)], where PCD stands for the probability of an individual suffering chest discomfort in one day, ozone is measured in PPM, and a = 0.017, b = 3.53, and c = 0.23. In Mexico City this means a reduction of 2 percent in the number of cases of chest discomfort.

(3) Headache: % Headache = 4.95 + 0.015 (dose). An alternative relation has also been provided by the same references as in item (2), with parameters a = 0.0976, b = 4.88, and c = 4.7. In Mexico City this means a reduction of 6 percent in the current numbers of headaches.

(4) Eye irritation: % EI = -8.63 + 85.45 (exposure concentration), with exposure concentration measured in PPM. As in (2) and (3) above, in the alternative relation for eye irritation a = 0.0407, b = 4.96, and c = 9.07. In Mexico this means a reduction of 30 percent in the current number of eye irritations.

(5) Sore throat: % ST = 14.7 + 0.025 (dose), no alternative relations.

(6) Asthmatics: Chestnut and Rowe (1985) present an estimate of the change in the probability of an asthmatic person having an asthma attack (after Whittemore and Korn 1980): (Δ Pt) = 1.66 x Pt * (1-Pt) x (Δ ozone), where (Δ Pt) stands for a change in the probability of an asthma attack on day t and (Δ ozone) is the change in the daily high ozone hour measured in PPM. To estimate the changes in the number of cases in the population, the probability should be multiplied by the number of asthmatics in the population. In Denver, Colorado, asthmatics in the population are estimated at 4.5 percent, while the daily probability of an asthmatic having an asthma attack is estimated between 0.014 and 0.028 (for the U.S., based on EPA 1985).

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