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**Costs of Preventable Childhood Illness:**

**The Price We Pay  
for Pollution**

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# Costs of Preventable Childhood Illness: The Price We Pay for Pollution<sup>1</sup>

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## ABSTRACT

A growing body of scientific literature implicates toxic exposures in childhood illnesses and developmental disorders. When these illnesses and disabilities result from environmental factors under human control, they can and should be prevented. This report documents monetary costs associated with five major areas of health problems in children that have been linked to preventable environmental exposures: cancer, asthma, lead poisoning, neurobehavioral disorders, and birth defects. We review incidence and prevalence estimates for these disorders, as well as estimates of the associated monetary costs. We apply the concept of the "environmentally attributable fraction" (EAF) of an illness, where EAF is the estimated percentage of cases of an illness that result from an environmental exposure. Preventable childhood illnesses and disabilities attributable to environmental factors are associated with large monetary costs. Our estimate of direct and indirect costs ranges from \$1.1 to \$1.6 billion annually in Massachusetts. Of course, there is no dollar measure of the full practical and emotional burden borne by these children, their families, and the communities in which they live.

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## I. INTRODUCTION

Exposures to toxic chemicals have been implicated in childhood illnesses and disabilities that impair children's ability to grow, learn, and play, and eventually to become productive working adults and parents themselves. These illnesses and disabilities can cause children to stay at home, visit doctors, or lie in a hospital bed when they should be in school or at play. They cause parents to miss work days or even give up their jobs. They require special equipment and services. Many disabilities that do not cause episodes of acute illness nonetheless dramatically alter the lives of affected children and their families. And no matter how many resources are brought to bear to address these problems, the lives of affected children are never the same as they would be in the absence of the illness or disability.

Other disorders have a range of effects beyond, or independent of, physical illness. Some conditions caused by toxins in the environment can prevent children from participating in regular activities at home and at school. Moreover, toxic exposures that affect a child's ability to learn results in fewer children with extraordinary intellectual ability and more children who are unable to reach their full potential. Tomorrow's workers will produce and earn less if they are damaged as children today.

Severe children's illnesses, especially those that create lifelong deficits, reshape every aspect of the affected children's lives. **Most of these effects cannot be described or understood in monetary terms. It is meaningless to talk about a monetary value associated with lost opportunities to play, learn, and make friends.** There is no dollar value that captures the pain to a mother or father of sitting helplessly by a sick child's hospital bed. But when policy-makers talk about ways to protect children's health, financial considerations often come to dominate the discussion. It is not uncommon to encounter arguments to the effect that measures to protect public health and the environment are a luxury we can ill afford.

In this report, we explore some of the monetary costs that society bears when children develop preventable illnesses associated with toxic exposures to substances under human control. We look at the amount of money spent in Massachusetts to treat and cope with these children's illnesses through medical treatment, education, and other services.

We also look at estimates of the earning power lost to children who suffer from illnesses associated with toxic exposures. We explore the distribution of the costs imposed by these exposures, looking at the ways in which the poorest communities in Massachusetts sometimes bear the highest costs.

## II. CHILDREN'S ENVIRONMENTAL HEALTH

A growing body of evidence implicates environmental factors in the principal chronic illnesses affecting children in Massachusetts (see, for example, Schettler et al. 1999, 2000; U.S. EPA 2003; Gouveia-Vigeant and Tickner 2003). In some cases, such as lead poisoning, there is no natural "background rate" of illness; every case of lead poisoning results from environmental factors under human control, and thus is preventable. Other illnesses, such as cancer, asthma, and neurobehavioral disorders, result from complex interactions among genetic and environmental factors; a portion of these illnesses and disabilities could be avoided by preventing toxic exposures.

**Children's vulnerability.** In general, children are more vulnerable to environmental hazards than adults. Infants and children breathe, eat, and drink more than adults per unit of body weight. Their organ systems change and develop rapidly, making them vulnerable to small exposures at crucial windows of development. Children's detoxification mechanisms are underdeveloped in some ways compared with those of adults, making them more susceptible than adults to injury from toxic exposures. Children are disproportionately exposed to some hazards because they engage in normal childhood behaviors such as playing on the ground and putting objects in their mouths (Schettler 1999, 2000).

**Toxic exposures and illness.** A wide variety of avoidable exposures to toxic substances in the environment affect children's health. Pesticides used in homes, lawns, gardens, and schools can cause cancer as well as neurological and other damage. Drinking water contaminated with organic solvents can cause leukemia and other cancers. Exhaust from buses and cars can cause birth defects when exposure occurs during pregnancy, and can cause or exacerbate asthma in exposed children. Children are exposed to lead in chipping leaded paint and in soil that was contaminated by use of leaded gasoline in the past. Contaminants found in food can damage the developing brain (Schettler et al. 2000).

Schools are supposed to be safe environments for children to learn and grow in, but schools themselves can sometimes contribute to children's health problems. Indoor air quality in schools is often poor, contributing to asthma and other disorders. According to Michael Shannon, MD, MPH, director of the Pediatric Environmental Health Center and associate chief of Emergency Services at Children's Hospital Boston, problems at schools range from mold and toxic cleaning materials through exposure to contaminated soil and chemicals from toxic waste sites located near schools ("Sick Schools" 2002).

Diseases can have multiple causes; some are inherited, some are caused by infections, and some are caused by chemicals and other factors in the environment in which a child develops or lives. Inherited, infectious, and chemical factors may often interact with one another.

Some environmental factors include personal choices, including diet, exercise habits, or use of alcohol, tobacco, or drugs. Our focus in this report is on environmentally

induced illnesses that result not from personal choices but from exposure to chemical pollutants in the environment. Individual families can take some steps to protect their children from hazardous exposures, but many chemical hazards are beyond the control of individual families. The decision whether or not to protect children from these hazards, therefore, is collective.

**Rising rates.** Incidence and prevalence of some children's illnesses have increased substantially in the past two to three decades. For example, from 1975 to 2000, cancer incidence increased 31.7% nationwide in children under the age of 15, or 29.6% in children under the age of 20 (SEER Cancer Statistics 1975-2000). The largest increases in individual types of children's cancer include those in acute lymphocytic leukemia (57.2% increase), brain and other nervous system cancers (49.6% increase), and cancers of the kidney and renal pelvis (47.5% increase).

The prevalence of neurodevelopmental disorders appears to have surged upward as well. For example, recent studies conducted in California show that rates of autism in California have risen dramatically in the past two decades. A 1999 report by the California Department of Developmental Services recorded a 273% increase in autism rates between 1987 and 1998 (California Department of Developmental Services 1999). A follow-up report released in August 2002 concluded that the observed increase in autism rates was real, and was not simply an artifact of changing diagnostic practices (Byrd 2002). In 1987, 2,778 California children had full-spectrum autism (a severe and comparatively easily diagnosed form of autism); in 1998, 10,360 children had the disorder. As of July 2002, the number had risen to 18,460 (Blakeslee 2002).

Nationwide asthma prevalence has increased in the past two decades. Between 1980 and 1994, according to EPA, "the self-reported prevalence of asthma increased 75% from 1980 to 1994 to 13.7 million people." This trend was evident "among all races, sexes, and age groups." The most dramatic increase was a 160% increase in asthma prevalence among children aged zero to four, from about 22 children per 1,000 to about 58 per 1,000. In a recent review of Centers for Disease Control (CDC) data, the New England Asthma Regional Council found that Massachusetts had the highest self-reported asthma rate among adults nationwide in 2001 (Asthma Regional Council 2003).

**Unequal burden** Environmental threats to children's health affect everyone. Living in a wealthy neighborhood, going to a private school, and getting the best possible medical treatment will not protect a child from the health hazards of toxic environmental exposures. In Massachusetts, not even the wealthiest communities are free from toxic pollution from military and industrial sources, as well as from everyday household products.

Poor and minority communities, however, bear a disproportionate environmental burden. A recent study of the distribution of hazardous sites and polluting facilities around Massachusetts found that communities of color and working-class communities are home to significantly more hazardous sites and facilities than wealthier communities and those with a small minority population (Faber and Krieg 2002). Low-income and

minority populations are also more likely to live in areas where high lead exposure is likely, due either to soil contamination or to lead paint.

The researchers looked at the distribution of hazardous waste sites, landfills and transfer stations, polluting industrial facilities, power plants, and incinerators; they also created a measure of exposure to cumulative environmental hazards, looking at all the exposure sources together. They found that "high-minority communities face a cumulative exposure rate to environmentally hazardous facilities and sites that is nearly nine times greater than that for low-minority communities." Similarly, cumulative exposure in low-income communities is about three to four times higher than in other communities in Massachusetts.

This disproportionate burden of toxic exposures in minority and low-income communities is mirrored by disproportionately high rates of some illnesses in these communities (see, for example, Perera et al. 2002, Zahm 1995). As we discuss in detail below, minority communities both within Massachusetts and nationwide bear a disproportionate burden from asthma. Childhood cancer data in Massachusetts suggest an unequal burden as well, although the figures must be interpreted with caution; incidence of childhood cancer from 1995 to 1999 was about 25% higher in Latino and African-American children than among white and Pacific Islander children (Massachusetts Department of Public Health 2003).

The effects of toxic exposures can also be compounded by other aspects of poverty. For example, poor nutrition can exacerbate the effects of lead exposure (U.S. EPA *COI*: III.9-3, III.9-4). Limited income also means fewer choices in housing and nutrition options; low-income families are often forced to live in poorly maintained housing and choose food that is cheaper, but less nutritious.

Caring for one child with an illness or disability can be a crushing burden for a family. It is also important to recognize that since the children in a given family typically share many of the same environmental exposures, more than one child per family may suffer from an illness or disability. For example, geographic areas characterized by high children's lead exposure may overlap with areas characterized by high asthma rates. Thus, several children in a single family may suffer from asthma, or one family may include both a child with asthma and a child with disabilities resulting from lead exposure (Jean Zotter, Boston Urban Asthma Coalition, pers. com. September 2003).

### III. MONETIZING COSTS

In this section, we describe some principal categories of costs that researchers attempt to estimate. Some are relatively easy for researchers to agree upon, while others are controversial.

**Treatment costs.** Costs in this category can include costs of medications, doctor visits, therapy sessions, special equipment such as braces or crutches, and costs of

hospitalization. Even in this relatively straightforward category, there are ambiguities. For example, the costs of medical services may vary depending whether they are paid for by individuals, private insurance companies, or Medicaid and Medicare. Medical treatment costs, though large, may be dwarfed by other costs.

**Lost school and parental work time.** Sick children miss days of school. This often translates into lost work days for parents. In addition, extensive lost school time can translate into educational deficits, which have implications for productivity in adulthood.

**Special education** Increasing numbers of children receive special education services, often paid for by the state. Special education requires high teacher-to-student ratios, and costs substantially more per child than regular schooling.

**Home and institutional care.** Children with illnesses and developmental disabilities often require special care outside school hours, either at home or at an institution. Care at home may be provided by a paid caretaker or by a parent or other family member; in the latter case, the time spent at home may translate into foregone earnings. Having a sick or disabled child may make it necessary for one parent to stay at home full time, in a family where both parents would otherwise work outside the home.

**Costs of related illnesses in adulthood** Some childhood exposures are associated with illnesses in adulthood. For example, elevated blood lead levels are associated with high blood pressure in adulthood. Children who have cancer have an increased likelihood of developing cancer later in life as well; and children who suffer from asthma may suffer additional lung disorders in adulthood. In addition, some illnesses, including many cancers, have long latency periods, so that exposures during childhood do not produce disease until adulthood.

**Loss of projected future earnings.** Childhood illnesses and disabilities can translate into decreased productivity and lost income in adulthood. For example, lead exposure in childhood decreases IQ, and radiation therapy for childhood brain cancer can produce serious learning disabilities. Thus, the value of foregone future earnings can form a component of an estimated cost per illness. This figure sometimes turns out to be much larger than treatment costs. In estimates of the societal costs of lead exposure, for example, the cost of lost future earnings due to impaired intelligence is much greater than the cost of attempts to treat lead-poisoned children medically.

**Costs of suffering and death.** Often, economists who attempt to put a dollar value on the entire experience of illness include estimates of the value of the suffering associated with the illness. Economists have even developed estimates of the monetary value of death. These values are either inferred from observation of indirectly related market decisions, or based on surveys that ask people about what economists call "willingness to pay" (WTP) for things that are not actually for sale.

In general, prices are determined by markets. The cost of a dozen eggs, a house, or a visit to the doctor is determined by the interaction of supply and demand for those



goods. Suffering and death, in contrast, are not exchanged in markets. You cannot buy or sell a unit of suffering; you cannot offer to die in exchange for a sum of money, or go to a store and purchase extra years of life. Thus, suffering and death have no market price. Nonetheless, economists have employed several methods to develop surrogate prices for these unmarketed values.

*Contingent valuation.* One methodology for estimating willingness to pay to avoid the suffering associated with an illness is a "contingent valuation" (CV) survey. In this approach, researchers develop a questionnaire that asks a random selection of individuals what they would be willing to pay to avoid the illness. Since the researchers are posing an unfamiliar choice that is not available in reality, considerable effort is required to perform and analyze such studies. For example, in one study researchers conducted a survey among shoppers in a mall, attempting to determine the value of chronic bronchitis. They provided a description of chronic bronchitis to each participant, then asked whether he or she would prefer to live in a neighborhood with a slightly higher cost of living and a slightly lower rate of the disease. Contingent valuation is used to gauge other non-market values as well; for example, it has been used to estimate what Americans are willing to pay to protect certain endangered species or to preserve threatened ecosystems.

Contingent valuation studies present a variety of methodological problems, which we mention just briefly here. At the most basic conceptual level, price estimates based on surveys are fundamentally different from real prices. By definition, prices are negotiated in and defined by markets, reflecting amounts that people are actually willing to pay. The sums of money people state in a survey do not necessarily reflect the actual amount they would pay, if they could buy the nonmarketed goods to which the surveys refer. No one had to follow up on their stated desire to live in a neighborhood with higher prices and lower bronchitis rates, since the researchers did not offer such an option in reality.

Furthermore, it can be argued that it simply makes no sense to place a dollar value on human lives and human health; these goods are priceless (Ackerman and Heinzerling 2004). At a more detailed level, some of the techniques used for CV studies are questionable. For example, some respondents are unable or unwilling to state a price for the goods in question; they refuse to say how much they would be willing to pay to prevent bald eagles from going extinct, or to keep their children from dying of cancer. These respondents are simply left out of the survey results. This means that CV studies do not reflect the responses of those people who consider their health, lives, or natural surroundings too important to be priced the way a house, a car, or a new piece of clothing might be.

*Value of a statistical life.* Cost-benefit analyses from the end of the Clinton administration set the value of a "statistical life" -- that is, the value of events that would, on average, be expected to cause one person to die, without reference to who that person is -- at around 6.1 million dollars. More recent federal government analyses have used a variety of technical arguments to argue for a lower value. A recent initiative at EPA, which has now been reversed, adjusted the value of a statistical life downward, reflecting

an assessment that the value of an elderly person's "statistical life" is lower than that of a younger adult. (For an overview of recent controversies surrounding the calculation of the value of a statistical life and related measures, see "Subjective Science," 2003.)

The most popular method for arriving at a value for life involves an apparently logical but very indirect process. Economists collect data and perform calculations to find out how much money people are generally willing to spend in order to avoid a small risk of death. Most often, they look at the wage premium associated with working in a dangerous job. Data collection of this sort has shown (largely in studies performed 20 or more years ago, adjusted for inflation since then) that more risky jobs do pay slightly higher wages. A rough average extracted from these studies is that at today's prices, an annual rate of death on the job of 1 in 10,000, a typical level for male blue-collar workers, would be associated with a annual wage increase of about \$600 per year, or about 30 cents per hour, above a risk-free job such as white-collar work. (There are occupational stresses and illnesses associated with white-collar jobs, but there are virtually no deaths on the job.) Thus the implied "value of a life" is roughly  $\$600 * 10,000 = \$6$  million.

There are serious problems with this approach. Money has no meaning for a person who is dead, and people who have more than \$6 million at their disposal will, in general, spend whatever it takes to save their own lives or their children's lives. Many others, who care equally deeply about their own lives and their children's lives, are obviously unable to spend \$6 million on life-saving measures or anything else. Furthermore, it goes against most people's ethical beliefs and common-sense instincts to place a dollar value on a human life. In reality there is no such thing as a "statistical life": a loss of statistical life is, finally, a polite way of referring to one real person's death.

There are also methodological problems with the ways economists estimate the value of reducing risk of death; for example, workers may not have other jobs freely available to them, or may not know the actual risks of death in particular jobs, so they may not be freely choosing the dangerous work. Furthermore, workers' individual decisions about risky jobs may not accurately reflect society's judgement about the value of avoiding very different kinds of hazards, such as environmental threats to children's health. Despite these concerns, many studies that estimate costs of illness build in a dollar value per human life lost.

Another approach to valuing the loss of a human life is to calculate the amount the person might have earned over the remainder of his or her lifetime, if he or she had survived. This approach puts a higher value on people who were likely to become rich than on people who were expected to pursue a middle- or low-income career path. It also puts a higher value on male lives than on female lives, because men earn more than women on average; likewise, it puts a higher value on the lives of white people than on the lives of minorities. It dismisses the lives of retired people or others who are not gainfully employed. For all but the richest people among us, it produces a much lower estimate than the wage-risk calculations.

Yet another method is a CV survey, asking people what they would pay to avoid a small risk of death. All the problems with CV methods described above apply here as well; since the "commodity" being purchased is not for sale, the question remains hypothetical and the answers remain of dubious validity. CV survey estimates of the value of life are often larger than lost earnings estimates, but smaller than wage-risk estimates.

**Discounting.** Economists frequently use a technique called "discounting" to compare costs that are expected to occur at different times in the future. In effect, it amounts to compound interest in reverse: at a 3% discount rate, costs are reduced 3% for every year into the future. Some of the monetary estimates we report here use discounting to present summaries of costs over a number of years. More controversially – in fact, entirely inappropriately – some cost-benefit analyses also discount future deaths and illnesses. We have not included discounting of nonmonetary future events in our calculations. (For an extended critique of discounting, see Ackerman and Heinzerling 2002, 2004, and sources cited there.)

This report discusses direct costs of illnesses and disabilities, including costs of medical treatment, equipment, special education and care, and lost parental work time. We also discuss estimates of foregone future earnings associated with these illnesses and disabilities. We comment on some of the figures that economists have developed in attempts to place a dollar value on a child's life. However, we do not make these values central to our analysis, because we believe strongly that human lives cannot be valued in monetary terms.

**Incidence-based vs. prevalence-based costs.** Illness and disability information may be analyzed in terms of incidence (the number of new cases that appear or are diagnosed in a year), or prevalence (the total number of individuals suffering from the illness or disability in a given year). Incidence-based costs are calculated as the present value of the costs incurred over the lifetime of the individual, whereas prevalence-based costs are calculated as all the expenses associated with treating people with a given illness or disability in a single year, regardless of when the illness or disability developed. Due to variations in the kinds of data available on different illnesses and disabilities, we use both kinds of cost information in this report, as noted in individual sections.

#### **IV. THE ECONOMIC BURDEN OF CHILDHOOD ILLNESSES**

A sizeable literature exists on the monetary costs of illness. The U.S. Environmental Protection Agency (EPA), for example, has estimated the "cost of illness" for a variety of health problems, including asthma. About a decade ago, a group of researchers estimated the monetary costs of treating birth defects. Most existing cost-of-illness studies do not focus specifically on chemically-induced health problems.

A recent study set out specifically to estimate the monetary costs of environmentally induced illnesses. A team of distinguished researchers headed by

physician Phillip Landrigan of the Mount Sinai School of Medicine looked at estimated costs for four categories of childhood illness that have been linked to environmental factors: cancer, asthma, neurobehavioral disorders, and lead poisoning (Landrigan et al. 2002).

Landrigan et al. examined existing data on costs associated with each of these categories of illness. They looked at the costs of treating and managing the disorders, including physician visits, hospitalizations, medications, special equipment needed to allow disabled children to ride in cars or go to school, and income foregone by parents who had to take time off work to care for their sick children. They also estimated foregone future earnings of children whose ability to learn was impaired by illness. Where applicable, they built in cost estimates for lives lost.

They then calculated what they called an "environmentally attributable fraction" for each category. The concept of an environmentally attributable fraction, or EAF, derives from the recognition that diseases can have multiple causes. If some cases of a disease are caused by environmental factors and others are not, the EAF represents the estimated percentage of cases that are caused by environmental factors.

EAFs were estimated by groups of experts reviewing the existing data. In general, "environmental" factors are considered to be any factors that are not inborn; this could include exposure to toxic chemicals, but could also include diet, exercise habits, and other factors that vary from one person to another. The Landrigan team, however, used a restricted definition of "environmental." Their EAFs refer *only* to "chemical pollutants in the ambient environment." They "chose deliberately not to consider outcomes that are the consequence at least in part of personal or familial choice," such as "tobacco, alcohol, or drug abuse" (Landrigan et al. 2002: 721-2).

The Landrigan team set the EAF for lead exposure at 100%, because all lead exposure is caused by factors under human control. They estimate the EAF for asthma to range from 10% to 35%, with a best guess of about 30%. Based on a study by the National Academy of Sciences, the EAF for neurobehavioral disorders is estimated to range from 5% to 20%, with a best guess of about 10%. For cancer, the panel of experts convened by the Landrigan team was able to define only a broad range of possible EAFs. In the opinion of the panel, only 10 to 20% of childhood cancers could be explained by genetic predisposition alone, meaning that "extragenetic factors, defined broadly," contribute to or cause 80 to 90% of childhood cancers. However, the panel members decided that "insufficient evidence exists to assign a best estimate of the fraction of childhood cancer specifically attributable to toxic chemicals in the environment. The panel agreed that the correct EAF would prove to be at least 5-10% and less than 80-90%, but could not further refine that broad range" (Landrigan et al. 2002: 723).

We draw on the analysis by the Landrigan team in our examination of the burden of children's illnesses associated with toxic exposures in Massachusetts, using both their EAF estimates and significant portions of their cost estimates. We make certain adjustments, however, to allow for different possible views of what elements should be

taken into account in estimating costs of illness. For example, we offer estimated costs of cancer that draw only on direct and indirect medical costs, omitting the additional elements of projected future income and estimated cost of a human life. We also suggest that if a value is to be placed on a human life, higher values are available in the literature than those used by Landrigan et al.

## V. COSTS IN MASSACHUSETTS

In this section, we look at the costs we face in Massachusetts due to avoidable environmental exposures. We focus on estimates of direct costs, such as medical treatment, special education, and work time lost by parents whose children are ill. We also discuss existing estimates of foregone future earnings resulting from illnesses that impair children's ability to learn. The cost estimates we present here are based on a combination of Massachusetts-specific incidence and prevalence data plus cost data generated in other studies, which have looked at costs of certain illness categories nationwide. Unless otherwise specified, all monetary costs have been converted to 2002 dollars using the consumer price index.

Figures of this kind, of course, are only one small window on a child's well-being. The costs we discuss below are an indication of the significant burden we bear in Massachusetts due to avoidable environmental exposures; but they are by no means a measure of the value to parents, to children, or to society as whole, of a child's well-being.

### 1. CANCER

As we saw above, incidence of cancer in children has risen substantially since the mid-1970s. Studies support the view that environmental factors -- broadly defined to include all factors that are not inherited -- may be implicated in rising cancer rates. Dietary habits and choices, exposure to infections, indoor air quality, and other "lifestyle" factors can all be included under the general category of environmental factors, as can exposure to industrial toxins.

**Incidence in Massachusetts.** According to the Massachusetts Community Health Information Profile (MassCHIP) database, in 1999, 271 Massachusetts children were diagnosed with invasive cancer. Note that these figures only represent new diagnoses (i.e., annual incidence); the number of children suffering from cancer in any given year (prevalence) is higher. Of the children diagnosed in 1999, 87 were under the age of four; 52 between the ages of five and nine; 50 between the ages of ten and fourteen; and 82 between the ages of fifteen and nineteen. Among young children, leukemia and cancers of the brain and central nervous system accounted for a substantial number of cases (MassCHIP 2003). In 1998, the last year for which records are available on children's cancer mortality, thirty-four children died of cancer (MassCHIP, 2003).

**Causes of childhood cancer:** Studies suggest links between childhood cancer and environmental factors including exposure to solvents, pesticides, and air pollution. These studies are summarized in a recent overview report produced by the Lowell Center for Sustainable Production (Gouveia-Vigeant and Tickner 2003). Among other findings, this overview finds that parental and childhood exposure to pesticides and solvents are consistently linked to some cancers; prenatal exposures can be linked to childhood cancers; and there is particularly strong evidence of a connection between toxic exposures and leukemia, brain, and central nervous system cancers, which account for about half of children's cancers (Gouveia-Vigeant and Tickner 2003: 6).

**Costs of cancer:** Landrigan et al. estimate national costs of children's cancer by looking at costs of medical treatment for children with cancer, costs faced by parents who miss work days in order to care for their sick children, and a "cost per life" for each child who dies.

Landrigan et al. construct estimates of the cost of childhood cancer treatments by reviewing records of physician visits, hospital stays, and other treatment services for children with cancer. According to their calculations, the average annual cost per child with newly diagnosed cancer for physician services, inpatient services, and outpatient services is \$271,400. Adding in the cost of laboratory services brings the cost of treatment up to \$562,800. Accounting for lost parental wages, based on five lost wage days per seven child hospital days, adds another \$14,900 to the total cost.

Including the present value of the child's lost future earnings due to reduced IQ associated with radiation treatment for brain cancer increases the total by another \$66,800. Individuals who survive childhood cancer have an increased likelihood of developing a second primary cancer later in life. Landrigan et al. assumed that treating this second cancer would be the same as the cost of the first. With discounting to account for the time lag, this brought the total cost up to \$688,000.

From these estimated costs per child, Landrigan et al. scale up to a national costs figure, estimating a present value of lifetime cancer-related costs for each year's new childhood cancer cases at \$5.3 billion. Finally, they calculate the cost of deaths from primary and secondary cancers at \$1.99 billion, bringing the total to \$7.28 billion (see "Note on Methodology: Adjusting Value of Life Estimates," below).

In Table 1, we apply the Landrigan et al. estimates of cost per case, converted to 2002 dollars, to the number of new cancer diagnoses in Massachusetts children in 1999. This figure does not include any estimate of lost income due to effects on IQ, and does not put a dollar value on children's deaths. Based on this estimate, the total cost of children's cancers diagnosed in Massachusetts in 1999 was around \$164 million. Based on the range of EAFs estimated in Landrigan et al., the cost of childhood cancer attributable to environmental factors can be estimated to be between \$8.2 million and \$147.6 million. This estimate excludes estimates of future income foregone due to brain damage associated with cranial irradiation for brain tumors. Including this factor, the estimated total cost of the environmentally attributable childhood cancers rises to a value

ranging from \$9.1 million to \$163.8 million, depending on the assumptions we make regarding EAF.

<b>Table 1: Estimated Costs - Cancer</b>					
	<b>Number of children diagnosed (1999)</b>	<b>Care and treatment cost per child (2002\$)</b>	<b>Total costs (2002\$)</b>	<b>EAF</b>	<b>Cost of environmentally attributable fraction</b>
Excluding loss of projected income	271	\$ 607,500	\$ 164,000,000	0.05	\$ 8,200,000
				0.1	\$ 16,400,000
				0.8	\$ 131,200,000
				0.9	\$ 147,600,000
Including loss of projected income	271	\$ 672,840	\$ 182,000,000	0.05	\$ 9,100,000
				0.1	\$ 18,200,000
				0.8	\$ 145,600,000
				0.9	\$ 163,800,000
Sources: MA incidence from MassCHIP; cost per child and EAF from Landrigan et al., 2002 Care and treatment costs include treatment during childhood, lost parental wages, and later treatment for a second cancer later in life.					

## 2. ASTHMA

Asthma is a leading cause of illness in children. It accounts for about a third of all missed school days and is the most common cause of children's hospitalization (U.S. EPA COI: p. IV.2-3). Asthma rates have increased dramatically in the past two decades. Between 1980 and 1996, the number of people suffering from asthma in the U.S. doubled; the most dramatic increase occurred in children under the age of five (Department of Health and Human Services 2000).

**Causes of asthma.** A distinction is made between factors that initially cause asthma to develop and the triggers that produce symptoms in asthmatic individuals. Environmental factors are likely to contribute to both, although the triggers of asthma symptoms and attacks are better understood than the factors that cause initial onset of asthma. An individual with asthma may suffer symptoms or attacks triggered by natural allergens such as house dust mites, cockroaches, mold, and animal dander, as well as by pollutants such as ozone, sulfur dioxide, particulate matter, and second-hand tobacco smoke. Studies have found that asthma hospitalizations increase during episodes of severe air pollution (U.S. EPA COI: IV.2-21-IV.2-23). Exposure to irritants and toxins during fetal and infant development may increase a child's likelihood of developing asthma. Some scientists have postulated a possible link between development of asthma and exposure to certain pesticides (Eskenazi et al. 1999).

**Massachusetts prevalence.** Most states in the US lack a systematic tracking system to assess asthma prevalence. Massachusetts is no exception: at the state level, data are collected on asthma-related hospitalizations, but little information is available on the number of children who suffer from, are medicated for, and miss school because of this chronic disease. Efforts are under way to collect more information in Massachusetts and

elsewhere, but for the moment, many basic questions remain unanswered. Specific information is available on the number of children hospitalized with asthma each year, but the total number of children suffering from asthma is not known precisely.

For children ages 0 to 19, Massachusetts counted 2,655 asthma hospitalizations in 1999 and 2,410 in 2,000 (MassCHIP, March 2003). Hospitalization is most common in young children, and is unusual above the age of 15 (Boston Public Health Commission 2002: 55).

**Table 2:**  
**Asthma Hospitalizations in Massachusetts: 1999 and 2000**

Age	Hospitalizations in 1999	Hospitalizations in 2000
0 to 4	1,166	1,073
5 to 9	690	616
10 to 14	444	404
15 to 19	355	317
<b>total</b>	<b>2,655</b>	<b>2,410</b>

Source: MassCHIP 2003

A variety of estimates of total asthma prevalence among Massachusetts children are available; all are based on incomplete information. The Centers for Disease Control, an authoritative source for national health statistics, does not currently publish state-specific asthma prevalence estimates for children. An estimate by the American Lung Association sets the number of children suffering from asthma in Massachusetts at 77,300 (Boston Public Health Commission 2002: 55). A study commissioned by the Asthma and Allergy Foundation of America estimated that 105,900 Massachusetts children age 17 and under had asthma in 1998 (Weiss et al. 2000).

Probably the most detailed information collected to date on asthma prevalence in Massachusetts children is contained in a forthcoming study by the Bureau of Health Assessment of the Massachusetts Department of Public Health. For this study, researchers gathered information from elementary school health records in six communities in the Merrimack Valley, for the 1999-2000 school year. One hundred percent of the schools in these communities participated in the study, allowing the researchers to gather comprehensive data. Based on preliminary study results, 9.4% of the elementary school children in these six communities, ages 5 to 14, have asthma (Suzanne Condon, Massachusetts Department of Public Health, pers. com. September 2003). These results are preliminary and are limited in age range as well as geographically, so we cannot be certain that they apply to the broader population of Massachusetts children. However, if this prevalence rate does hold true for children across Massachusetts, applying it to the population of children ages 0 to 17, we can estimate that nearly 138,000 Massachusetts children suffer from asthma.



**Other state-level data.** A recent study looked at prevalence and distribution of asthma in school-age children in Connecticut (Environment and Human Health 2000). The study was designed to fill in the gaps in information collected by the state, which records asthma-related emergency room visits, hospitalizations, and deaths. The researchers worked with school nurses to collect and systematize information that was readily available in school health service offices.

The researchers were able to gather information on 83% of all children attending school in Connecticut in 1999-2000. They found that on average, 8.7% of school children in the state suffer from asthma. This is a conservative estimate; some children with asthma may not have been included in these counts, because school nurses may not be aware of children with mild asthma who do not require medication or nursing attention during the school day.

Location in an urban, suburban, or rural area did not make a significant difference in the asthma rate for a given school district. However, the researchers found a strong relationship between average income level and asthma prevalence. The county with the highest per capita income had the lowest asthma prevalence rate, and the county with the lowest per capita income had the highest asthma prevalence rate. They point out that if it were possible to identify and address the factors that are causing elevated levels of asthma in poorer areas of the state, a quarter to a third of all asthma in Connecticut could be prevented.

**Costs of asthma.** Asthma cost estimates include direct medical treatment costs; costs of missed school and lost parental work time; and, in some cases, "willingness to pay" estimates of the costs associated with suffering and death from asthma. We focus in this discussion on the costs of preventable asthma associated with exposure to outdoor pollution. Following Landrigan et al., we do not consider other preventable factors associated with asthma, such as exposure to cigarette smoke. We also do not explore the large reduction in asthma costs that could be achieved through measures to improve indoor air quality and to improve children's access to health care.

*Costs of hospitalization.* Only a minority of asthma cases end up in the hospital; the great majority of cases are treated on an ongoing, outpatient basis, involving continual expenses for medications and visits to the doctor. However, asthma-related hospitalizations are tracked more reliably than asthma cases treated only on an outpatient basis. In Table 3, we estimate only the cost of asthma-related hospitalizations in Massachusetts in 2000, using the cost per case figures developed by EPA and the environmentally attributable fraction estimated by Landrigan et al. Using these figures, we estimate that the "environmentally attributable" cost of asthma hospitalizations in 2000 ranged from over \$735,000 to more than \$2.5 million.

<b>Table 3: Cost of Asthma Hospitalizations in Massachusetts</b>				
Ages 0 to 19				
<b>Number of hospitalizations in 2000</b>	<b>Average cost per hospitalization (2002\$)</b>	<b>Total hospitalization cost (2002\$)</b>	<b>EAF</b>	<b>Cost of environmentally attributable fraction</b>
2,410	\$ 3,051	\$ 7,352,000	0.1	\$ 735,000
			0.35	\$ 2,573,000

Sources: MassCHIP 2003; EPA Cost of Illness Handbook, p. IV.2-63; EAF from Landrigan et al. Cost estimates from EPA are updated to 2002\$.

*Direct cost of treatment.* The U.S. Environmental Protection Agency (EPA) has developed detailed estimates of direct medical costs associated with asthma in its *Cost of Illness Handbook*. EPA explains that these figures can be used as a lower-bound estimate of the costs of asthma. EPA uses data on cost of medications, diagnostic and other medical visits, emergency room admissions, and hospitalizations to develop an estimate of lifetime direct medical costs for asthma patients.

EPA works with an assumed average life expectancy of 75 years, with the assumption that 30% of children with mild asthma will not require treatment after the age of 18 (U.S. EPA *COI*: IV.2-32). EPA notes that around 60% of children with asthma cease having symptoms as young adults, but about half of this group becomes symptomatic again after some time. In some cases, however, problems become increasingly serious over time; asthma attacks can produce long-term damage and permanent changes in lung tissue (U.S. EPA *COI*: IV.2-25)

EPA identifies three principal phases of asthma care: initial diagnosis and treatment to stabilize the patient; ongoing care; and acute care for asthma attacks. "Estimates of the direct costs of asthma are constructed using national data on asthma medical services, utilization, reimbursement by Medicare, and national recommendations and private sector costs regarding drug therapy. The probabilities of patients utilizing various services are multiplied by the cost per service" (U.S. EPA *COI*: IV.2-27.) Costs can vary substantially depending on how an individual's asthma is managed.

EPA provides estimates of the average annual medical costs for asthma treatment, broken down by age group. For four- and five-year-old children, the combination of office visits, drug therapy, emergency room use, and hospitalization add up to an average cost of \$822. For children between the ages of 6 and 17, the corresponding figure is \$977 (U.S. EPA *COI*: IV.2-65). Table 4 summarizes the estimated costs in Massachusetts associated with treating 4- to 17-year-old children with asthma, using EPA's cost figures and the number of children with asthma in 1998, as estimated by Weiss et al. Applying EAFs of 10% to 35%, we can estimate that the medical costs alone for environmentally-induced asthma cases could range from over \$10 million to over \$35 million per year in Massachusetts.

<b>Table 4: Estimated Costs of Asthma in Massachusetts</b>					
All direct medical costs, including hospitalization and medications					
	<b>Estimated number of children affected, 2002</b>	<b>Cost per child</b>	<b>Total Costs (2002\$)</b>	<b>EAF</b>	<b>Cost of environmentally attributable fraction (2002\$)</b>
Asthma - all direct medical costs, age 4-5	15,129	\$ 822	\$ 12,436,000		
Asthma - all direct medical costs, age 6-17	90,771	\$ 977	\$ 88,710,000		
<b>TOTAL</b>	105,900		\$ 101,146,000	0.1	\$ 10,114,000
				0.35	\$ 35,401,000
Average annual cost per child from EPA Cost of Illness Handbook (p. IV.2-65); number of children from Weiss et al. 2000.					

EPA notes that several important factors are left out of its calculations, making them a low estimate of direct costs associated with asthma. Asthma is associated with other respiratory diseases in children and adults; for the most part, the causal relationship between asthma and these other diseases is not known. Drugs used to treat asthma can cause other diseases and disorders. Asthma can exacerbate other existing health problems, and can cause permanent damage to the lungs (U.S. EPA *COI*: IV.2-21). None of these additional problems are factored into EPA's conservative cost estimates.

An alternative approach to estimating costs of asthma in Massachusetts is to take 2% of the national costs calculated by Landrigan et al.; Massachusetts is home to about 2% of the population of the U.S. Landrigan et al. estimate the total cost of children's asthma as the sum of medical expenses plus school days lost and the cost of premature deaths from asthma. They calculate the national cost of medical expenses plus school days lost as over \$7.14 billion in 2002 dollars. Including their estimate of the cost of premature deaths, the figure rises to \$7.36 billion.

Excluding estimates of the value of a human life, and taking 2% of all other costs, including medical expenses and school days lost, we estimate costs in Massachusetts of nearly \$143 million. Applying the 10% to 35% range of EAFs, this implies environmentally attributable costs in Massachusetts ranging from over \$14 million to over \$50 million.

**Cost summary.** An estimate based on EPA calculations suggests that the total costs of treating environmentally attributable asthma in Massachusetts range from \$10 million to more than \$35 million. Hospitalization costs alone for environmentally attributable asthma are estimated at between \$735,000 and \$2.5 million. Taking an alternative approach, if we calculate Massachusetts costs as 2% of the national figure calculated by Landrigan et al., then estimated costs range from over \$14 million to over \$50 million.

**Environmental justice.** Increases in asthma rates have affected all sectors of society, but the burden of asthma is not evenly distributed. In general, poorer families have higher rates of asthma. According to EPA data, asthma rates for people under the age of 45 are substantially higher in families with incomes under \$10,000 than in those with incomes over \$35,000 (Centers for Disease Control statistics for 1999, cited in U.S. EPA *COI*: IV.2-6).

Data collected in the state of Washington show that "family incomes below \$20,000 per year were associated with an approximately two-fold increase in asthma prevalence among children" (U.S. EPA *COI*: IV.2-7) Death from asthma is rare in all age and race groups, but death rates from asthma are substantially higher for black people than for white people. For ages 10 to 14, black children are six times as likely to die of asthma as white children. For ages 15 to 19, black children are more than three times as likely to die of asthma as white children (U.S. EPA *COI*). According to the American Lung Association, the hospitalization rate for asthma is 3 times as high for black children as for white children, and the rate of emergency room treatment for asthma is 4 times as great for black children as for white children (Boston Public Health Commission 2002: 55). The *New York Times* recently reported on a study in Harlem that found a quarter of all children screened had asthma (Perez-Pena 2003).

**Head Start Data.** A recent study looked at prevalence of asthma among preschool children enrolled in a Massachusetts Head Start Program in the city of Lowell. This study illustrates the magnitude of the problem of asthma in Massachusetts and the excessive burden this disease places on low-income families (Ladebauche et al. 2001).

According to the U.S. Administration for Children and Families Head Start Bureau, 13,040 Massachusetts children are currently enrolled in Head Start programs. Criteria for eligibility to participate in a Head Start program include family income at or below the federal poverty level (U.S. Administration for Children and Families 2003). No more than 10% of the children in a Head Start program can be above the federal poverty level (Alice Barton, Early Learning Services, Massachusetts Department of Education, pers. com. May 2003).

The study found an asthma prevalence rate of 35% among the Lowell Head Start pupils. A total of 510 children were enrolled in the program; 316 participated in the study. Of these, 112 were categorized as having asthma or asthma-like symptoms. (It is possible that the study sample was not random; parents whose children have asthma may have been more likely to participate. However, even if *none* of the nonparticipants had asthma, the prevalence of asthma among Lowell Head Start pupils as a whole would still be high, at 22%.)

On average, these children suffered from wheezing, coughing, or shortness of breath more than twice a week. More than half of the children with asthma or asthma-like symptoms "were reported to have required physical activity limitations due to their disease." Most of the children were taking medications to control their asthma; some were on more than one medication.

Most of the Head Start children with asthma had a sufficiently serious condition that they had been brought to the emergency room at some point. Seventy-four percent had been taken to the emergency room for an asthma attack at least once, and forty-one percent had been hospitalized for asthma treatment at least once. Six had been in intensive care. About a fifth of the children had missed at least ten days of school within six months due to asthma, and a fifth of the parents said they had missed five or more days of work within six months because of their child's asthma.

Not all the children in this program had adequate access to health care. Thirty-six of the children included in the study either had no health insurance, or no information was available about their insurance coverage. Only 18 of the 112 children with asthma "had ever been referred to an allergist or lung specialist." The authors note that children at increased risk of asthma are more likely to have inadequate access to health care. In addition to affecting health outcomes, this also means that health care databases may not reflect true prevalence rates in these populations (McGill et al. 1998: 77).

If the asthma rates among all children in Head Start programs match the rate of 35% found in this study, given that there are more than 13,000 children in Head Start, that means that over 4,500 of the most vulnerable preschoolers in the state suffer from this disease, placing a huge burden on the families that have the fewest resources with which to cope with such a problem. If the rate is 22%, assuming a nonrandom sample in the Lowell study, then over 2,800 of these preschoolers are affected.

Studies conducted in other states have also found high asthma rates among Head Start preschoolers. A Wisconsin study published in 1998 found an asthma prevalence rate of 15.8% among a group of Head Start children; more than half of these children had been taken to the emergency room for asthma attacks. A Virginia study found an asthma prevalence rate of 19% among children in a Head Start program.

### 3. NEUROBEHAVIORAL DISORDERS

Neurobehavioral disorders and disabilities include a range of problems, such as attention deficit hyperactivity disorder (ADHD), autism and related disorders, and a variety of learning disabilities. There is strong evidence that rates of some neurobehavioral disorders are increasing over time.

**Causes of neurobehavioral disorders.** Evidence both from the laboratory and from epidemiological studies shows links between toxic chemicals and a variety of developmental disabilities. Developmental neurotoxins to which children may be exposed include lead, mercury, cadmium, manganese, nicotine, pesticides such as organophosphates, dioxin, PCBs, and solvents (Schettler et al. 2000: 2-6, 59-94.) (Lead exposure is discussed in a separate section, below.)

For example, prenatal exposures to mercury can produce adverse effects on fetuses even at low doses that do not produce visible effects in the mother. Mercury exposure is associated with problems with fine motor function, attention, language, visual-spatial abilities such as drawing, and verbal memory, among other health effects. In 1999-2000, around eight percent of U.S. women of child-bearing age had at least 5.8 parts per billion (ppb) of mercury in their blood; according to EPA, blood mercury above this level can produce adverse effects in fetuses (U.S. EPA 2003: 58-59). The threshold above which mercury exposure is considered harmful has declined steadily over time, as scientists have gathered information on mercury's effects at increasingly low doses (Schettler et al. 2000: 15). The threshold for adverse effects currently identified by EPA may well be adjusted downward as the evidence of harm continues to accumulate.

**Prevalence in Massachusetts.** Prevalence of neurobehavioral disorders is difficult to measure, in part because Massachusetts, like other states in the US, lacks a systematic means of tracking many of these disorders.

Data provided by the Massachusetts Department of Education provide an overview of the breakdown of children who are enrolled in special education programs in 2001-02. In total, just over 150,000 children ages 3 through 21 were enrolled in special education programs. The largest category of disability, "specific learning disability," accounts for over 81,000 children. Other large categories are developmental delay (over 10,000), emotional (over 12,000), communication (over 17,000), and intellectual (over 11,000). In smaller but significant categories, 2,898 children had neurological disabilities; 3,451 had autism; 5,066 had multiple disabilities; and over 4,000 fall into the categories of "physical" and "health" disabilities. The 150,000 children in special education account for between eight and nine percent of the total population in this age group (Massachusetts Department of Education 2001).

Most of these children receive services categorized as "general education," "resource room," and "separate class." Smaller numbers of children are in a "public separate class," "private separate class," residential facility, home or hospital, or program for children three to four years of age (Massachusetts Department of Education 2003).

**Costs of neurobehavioral disorders.** Neurobehavioral disorders lead to costs both for medical treatment and for special education or other special care. Researchers have also estimated costs associated with loss of future earnings due to impairment of intellectual capacity.

We use the number of children in special education as an approximation for the number of Massachusetts children with neurobehavioral disorders. Children must be diagnosed with a disability in order to receive special education services. In some instances, children who are not disabled may receive special education services due to misclassification; in addition, some children in special education suffer physical disabilities that are distinct from neurobehavioral disorders. Counterbalancing these factors, a large number of children with true neurobehavioral disabilities are not tested or offered special education (Learning Disabilities Association of Massachusetts, pers. com).

August 2003). Thus, while the number of children in special education does not exactly overlap with the number of children suffering from neurobehavioral disorders, it is a reasonable proxy for that number.

Massachusetts expenditures for special education were \$10,249 per pupil in 1999, compared with \$5,487 per pupil for regular education (Berman et al. 2001: 191). Thus, the incremental cost of special education is the difference between these two figures, or \$4,762 (converted in the table below to \$5,143 in 2002 dollars). We can use this figure to estimate the total costs associated with providing special education for children with environmentally induced neurobehavioral disorders.

The National Academy of Sciences estimate used by Landrigan et al. places the EAF for neurobehavioral disorders between 5 and 20%, with a best guess of about 10%. Applying this range of EAFs to the total number of children in special education in one year, we estimate costs ranging from over \$38.5 million to over \$154 million for education alone. This figure includes individuals ranging in age from 3 to 21, since some disabilities prolong the number of years spent in school.

**Table 5: Estimated costs of Neurobehavioral disorders in MA:  
Costs of Special Education**

Students in special ed., 2000-01	Extra cost per child, 1999	Estimated MA costs (one year)	EAF	Cost of environmentally attributable fraction
150,000	\$ 5,143	\$ 771,444,000	0.05	\$ 38,572,200
			0.1	\$ 77,144,400
			0.2	\$ 154,288,800

All cost figures have been converted to 2002\$.

For certain disorders, estimates are also available for the costs of home care and other expenses. Landrigan et al. consider the costs of just three neurobehavioral disorders: mental retardation, autism, and cerebral palsy (Landrigan et al. 2002: 725). Categories in the analysis include physician visits, prescription drugs, hospitalization, auxiliary devices, therapy and rehabilitation, long term care, home and auto modification, special education services, and home care. In addition to these sources of direct costs, Landrigan et al. built in estimates of productivity losses in adulthood. Their estimate of the total national cost comes to around \$103 billion.

Because Massachusetts has about 2% of the US population, we can estimate that it bears about 2% of the national costs of neurobehavioral disorders. Thus, total Massachusetts costs for neurobehavioral disorders, using the Landrigan et al. figures which include future income foregone, can be estimated at around \$2 billion. Applying the range of EAFs estimated by the National Academy of Sciences, we estimate Massachusetts costs due to environmental exposures ranging from over \$103 million to over \$412 million for care and education plus foregone future earnings. This figure refers *only* to the three categories of neurobehavioral disorders considered by Landrigan et al.

#### 4. LEAD EXPOSURE

Lead, a heavy metal, is toxic to the developing nervous system. In adults, high blood lead levels can produce hypertension (high blood pressure). Lead exposure in babies and children, especially during the first five years of life, causes permanent damage to the developing brain. Because there is no "natural" or "baseline" level of lead poisoning in humans, the environmentally attributable fraction (EAF) of lead poisoning is 1. In other words, 100% of lead poisoning cases can be attributed to environmental factors under human control. It was once assumed that lead was dangerous only at high exposure levels, but evidence has accumulated steadily on the adverse effects of low exposures.

Lead exposure causes neurobehavioral disabilities, but is treated as a separate category here because it is a large category for which there has been relatively extensive data collection and analysis. Lead poisoning also differs from the other categories of illness we discuss in this report, because lead levels in children are declining, rather than rising, due to policy changes that have reduced lead exposure. However, the level at which lead is known to be harmful is also declining.

New data suggest that lead impairs cognitive development at levels previously assumed to have little or no effect. Landrigan et al. estimate that one microgram per deciliter (1g/dL, or mcg/dL) of lead in a child's blood corresponds to a reduction in intelligence of about 0.25 IQ points. A recent study suggests that the effect of lead at low levels is even greater than the estimate used by Landrigan et al. Researchers tested blood lead levels of 172 children, beginning at the age of six months and continuing until they were five years old. They found that blood lead level is "inversely and significantly associated with IQ." An increase of 10 1g/dL in lifetime average blood concentration corresponded to a 4.6 point decrease in IQ. For those children whose blood lead levels never exceeded 10 1g/dL, the effect on IQ was even greater per unit change in blood lead level (Canfield et al. 2003: 1517-1526).

**Sources of lead exposure.** Children are exposed to lead from a variety of sources. Many children are exposed to lead through lead-based paint used in homes. This paint can poison children when it flakes off walls or produce lead contaminated dust. Although its use is now illegal, lead paint applied in the past remains in many Massachusetts homes. Another major source of lead exposure is through contaminated soil. Policy measures have led to a steady reduction in lead poisoning rates, but thousands of children still suffer permanent brain damage due to lead exposure each year.

**Blood lead levels in Massachusetts.** Information from the Childhood Lead Poisoning Program of the Massachusetts Department of Public Health shows the number of children with blood lead levels greater than or equal to 10 µg/dL in each year from 1994 to 2002. In 1994, 12,479 children between the ages of 6 months and 6 years were identified as having blood lead levels greater than or equal to 10 µg/dL. There has been a steady decline in the numbers since that year, indicating that efforts to reduce lead exposure have been effective, although significant numbers of children are still exposed.



In 2002, 2,940 children were found to have blood lead levels great than or equal to 10 µg/dL (Massachusetts Department of Public Health Childhood Lead Poisoning Prevention Program 1994-2002).

**Table 6: Blood Lead Levels  $\geq$  10 mcg/dL in Massachusetts**  
Children 6 months to 6 years

<i>Year</i>	<i>Number of children</i>
1998	5,962
1999	5,092
2000	3,876
2001	3,255
2002	2,940

Figures show number of children screened and identified with levels  $\geq$ 10 mcg/dL each year.

Source: Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, Childhood Lead Poisoning Prevention Program, Screening and Incidence Statistics

Specific data are also available on the number of children found to have blood lead levels at or above 15 µg/dL. Data collected by the Childhood Lead Poisoning Prevention Program in 2000-01 groups children in three categories: those with "moderately elevated" blood lead levels, between 15 and 19 µg/dL; those with "elevated" blood lead levels, between 20 and 24 µg/dL; and those considered to be "lead poisoned," with blood lead levels at or above 25 µg/dL.

The program screened slightly more than half of the total population of children between the ages of six months and six years. The results showed that 426 children had "moderately elevated" blood lead levels of 15-19 µg/dL; 159 had "elevated levels" of 20-24 µg/dL; and 159 qualified as "lead poisoned," with blood lead levels at or above 25 µg/dL.

**Table 7: Blood Lead Levels  $\geq$  15 mcg/dL in Massachusetts, 2000-01**  
Children 6 months to 6 years

<i>Category</i>	<i>Blood lead level (mcg/dL)</i>	<i>Number of children</i>
Moderately Elevated	15-19	426
Elevated	20-24	159
Poisoned	$\geq$ 25	159
<b>Total <math>&gt;</math>15</b>		<b>744</b>

Figures show number of children confirmed for the first time with listed blood lead levels in 2000-01. Source: MA Department of Public Health Childhood Lead Poisoning Prevention Program Screening and Incidence Statistics, Fiscal year 2001

**Blood lead levels in Boston.** A study of young children in Boston, conducted from 1994 to 1999, found that the prevalence of children with blood lead levels (BLLs) greater than or equal to 10 micrograms per deciliter decreased over this five year period from 9.3% of the population studied (3,265 children) to 5.1% of the population studied (1,398 children). The prevalence of children with blood lead levels greater than or equal to 20 micrograms per deciliter also declined. The researchers say that "approximately 1300 children in Boston are identified annually with BLLs  $\geq 10 \mu\text{g/dL}$ , levels high enough to adversely affect cognitive development and behavior" (S. Franco 2001: 337-9).

**Costs of lead exposure.** A substantial literature exists on the costs associated with lead poisoning. Estimated costs of lead poisoning differ from the estimated costs of cancer and asthma in that treatment costs are relatively low compared with the costs of care and education of lead-injured children, and particularly the projected future earnings of children whose lifetime productivity is impaired. Medical treatment costs are limited in part because the damage that lead inflicts on the developing brain is largely irreversible.

*Basic treatment costs.* The EPA *Cost of Illness Handbook* explores the direct medical costs of screening and treating children for lead exposure (U.S. EPA *COI*: Chapter III:9). In this case, EPA looks *only* at treatment aimed at reducing blood lead levels; it does not consider the costs of treating the health effects that may result from the exposure. EPA also does not look at "elements such as indirect medical costs, pain and suffering, [or] lost time of unpaid caregivers." (EPA *COI*, p. III.9-2)

EPA categorizes children into six "risk levels," each associated with a set of costs. Costs for children in the lower risk categories consist primarily of screenings and family education about lead hazards. Costs for those in the higher risk categories include the cost of chelation therapy, a medical technique used to lower blood lead levels. Costs are estimated for a five-year period beginning with the year of initial screening. The estimates range from \$522 per child in the level of lowest concern to \$5200 per child for those requiring the most aggressive treatment and follow-up. These figures are given in 1987 dollars. Elements included in the estimates include costs of initial screening; chelation; costs of additional tests, such as checking for iron deficiency; a neuropsychological evaluation; family education; and follow-up tests (U.S. EPA *COI*: III.9-9).

*Lost productivity.* Landrigan et al. employ a widely accepted model in which the costs of lead poisoning are estimated based on expected loss of future earning potential due to diminished IQ. They calculate that the mean blood lead level in 1997 among five-year-old children was 2.7  $\mu\text{g/dL}$ . According to models available at the time, they calculated that a blood lead level of 1  $\mu\text{g/dL}$  corresponds to an average loss of 0.25 IQ point per child. Thus, the average blood lead level in 1997 corresponded to an average decrease of 0.675 IQ points in all five-year-old US children. Landrigan and collaborators translate this into an expected loss of 1.61% of lifetime earnings, or a total of \$43.4 billion across the country in 1997, or \$48.7 billion in 2002 dollars (Landrigan et al. 2002: 724).

Since Massachusetts is home to approximately two percent of the US population, we can estimate that foregone future earnings due to lead-induced damage amount to two percent of the national figure, or \$972 million for each year's cohort of five-year-olds. Because Massachusetts has a high proportion of relatively old housing with lead paint<sup>2</sup>, the figures may be even higher than this rough estimate suggests.

An alternative calculation using somewhat different assumptions produces a broadly similar result. In Table 8, we use one of the standard values per IQ point used by EPA in its cost calculations. This value is lower than the value used by Landrigan et al. Counterbalancing this lower value per IQ point, we build in an estimated average loss of 0.46 IQ points per  $\mu\text{g}/\text{dL}$ , based on the recent findings cited above, which were published after the Landrigan et al. study. (These figures are necessarily approximate, and do not reflect more complicated factors such as the nonlinear relationship between blood lead levels and IQ.) Assuming that average blood lead levels among Massachusetts children are similar to the national average<sup>3</sup>, our alternative estimate of the foregone future earnings due to lead exposure is over \$894 million.

**Table 8: Alternative estimate of the cost of lead exposure in MA**

Children affected (2002)	Average BLL (mcg/dL)	Estimated IQ lost per mcg/dL	Earnings loss per IQ point	Total estimated value
83,000	2.7	0.46	\$8,680	\$894,700,000

IQ loss estimate is derived as 1/10 of the 10 mcg/dL estimate in Canfield et al., 2003. Value per IQ point is from EPA, "Economic Analysis of Toxic Substances Control Act," 2000, updated to 2002\$. Average blood lead level estimate is from Landrigan et al. 2002.

## 5. BIRTH DEFECTS

According to the March of Dimes, birth defects affect about 1 in 28, or about 150,000 babies each year in the US (Massachusetts Department of Public Health 2001). Some birth defects can be corrected at least partially through surgery. Others create life-long disabilities requiring institutionalization, specialized equipment, special educational arrangements, and special care. The most serious types of birth defects include congenital heart defects, neural tube defects, cerebral palsy, Down syndrome, and others.

<sup>2</sup> According to the Massachusetts Department of Public Health, 47% of Massachusetts housing units were built before 1950.

<sup>3</sup> The Massachusetts Department of Public Health Childhood Lead Poisoning Program has estimated mean blood lead levels (BLLs) in Massachusetts at 2.514  $\mu\text{g}/\text{dL}$  in 2002 using one data point per child tested (incidence), or 3.557  $\mu\text{g}/\text{dL}$  including the same children in multiple years (prevalence) (Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, Childhood Lead Poisoning Program: Mean Blood Lead Level Statistics, 2003).

**Causes of birth defects.** Some birth defects occur by chance, or are inherited; others can be caused by nutritional deficiencies or by exposure to alcohol, drugs, or environmental toxins. Some toxic exposures are widely recognized as causing birth defects. A recent EPA report on children's health and the environment reviews some of the evidence on links between birth defects and toxic exposures. Instances of high exposure have demonstrated the toxic effects of contaminants such as mercury and polychlorinated biphenyls (PCBs); for example, fetal mercury poisoning can cause deafness and blindness, and fetal exposure to high levels of PCBs causes skin and nail abnormalities.

In addition, epidemiological studies have documented links between birth defects and a variety of parental exposures. For example, studies have found an association between women's occupational exposure to organic solvents and increased likelihood of having children with certain birth defects, including heart defects and cleft lip or palate. Studies have also found links between birth defects and both maternal and paternal exposure to pesticides. (These and other studies are reviewed in U.S. EPA 2003: 114.) A recent study in England found increased rates of spina bifida and heart defects among the children of women who lived near incinerators during pregnancy (Dummer et al. 2003). A study in southern California found links between certain birth defects and ambient air pollution, suggesting a possible relationship between heart abnormalities and fetal exposure to ozone and carbon monoxide pollution (Ritz et al. 2002).

**Incidence of birth defects in Massachusetts.** The first comprehensive report on birth defects in Massachusetts was published in 2001, presenting data collected for births in 1999. In 1999, there were 80,866 live births to Massachusetts residents. Of these, 875 had one or more birth defects. In addition, 29 stillbirths were identified as having a birth defect, for a total of 904 cases recorded (Massachusetts Department of Public Health 2001). Table 9 shows the breakdown of recorded birth defects, according to medical category. Some infants were born with multiple defects, so the total number of defects is larger than the total number of infants affected.

The tracking system that produced these figures is likely to have underestimated the incidence of birth defects; defects that are not diagnosed at the time of birth may not be recorded. In addition, the report only included diagnoses that were confirmed before one year of age, and thus would not reflect abnormalities that became evident later. Some heart defects and other organ malformations, as well as some syndromes that produce developmental delays, are not necessarily detected in the first year of life (Massachusetts Department of Public Health, 2001).

**Table 9: Birth Defects: Incidence in Massachusetts, 1999**

Birth defect category	Overall Count: live births
Central Nervous System	89
Eye	24
Ear	13
Cardiovascular/Respiratory	300
Orofacial	124
Gastrointestinal	87
Genitourinary	116
Musculoskeletal	227
Chromosomal/Syndromes	145
Other	11
<b>Total birth defects observed</b>	<b>1136</b>
<b>Total Number of Cases</b>	<b>875</b>

Note: Some infants are born with multiple defects. Therefore, the total number of cases is smaller than the sum of the counts for each category. Source: Massachusetts Department of Public Health, *Massachusetts Birth Defects 1999* (November 2001)

**Costs of birth defects.** A 1995 article presented estimates of the costs of cerebral palsy and 17 other selected birth defects (Waitzman et al. 1995). The researchers developed estimates of both "direct" and "indirect" costs associated with birth defects. Direct costs include medical services and other forms of special care and education required by children with birth defects. Indirect costs include the future income and/or household productivity lost by these children due to the disorders. They based their estimates on incidence rates and cost figures for the state of California. A further, detailed analysis was published in 1996 by the same study group (Waitzman et al. 1996).

The total estimated cost of the 18 conditions examined in this study was around \$10 billion in 1992. Costs per case varied considerably depending on the type and severity of the defect, ranging from \$96,000 to \$645,000 per new case. The disabilities with the highest costs included cerebral palsy, Down syndrome, and spina bifida. Heart defects also had high direct costs due to the need for complicated surgery, and high indirect costs due to high rates of death during the first year of life. This study did not look at the costs of time spent by family members caring for children with birth defects. The researchers also did not try to evaluate the amount that parents or children would be willing to pay to avoid the suffering and death associated with birth defects.

The editors of *Morbidity and Mortality Weekly Reports*, where the results of this study were published, note that approximately 120,000 infants (3% of all live births) are born with serious birth defects each year; the costs estimated in this study cover only a fraction of the birth defects that affect the children born each year. The editors also note that "excess medical and education costs probably were underestimated for some conditions because they could not be ascertained completely."

The editors illustrate the type of lesson that can be learned from these data by looking at the case of spina bifida, a serious birth defect that may be prevented in some cases if pregnant women take supplements of the vitamin folic acid. They suggest that if all women capable of becoming pregnant were to take folic acid supplements at the level recommended by government agencies, "a substantial proportion of the \$489 million in total costs associated with spina bifida could be averted."

Calculating costs associated with environmentally induced birth defects is a challenging task. No environmentally attributable fraction (EAF) has been calculated for birth defects in general. Furthermore, specific cost estimates are not available for all birth defects. The wide variation in birth defects, ranging from cosmetic problems to debilitating disorders, makes it difficult to develop meaningful average costs.

In Table 10, we combine the Massachusetts data on specific birth defects in 1999 with existing cost estimates for individual defects from the study described above. This approach allows greater precision, but is limited by the fact that cost estimates are available for only a subset of the defects recorded in Massachusetts. Of the 1183 total birth defects observed, cost estimates are available for only 400. Just for this subset of birth defects in 1999, the estimated cost of medical care plus special education is over \$37 million. If we were to build in the estimated loss of future earnings, the cost would rise to over \$80 million. There is an urgent need for more and better data on rates of birth defects associated with toxic exposures, not only so that cost estimates can be improved, but more importantly, to help prevent these illnesses.

<b>Table 10: Estimated costs of Birth Defects in Massachusetts, 1999</b>				
Costs are in 2002\$.				
<b>Birth defect category</b>	<b>No. of cases (live births)</b>	<b>Direct medical cost per case</b>	<b>Special education cost per case, CA</b>	<b>Total direct medical plus special ed costs</b>
Spina bifida	11	\$ 194,560	\$ 46,824	\$ 2,655,220
Truncus/Aortic Septal Defects	1	\$ 346,560	\$ 2,693	\$ 349,253
Transposition of Great Arteries	21	\$ 110,960	\$ 4,212	\$ 2,418,610
Tetralogy of Fallot	24	\$ 179,360	\$ 5,355	\$ 4,433,159
Single Ventricle	3	\$ 209,760	\$ 3,238	\$ 638,993
Cleft Lip and/or Palate	111	\$ 18,240	\$ 4,817	\$ 2,559,314
Tracheoesophageal Fistula	20	\$ 66,880	\$ -	\$ 1,337,600
Rectal and large intestinal atresia	17	\$ 41,040	\$ -	\$ 697,680
Small Intestinal Atresia	21	\$ 53,200	\$ -	\$ 1,117,200
Renal Agenesis/Hypoplasia	3	\$ 18,240	\$ -	\$ 54,720
Urinary Obstruction	42	\$ 13,680	\$ -	\$ 574,560
Upper Limb Reduction	14	\$ 7,600	\$ 26,193	\$ 473,097
Lower Limb Reduction	6	\$ 36,480	\$ 26,156	\$ 375,817
Gastroschisis	14	\$ 66,880	\$ -	\$ 936,320
Omphalocele	11	\$ 45,600	\$ -	\$ 501,600
Diaphragmatic Hernia	16	\$ 53,200	\$ -	\$ 851,200
Down Syndrome	65	\$ 130,720	\$ 133,067	\$ 17,146,147
<b>Total</b>	<b>400</b>			<b>\$ 37,120,490</b>

Sources: Massachusetts Department of Public Health, *Massachusetts Birth Defects 1999* (November 2001); direct medical costs from Waitzman et al. 1996, pp. 84 and 114: medical costs and special education costs originally calculated for California, 1988

## 6. NOTE ON METHODOLOGY: VALUE-PER-LIFE ESTIMATES

Our discussion has focused on costs associated with medical treatment, lost work and school days, and other cost categories that do not require estimating a dollar value for a human life. However, including an estimated value per life, or "cost of premature death," is standard in many economic analyses. As we have noted above, Landrigan et al. include an estimated value per life in their calculations of the costs associated with asthma and cancer. While these values are not the focus of our report, they deserve some comment.

Landrigan et al. estimate the cost of premature deaths based on the foregone future earnings of a child who dies from asthma or cancer. Based on the figures they provide on total cost of premature deaths and total number of premature deaths from asthma, we calculate that the cost per life they have used is \$780,000.

The U.S. Environmental Protection Agency has developed a number of estimated values per human life. An EPA study published in 2000 sets the value of a human life at \$6.1 million. If we apply this value to the Landrigan calculations in place of the far more

conservative \$780,000, the estimated total cost of children's asthma and cancer is substantially higher. If we again calculate Massachusetts costs as 2% of the national costs estimated by Landrigan et al., the state's environmentally attributable costs of children's cancer more than doubles from the numbers reported above (and below in Table 11), reaching \$19.4 million with an EAF of .05, or \$350 million with an EAF of .9. The cost of children's asthma is more moderately affected, because death from asthma is less common (but not unknown). The \$6.1 million value per life lost would increase our asthma estimates by about 20%, raising them to \$17 million with an EAF of .10, or \$61 million with an EAF of .35.

## VI. CONCLUSION

A significant number of children in Massachusetts are affected by cancer, asthma neurobehavioral disorders, lead exposure, and birth defects. The exact fraction of some of these disorders attributable to environmental causes will never be known precisely. However, the weight of the evidence suggests that a subset of the cases in each category (and all the cases, for lead) are linked to environmental factors. Whether it is 5% or 90%, some fraction of the children who had cancer in 1999 became ill due to avoidable toxic exposures. Whether it is 10% or 35%, many of the children who were hospitalized for asthma in the same year became ill because of preventable exposures to contaminants.

The financial costs alone of children's environmentally induced illnesses are significant. Society spends hundreds of thousands of dollars per child with cancer; society loses millions of dollars in decreased productivity due to loss of IQ points among children exposed to lead, mercury, and other toxins that affect brain development. The quantifiable dollar costs, of course, are only a tiny portion of the true cost that communities bear as a result of these illnesses.

Table 11 summarizes the main estimates we have discussed in the sections above. Drawing on data from 1999-2002, we estimate the burden of the five categories of illness considered in this report for a single year in Massachusetts. The cost comes out at over \$1 billion for medical care, special education, and other direct costs associated with caring for children with these illnesses, and is over \$3.4 billion if we include estimates of school days lost and future income foregone. As noted above, the totals would be even larger if we included dollar values for human lives lost.



<b>Table 11: Total costs for one year, no EAF applied</b>		
	<i>Medical expenses, care, and education</i>	<i>Medical, care, education, and lost future income</i>
<i>Cancer, 1999</i>	\$ 164,000,000	\$ 182,000,000
<i>Asthma, 1998</i>	\$ 101,146,000	\$ 142,912,000
<i>Neurobehavioral (2% of national, 1997)</i>		\$ 2,060,800,000
<i>Neurobehavioral - special education only, 2001-02</i>	\$ 771,444,000	
<i>Lead exposure (2% of national, 1997)</i>	n/a	\$ 972,000,000
<i>Selected birth defects, 1999</i>	\$ 37,120,000	\$ 80,668,000
<b>Total</b>	<b>\$ 1,073,000,000</b>	<b>\$ 3,438,000,000</b>
All costs are in 2002\$.		

In Table 12, we present the costs of the environmentally attributable fraction of these disorders (for various recent years, 1997-2002, based on data availability). We exclude birth defects from this calculation because no reliable estimate of the EAF for birth defects is available. Using the low end of the range of estimated EAFs, we calculate total costs of \$56 million per year if we exclude foregone future earnings, or over \$1 billion if we include those earnings. Using the high end of the range of estimated EAFs, we calculate costs of \$337 million without foregone future earnings, or nearly \$1.6 billion with these earnings.

<b>Table 12: Total costs, high and low EAFs</b>						
	<b>Low EAF</b>			<b>High EAF</b>		
	EAF	Direct costs	Direct costs plus lost future income	EAF	Direct costs	Direct costs plus lost future income
<i>Cancer, 1999</i>	0.05	\$8,200,000	\$9,100,000	0.9	\$147,600,000	\$163,800,000
<i>Asthma, 1998</i>	0.1	\$10,114,600	\$14,291,200	0.35	\$35,401,100	\$50,019,200
<i>Neurobehavioral (2% of national, 1997)</i>	0.05		\$103,040,000	0.2		\$412,160,000
<i>Neurobehavioral - special education only, 2001-02</i>	0.05	\$38,572,200		0.2	\$154,288,800	
<i>Lead exposure (2% of national, 1997)</i>	1		\$972,000,000	1		\$972,000,000
<b>Total</b>		<b>\$56,000,000</b>	<b>\$1,098,000,000</b>		<b>\$337,000,000</b>	<b>\$1,597,000,000</b>
Direct costs include medical costs, home and institutional care, lost parental earnings, and special education. Birth defects are excluded from this table because no formal estimate of EAF is available.						

While we spend resources to treat and compensate for environmentally induced illnesses, alternative approaches are available that would eliminate these costs. Increasingly, evidence shows that it is cost effective and practical to replace toxic chemicals with safer alternatives. By instituting clean production practices, we can eliminate major sources of unnecessary expense, as well as unnecessary suffering. For example, it is possible to eliminate the mercury that currently cycles from household products through incinerators, into our air and rainwater and finally into the fish we eat.

Eliminating mercury contamination would make it possible once again for children and pregnant women to eat freshwater fish, a highly valuable source of nutrition. Similarly, we can eliminate use of toxic plastics whose production and disposal byproducts contaminate breast milk and are found in the blood of newborn babies. Nontoxic dry cleaning fluids are available, and are already appearing on the market. Forward-looking policies in Europe are requiring the elimination of lead, cadmium, and other heavy metals from electronics products; we should be doing the same. By working proactively for changes of this kind, we can build a healthy economy where children can grow up into healthy, productive adults.

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## REFERENCES

Ackerman, Frank and Lisa Heinzerling. *Priceless: On Knowing the Price of Everything and the Value of Nothing* (NY: New Press, forthcoming 2004).

Ackerman, Frank and Lisa Heinzerling. "Pricing the Priceless: Cost-Benefit Analysis of Environmental Protection" *University of Pennsylvania Law Review*, 150:5 (May 2002), 1553-1584.

Asthma Regional Council. *Asthma in New England, Part I: Adults* (Dorchester, MA: Asthma Regional Council, May 2003).

Berman, Sheldon et al. "The Rising Costs of Special Education in Massachusetts: Causes and Effects." In Chester E. Finn, Jr. et al., eds, *Rethinking Special Education for a New Century* (Thomas B. Fordham Foundation and the Progressive Policy Institute, May 2001): 183-211.

Blakeslee, Sandra. "Increase in Autism Baffles Scientists," *New York Times* (October 18, 2002). Available at <http://www.ourstolenfuture.org/Commentary/News/2002/2002-1017-NYT-califautism.htm>, visited May 2003.

Blatter, B.M. and N. Roeleveld. "Spina bifida and parental occupation in a Swedish register-based study." *Scandinavian Journal of Work Environment and Health* 22:6 (1996), 433-437.

Boston Public Health Commission Research Office, *The Health of Boston 2002* (Boston, MA: Boston Public Health Commission, November 2002).

Byrd, R. S. "The Epidemiology of Autism in California: A Comprehensive Pilot Study: Report to the Legislature on the Principal Findings," 2002, cited and summarized at <http://www.ourstolenfuture.org/NewScience/behavior/2002/2002-10byrd.htm#1999califautism>, visited May 2003.

California Department of Developmental Services, *Changes in the Population of Persons with Autism and Pervasive Developmental Disorders in California's Developmental Services System: 1987 through 1998: A Report to the Legislature March 1, 1999*. Sacramento CA: California Health and Human Services Agency, 1999. Cited and summarized at <http://www.ourstolenfuture.org/NewScience/behavior/2002/2002-10byrd.htm#1999califautism>, visited May 2003.

Canfield, Richard L. et al., "Intellectual Impairment in Children with Blood Lead Concentrations below 10  $\mu$ g per Deciliter," *New England Journal of Medicine* 348:16 (April 17, 2003), 1517-1526.

Census 2000 Summary File for Massachusetts. Available at <http://factfinder.census.gov/servlet/BasicFactsServlet>.

Department of Health and Human Services (DHHS). *Action Against Asthma: A Strategic Plan for the Department of Health and Human Services* (Washington, DC: Department of Health and Human Services, 2000).

Dummer, TJB et al. "Adverse Pregnancy Outcomes around Incinerators and Crematoriums in Cumbria, Northwest England, 1956-93." *Journal of Epidemiology and Community Health* 57 (2003), 456-461.

Environment and Human Health, Inc., *A Survey of the Prevalence of Asthma among School Age Children in Connecticut*. (North Haven, CT: EHHi, 2000.) Available at <http://www.ehhi.org/pubs/Asthma.pdf>.

Eskenazi, Brenda et al. "Exposures of Children to Organophosphate Pesticides and their Potential Adverse Health Effects," *Environmental Health Perspectives* 107:Supplement 3 (June 1999), 409-19.

Faber, Daniel R. and Eric J. Krieg, "Unequal Exposure to Ecological Hazards: Environmental Injustices in the Commonwealth of Massachusetts." *Environmental Health Perspectives* 110:2 (April 2002): 277-288. Available at <http://ehpnet1.niehs.nih.gov/members/2002/suppl-2/277-288faber/EHP110s2p277PDF.PDF>.

Franco, S. "Trends in Blood Lead Levels Among Children --- Boston, Massachusetts, 1994--1999" *MMWR* (May 4, 2001); 50(17); 337-9. Available at <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5017a3.htm>

Gouveia-Vigeant, Tami and Joel Tickner, *Toxic Chemicals and Childhood Cancer: a Review of the Evidence* (Lowell, MA: Lowell Center for Sustainable Production, May 2003).

Ladebauche, Pauline et al. "Asthma in Head Start Children: Prevalence, Risk Factors, and Health Care Utilization." *Pediatric Nursing* 27:4 (July 2001), 396.

Landrigan, Philip J. et al., "Environmental Pollutants and Disease in American Children: Estimates of Morbidity, Mortality, and Costs for Lead Poisoning, Asthma, Cancer, and Developmental Disabilities." *Environmental Health Perspectives* 110: 7 (July 2002), 721-728. Available at: <http://ehpnet1.niehs.nih.gov/members/2002/110p721-728landrigan/EHP110p721PDF.PDFs>

Massachusetts Community Health Information Profiles (MassCHIP), 2003.

Massachusetts Department of Public Health, "Childhood Cancer in Massachusetts: 1990-1999." (Boston, MA: Massachusetts Department of Public Health, 2003).

Massachusetts Department of Education Information Services, "Special Education Enrollment by Age/Disability," December 1, 2001.

Massachusetts Department of Education, "State Total Percent Special Education Enrollment and Special Education Enrollment by Placement/Prototype," updated January 3, 2003.

Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, Childhood Lead Poisoning Prevention Program, Screening and Incidence Statistics, 1994-2002.

Massachusetts Department of Public Health, *Massachusetts Birth Defects 1999* (Boston, MA: Massachusetts Department of Public Health, 2001).

McGill, K. et al., "Asthma in non-inner city head start children." *Pediatrics* 102 (1998): 77-83.

McMartin et al., K.I. "Pregnancy outcome following maternal organic solvent exposure: a meta-analysis of epidemiologic studies." *American Journal of Industrial Medicine* 34:3 (1998), 288-92.

Perera, Frederica P. et al., "The Challenge of Preventing Environmentally Related Disease in Young Children: Community-Based Research in New York City," *Environmental Health Perspectives* 110:2 (February 2002), 197-204.

Perez-Pena, Richard. "Study Finds Asthma in 25% of Children in Central Harlem," *New York Times* (April 19, 2003).

Ritz, Beate et al. "Ambient Air Pollution and Risk of Birth Defects in Southern California." *American Journal of Epidemiology* 155:1 (2002), 17-25.

Schettler, Ted et al., *Generations at Risk: Reproductive Health and the Environment* (Boston: MIT Press, 1999)

Schettler, Ted et al., *In Harm's Way: Toxic Threats to Child Development* (Cambridge, MA: Greater Boston Physicians for Social Responsibility, 2000).

SEER Cancer Statistics Review 1975-2000, Section XXVII: Childhood Cancer by Site: Incidence, Survival, and Mortality. Available at [http://www.seer.cancer.gov/csr/1975\\_2000/results\\_merged/sect\\_27\\_childhood\\_cancer.pdf](http://www.seer.cancer.gov/csr/1975_2000/results_merged/sect_27_childhood_cancer.pdf).

"Sick Schools Affect Health of US Children," 2002. Available at <http://web1.tch.harvard.edu/pressroom/2002/oct18.html>.

"Subjective Science: Environmental Cost-Benefit Analysis," *Environmental Health Perspectives* 111:10 (August 2003), A530-A532.

U.S. Administration for Children and Families Head Start Bureau  
(<http://www.acf.dhhs.gov/programs/hsb/>) and 2003 Head Start Statistical Fact Sheet  
(<http://www.acf.dhhs.gov/programs/hsb/research/2003.htm>).

U.S. EPA, *America's Children and the Environment: Measures of Contaminants, Body Burdens, and Illnesses* (EPA 240-R-03-001, February 2003), pp. 58-59.

U.S. EPA, *The Cost of Illness Handbook (COI)*. Available at <http://www.epa.gov/oppt/coi>, visited February 2003. Document last updated July 23, 2002.

Waitzman, N.J. et al., "Economic Costs of Congenital Anomalies." *Morbidity and Mortality Weekly Report* 44:37 (September 22, 1995).

Waitzman, N.J. et al., *The Cost of Birth Defects: Estimates of the Value of Prevention*. (Lanham, MD: University Press of America, 1996).

Weiss, Kevin B. et al. "Trends in the Cost of Illness for Asthma in the United States, 1985-1994," *The Journal of Allergy and Clinical Immunology* 106:3 (September 2000), 493-499. Results available online at <http://www.aafa.org/states/sttab1.cfm>, visited September 2003.

Zahm, Shelia Hoar. "Racial, Ethnic, and Gender Variations in Cancer Risk: Considerations for Future Epidemiologic Research." *Environmental Health Perspectives* 103: Supplement 8 (November 1995).

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