



Minnesota  
Department of Health  
**ENVIRONMENTAL PUBLIC HEALTH TRACKING**



The Economic Burden  
of the Environment on  
Children's Disease:  
The Cost of Prenatal Mercury  
Exposure in Minnesota

SEPTEMBER 2015

# Economic Burden of the Environment on Children's Disease: The Cost of Prenatal Mercury Exposure in Minnesota

MINNESOTA DEPARTMENT OF HEALTH  
MINNESOTA ENVIRONMENTAL PUBLIC HEALTH TRACKING

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## Acknowledgements

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# Contents

- Introduction ..... 1
- Background ..... 2
  - Mercury exposure trends in the U.S..... 2
  - Disparities observed ..... 3
- The Costs of Prenatal Mercury Exposure: Methods & Results ..... 4
  - The formula..... 4
  - Estimating elevated mercury exposure cases ..... 4
  - IQ point loss attributed to blood mercury levels ..... 5
  - The environmentally attributable fraction (EAF) ..... 5
  - Estimating lifetime earnings capacity and loss..... 6
  - Limitations of this analysis..... 7
- Actions Addressing Prenatal Mercury Exposure in Minnesota ..... 9
  - Actions Addressing Mercury in Minnesota’s Environment ..... 9
  - Actions Addressing Mercury from National and Global Sources ..... 10
  - Actions Addressing Mercury in Newborns ..... 11
- References ..... 12

# Introduction

This report estimates the health impact and economic cost of prenatal mercury exposure attributable to human-caused sources of mercury in the environment. The Minnesota Biomonitoring Program is studying the amount of mercury exposure in newborns, and potential exposure disparities, in Minnesota communities. The purpose of this report is to help inform policy-makers about the health and economic benefits of policy, actions and interventions for reducing prenatal mercury exposure.

Babies *in utero* are exposed to mercury through their mothers' blood, which passes through the placenta. Developing babies are most at risk because small amounts of mercury can damage the developing brain and nervous system. Mercury exposure can affect a child's learning abilities, memory, and attention, and lead to learning problems later in life. In adults, ongoing exposure to mercury can damage the kidneys and nervous system.

For newborns, maternal consumption of fish that contain mercury is thought to be the major source of prenatal exposure to mercury. Older, larger fish and fish that eat other fish have the highest levels of mercury. Methylmercury is an organic mercury compound that is produced by bacteria from other forms of mercury in rivers, lakes and oceans, and is the most toxic form of mercury.

Pregnant women can also be exposed to inorganic or elemental mercury from broken thermometers in the home, skin-lightening creams that contain mercury, dental fillings and mercury used for ritual and folk purposes. Although more study is needed, inorganic mercury is known to cross the placenta and has been found in cord blood (U.S. Environmental Protection Agency, 2007).

The source of nearly all mercury in Minnesota waters (99%) is deposition from the atmosphere. Human-caused sources of mercury include emissions from energy production, material processing (mostly taconite), industrial boilers, refineries, recyclers, solid waste processors, smelters, crematories, product manufacturing, incinerators, and use of mercury in products such as button batteries, fluorescent light bulbs, old mercury-based thermometers, and some appliances (Minnesota Pollution Control Agency, 2009). Ninety percent of human-caused mercury deposition in Minnesota comes from sources outside the state. People are typically exposed to mercury by breathing or eating it. Spilled elemental mercury evaporates into the air and becomes an odorless, colorless, toxic vapor that can then be inhaled. Methylmercury in contaminated fish is likely to enter the bloodstream after ingesting and is carried by the blood to the brain and nervous system (Minnesota Department of Health, 2015).

Prenatal mercury exposure *in utero* can lower a baby's IQ (Axelrad, Bellinger, Ryan, & Woodruff, 2007) which, in turn, can lead to a loss in lifetime earnings (Landrigan, Schechter, Lipton, Fahs, & Schwartz, 2002). We estimate that nearly 6,000 children (3,020 boys and 2,879 girls) born each year in Minnesota

## Key Findings

We estimate that nearly 6,000 children born each year in Minnesota in 2011 and 2012 were potentially impacted by elevated mercury exposure.

We estimate that prenatal mercury exposure resulted in \$32.6 million of lost lifetime earnings (range: \$22.1-43.1 million) for babies born in Minnesota each year.

in 2011 and 2012 were potentially impacted by elevated mercury exposure (see Table 1). We estimate that elevated mercury exposure resulted in \$32.6 million of lost lifetime earnings (range: \$22.1-43.1 million) for babies born in Minnesota each year.

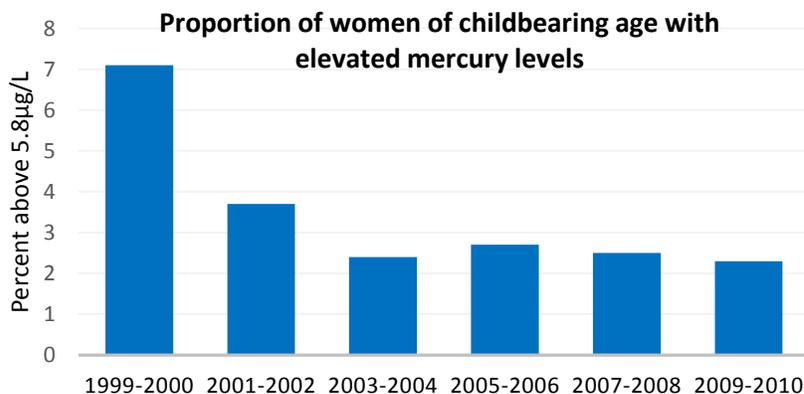
This report builds upon a previously published report from the MN Environmental Public Health Tracking (MN Tracking) Program (Minnesota Department of Health, 2014), which estimated the economic burden of two important environmentally-related health conditions in children: asthma and blood lead poisoning. The purpose of these reports is to use state and national biomonitoring data (measuring chemicals in people) and MN Tracking data in ways that help inform policy-makers about the health and economic benefits of policy, actions and interventions for protecting the health of future generations. Policy initiatives are described in the Actions Addressing Prenatal Mercury Exposure in Minnesota section (see page 9).

## Background

### Mercury exposure trends in the U.S.

#### The proportion of women of childbearing age with elevated mercury levels has declined over time

Only limited data exist on mercury levels in newborns, but we can examine trends in women of childbearing age from the National Health and Nutrition Examination Survey (NHANES), a nation-wide survey that includes biomonitoring. The EPA's reference level for mercury is the level beyond which it is thought to have harmful effects on health. The percent of women aged 16-49 with total blood mercury levels higher than the EPA's reference level for methylmercury (5.8 micrograms of mercury per liter of blood or  $\mu\text{g/L}$ ) declined from 1999-2000 to 2003-2004 and has since remained relatively stable. Just over 2% of U.S. women of childbearing age had blood mercury levels that exceed the reference level in 2009-2010.

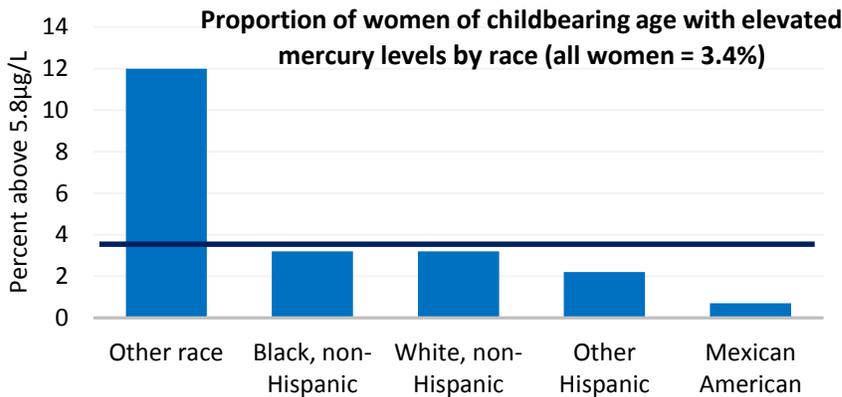


Data are for women age 16-49 and are from a paper by Birch et al. (2014) that used two-year cycles of NHANES data.

## Disparities observed

### The proportion of women of childbearing age with elevated mercury levels differs by race

Exposure to mercury differs by race/ethnicity. Most strikingly, 12.0% of women who identified themselves as “other race” (includes Asian, Native American, Pacific Islander, and Caribbean) exceeded the EPA reference level (above 5.8 µg/L). Similar percentages of black, white, and Hispanic women exceeded this level compared to the average for all women (3.4%). A lower percentage (0.7%) of Mexican American women exceeded this level.



*Data are for women age 16-49 and are from a paper by Birch et al. (2014) and uses 1999-2010 NHANES data.*

Studies of cord blood in newborns in the U.S. have found marked disparities by race/ethnicity in exposure to mercury. Certain groups, such as some Asian populations and African Americans, have been shown to have higher exposures than white newborns (King et al., 2013; Lederman et al., 2008). Although not a measure of newborn exposure, biomonitoring studies have also found elevated urinary mercury levels in Latina women who used skin-lightening creams (McKelvey, Jeffery, Clark, Kass, & Parsons, 2011; Weldon et al., 2000).

Information on newborn mercury exposures in Minnesota is very limited. One MDH study of cord blood collected from babies born to primarily white, affluent, urban mothers in the Twin Cities found 2% of participants had exposures above a 5.8 µg/L. An earlier study in the Lake Superior region of the state tested 1,100 newborn blood spots for total mercury and found that 10% of those tested had levels above 5.8 µg/L (Minnesota Department of Health, 2011). Current biomonitoring studies are expected to provide additional estimates. However, more study is needed to accurately measure mercury levels in Minnesota mothers and newborns. Limitations of the data and regional differences in the U.S. are described on page 7.

# The Costs of Prenatal Mercury Exposure: Methods & Results

This report adopts methods described in Trasande & Liu (2011) and Landrigan et al. (2002) and applies these methods using current Minnesota population statistics, U.S. population biomonitoring data, and economic information.

## The formula

The formula for estimating the economic burden of environmentally-related disease described by Landrigan, et al. (2002) is:

**Economic burden = case counts x environmentally attributable fraction (EAF) x cost per case**

Economic burden is estimated as the number of cases of disease in a defined population and time period, multiplied by the environmentally attributable fraction (EAF) and the cost per disease case.

## Estimating elevated mercury exposure cases

Research (Stern & Smith, 2003) has shown that the average ratio of mercury levels in a newborn's cord blood compared to maternal blood is 1.7. Therefore, Trasande et al. (2011) applied this 1.7 ratio to the U.S. EPA's reference dose of 5.8 µg/L and arrived at a level of 3.4 µg/L in women of childbearing age as a threshold level for estimating the number of elevated newborn mercury exposure cases.

From the most recent 2011-2012 cycle, NHANES measured the level of mercury in blood from a random sample of about 1,600 U.S. women of childbearing age (16-49 years). About **8.6%** of women of childbearing age sampled nationwide had a total mercury level above the threshold of 3.4 µg/L (138 women out of about 1,600 women overall). We applied this national percentage to the total number of births in Minnesota in 2014 to estimate the percent and number of newborns with elevated exposure. In 2011 and 2012, an average of 35,119 boys and 33,480 girls were born to Minnesota women per year. We applied the national estimate of 8.6% to Minnesota's birth data to approximate that 3,020 boys and 2,879 girls born in Minnesota were potentially impacted by prenatal mercury exposure each year in 2011 and 2012. (Table 1)

**Table 1: The estimated number of Minnesota babies born each year with elevated mercury levels, based on national biomonitoring data for 2011-2012.**

Proportion of children born to women with mercury levels above threshold		Average number of children born per year in 2011-2012	Estimated number of children affected
8.6%	Boys	35,119	3,020
	Girls	33,480	2,879

## IQ point loss attributed to blood mercury levels

Among women with an elevated mercury level ( $>3.4 \mu\text{g/L}$ ) in NHANES, the average mercury concentration in blood was **5.27  $\mu\text{g/L}$**  (95% confidence interval: 4.69-5.92  $\mu\text{g/L}$ ). We used this level for calculating average exposure and IQ points lost among Minnesota newborns as described below.

Axelrad et al. (2007) determined that **0.18 IQ points are lost per every unit increase** (1  $\mu\text{g/L}$ ) mercury in a newborn mother's blood above a threshold of 3.4  $\mu\text{g/L}$ . That means if a woman has a mercury level of 9  $\mu\text{g/L}$  (5.6 units above the threshold), her developing baby's IQ level would theoretically decrease by a full IQ point (5.6 x 0.18).

Given our estimate that the average mercury level in the blood of newborns born with exposures above the threshold is 5.27  $\mu\text{g/L}$ , and that this represents an average unit increase of 1.87  $\mu\text{g/L}$  above 3.4, we calculate an average IQ loss of **0.34 points** due to mercury exposure (all sources) for babies in Minnesota with elevated exposure (8.6% of births.)

## The environmentally attributable fraction (EAF)

The environmentally attributable fraction (EAF) estimates the fraction of the disease that would be avoided or eliminated if the modifiable environmental risks were removed or reduced to the lowest level possible. Based on the 1997 Mercury Study Report to Congress (U.S. EPA, 1997), Trasande et al. (2011) determined that 70% of mercury exposure in people can be attributed to anthropogenic (human-caused) sources. This estimate is consistent with a 1992 report of mercury accumulation in lakes in the upper Midwest of the U.S. which found that natural atmospheric mercury concentrations were only about 25% of modern levels (Swain, Engstrom, Brigham, Henning, & Brezonik, 1992). Global and regional human-caused emissions combined are estimated to account for about 70% of mercury entering Midwestern lakes (Engstrom & Swain, 1997; Swain, Engstrom, Brigham, Henning, & Brezonik, 1992). Accordingly, this report uses an **EAF of 70%**.

Given our estimate that the average IQ loss for babies born with elevated exposure is 0.34 points, and the EAF of 70%, we estimate that the average IQ loss attributed to sources caused by human activity is  $.70 \times 0.34$ , or **0.24 points lost**. (Table 2)

**Table 2: IQ points lost per child due to elevated mercury levels, 2011-2012.**

Average mercury level above threshold	Units of mercury above 3.4 µg/L	IQ points lost per unit increase above 3.4 µg/L	Average IQ points lost for children above mercury threshold	EAF	Environmentally-attributable IQ points lost for children above mercury threshold
<b>5.27 µg/L</b> (Range: 4.69-5.92 µg/L)	1.87 µg/L	0.18	0.34	70%	0.24

## Estimating lifetime earnings capacity and loss

Landrigan et al. (2002) estimates 2.39% of potential lifetime earnings are lost for every decrease in an IQ point, based on work by Salkever (1995). Given 0.24 IQ points are lost on average, this equates to an estimated 0.57% of lifetime earnings lost, on average, for babies born in 2011-2012 in Minnesota with elevated mercury exposure at birth.

Lifetime earning capacity was provided from market productivity estimates for boys and girls published in Grosse et al. (2009), but did not include household productivity. We chose lifetime earnings with 1% growth and 3% discount rate for children aged 0-4 years: \$1,203,318 for boys and \$709,824 for girls in 2014 dollars (Grosse et al., 2009). The original estimates were for 2007 dollars and we adjusted to 2014 dollars using the Consumer Price Index calculator (Bureau of Labor Statistics).

Human-caused prenatal mercury exposure in Minnesota is estimated to cost about \$20.8 million for all boys and \$11.7 million for all girls born within a single year in Minnesota due to lost lifetime earnings. Therefore, the total economic burden of environmentally attributable mercury exposure *in utero* to Minnesota children born in 2011 or 2012 is estimated to be about \$32.6 million in 2014 dollars of lost lifetime earnings for each year of babies born. Given the 95% confidence interval for the average mercury level above the threshold in Table 2, the total economic burden ranges from \$22.1 million to 43.1 million for each year of babies born in 2011-2012. (Table 3)

**Table 3: Total lifetime earnings lost attributed to elevated mercury levels for children born in Minnesota, 2011-2012.**

Lifetime earnings lost for every IQ point	Lifetime earnings lost for 0.24 IQ points		Lifetime earnings per child	0.57% of lifetime earnings per child	Estimated number of children affected (from Table 1)	Lifetime earnings lost	Total economic burden (2014\$)
2.39%	0.57%	Boys	\$1,203,318	\$6,902	3,020	\$20.8 million	<b>\$32.6 million</b>  (Range: \$22.1-43.1 million)
		Girls	\$709,824	\$4,072	2,879	\$11.7 million	

An alternative method for estimating the cost of prenatal mercury exposure would calculate an IQ deficit attributable to only methyl mercury levels from NHANES, rather than total mercury levels. The proportion of women with methyl mercury levels above the threshold decreases to 6.3%. Estimating the average methyl mercury level among these women, the total economic burden was lower at \$22.9 million in 2014 dollars of lost lifetime earnings for babies born in each year (range: \$13.5 to 28.2 million).

## Limitations of this analysis

### **Costs likely underestimate the true economic burden**

This report only estimates the cost of lifetime earnings lost due to mercury exposure's impact on IQ. It does not include other costs that are difficult to measure, such as decreased quality of life, increased crime, or increased use of education services. Estimated lifetime earnings in this report are limited to market productivity, and do not include the cost of mercury's impact on household productivity. If both market and household productivity were included in the cost, the impact of total mercury on lifetime earnings would amount to approximately \$40.7 million for babies born in each year (about \$8 million higher).

Full scale IQ is recognized as a composite index of cognitive function, predictive of later academic and occupational success (Neisser et al., 1996). However, it does not include all neurodevelopmental deficits associated with mercury, such as effects on motor skills and attention/behavior. Furthermore, the adverse impact of maternal mercury concentration on full scale IQ may be underestimated because concurrent consumption of fish fatty acids might enhance cognitive development (Pichery et al., 2012; Rice, Hammitt, & Evans, 2010). If exposure is assumed to be from fish consumption then the benefits of fatty acids found in fish need to be included in assessment of changes in IQ (FAO/WHO, 2011).

### **The environmentally attributable fraction (EAF) is an uncertain estimate**

The EAF for mercury exposure (70%) used in this report is based on a report by Trasande et al. (2011) and recent studies estimating the contribution of human-caused sources to environmental mercury in the Midwestern U.S. (Engstrom & Swain, 1997; Swain et al., 1992).

### **The level of mercury exposure in Minnesota newborns is unknown**

Blood mercury levels in U.S. women of childbearing age from NHANES are used in this report to estimate prenatal exposure in Minnesota newborns. Research (Mahaffey, Clickner, & Jeffries, 2009) using national data show that blood mercury levels are, on average, the lowest among Midwest women, compared to women from other U.S. regions but also that women in the Great Lakes Coast region may have higher blood mercury levels than nationally. Findings from a recent study in Minnesota (Minnesota Department of Health, 2011) also suggest that some populations in Minnesota may have higher levels and that exposure may vary seasonally.

ECONOMIC BURDEN OF THE ENVIRONMENT ON CHILDREN'S DISEASE:  
THE COST OF PRENATAL MERCURY EXPOSURE

More study is needed in Minnesota to know whether the published national measures of the proportion of women of childbearing age with mercury levels above a threshold are an accurate representation of Minnesota women. A direct measure of levels in Minnesota newborns (e.g. cord blood) would provide a better estimate for determining the impact of prenatal mercury exposure in the state.

### **The burden is not shared equally**

Some Minnesota communities or people of various racial/ethnic backgrounds may have higher exposures to mercury, and would share a larger economic burden due to this exposure. These populations may include communities that have higher fish consumption (especially local, subsistence fishing) such as Hmong and other Asian women, and those who may use skin-lightening creams containing mercury such as Latina and Somali women. No biomonitoring data are available on mercury exposures in these groups of Minnesotans.

Some Minnesotans may also be more vulnerable to the health and economic effects of mercury exposure due to inequities in other factors like health care access, housing conditions, or early childhood education.

Lifetime earnings used in this report are for the U.S. population of children aged 0-4 years. Lifetime earnings estimates for Minnesota may be different than the nationwide estimate, and children of different race/ethnicities may have higher or lower lifetime earnings than average.

# Actions Addressing Prenatal Mercury Exposure in Minnesota

## Actions Addressing Mercury in Minnesota's Environment

Statewide mercury reduction efforts have been underway since 1990. For example, Minnesota's schools are now mercury free zones, electric utilities have reduced mercury emissions by nearly 90% from 1990 levels, and there are bans in place on the sale of mercury containing devices. As of 2011, Minnesota's total mercury emissions have decreased by 76 percent compared to the 1990 baseline.

Not only is there a risk to human health from exposure to mercury vapor or methyl mercury via fish consumption, but the risk to wildlife from consumption of contaminated fish is likely even greater, largely because wildlife do not alter their food intake in response to consumption advice (Swain et al., 2007). An interagency collaboration between Minnesota's Pollution Control Agency (MPCA), Department of Natural Resources (DNR), and Minnesota Department of Health (MDH) monitors mercury status and tracks long term trends in fish from approximately 130 selected rivers and lakes each year. Data from the program are used for developing statewide fish consumption advisories, researching mercury cycling, and identifying impaired waters.

The state of Minnesota has formally adopted a plan to reduce mercury emissions in the state from 1990 levels by 93% by year 2025. If the plan is fully implemented, including similar reductions from national and global sources, 90% of Minnesota lakes and streams with mercury impairments will meet clean water standards for mercury levels in fish. The other 10% of those lakes and streams are concentrating (i.e. bioaccumulating) mercury in the food chain at a faster rate, and therefore will need additional actions (or more time) to fully achieve the standards. MPCA is currently researching mercury cycling in several streams to determine what factors make the bioaccumulation of mercury more efficient in those ecosystems.

Most recently, a new air emissions mercury rule was enacted in 2014 for the state of Minnesota that requires mercury reduction planning, emissions reporting, and performance standards for some mercury emission sources. To learn more, visit MPCA's mercury website [Mercury](http://www.pca.state.mn.us/index.php/topics/mercury/index.html) (www.pca.state.mn.us/index.php/topics/mercury/index.html).

## Actions Addressing Mercury from National and Global Sources

Minnesota is well on its way to meeting the goal of a 93% reduction in mercury emissions from Minnesota sources by the year 2025. However, reductions from national and global sources are also needed to significantly decrease mercury deposition into Minnesota waters. Minnesota is a national leader in reducing mercury emissions, and has joined other states in urging the federal government to develop a solution to the mercury problem.

The EPA has taken the following actions to reduce national mercury emissions:

- Announced in 2011, the Federal Mercury Air Toxic Standards (MATS) limit mercury emissions and other toxic pollution from coal-fired power plants by compliance dates in both 2015 and 2016.
- Finalized in 2012, clean air standards limit mercury pollution from industrial boilers, incinerators and cement kilns.

Over the last few decades mercury in products has been phased out: paint manufacturers no longer use mercury as an additive, vehicle manufacturers no longer use mercury switches in trunks and hood lights and the sale of mercury thermometers has dropped significantly. However, there are few national bans on products that contain mercury.

Some examples of global initiatives to reduce mercury in the environment include:

- **Minamata Convention on Mercury:** a 2013 global treaty, signed by the U.S., to protect human health and the environment from the adverse effects of mercury. It includes a ban on new mercury mines, phasing out existing mercury mines, control measures on air emissions, and the international regulation of artisanal and small-scale gold mining. Learn more about the [Minimata Convention on Mercury](http://www.mercuryconvention.org) ([www.mercuryconvention.org](http://www.mercuryconvention.org)).
- **Global Mercury Partnership:** established in 2008 by the United Nations Environment Programme (UNEP), aims to protect human health and the global environment from the release of mercury and its compounds by minimizing and, where feasible, ultimately eliminating global, human-caused mercury releases to air, water and land. The Partnership assists with the implementation of the Minamata Convention on Mercury. Learn more about the [UNEP Global Mercury Partnership](http://www.unep.org/chemicalsandwaste/Mercury/GlobalMercuryPartnership/tabid/1253/Default.aspx) ([www.unep.org/chemicalsandwaste/Mercury/GlobalMercuryPartnership/tabid/1253/Default.aspx](http://www.unep.org/chemicalsandwaste/Mercury/GlobalMercuryPartnership/tabid/1253/Default.aspx)).
- **Learn more about other global initiatives** from the U.S. Environmental Protection Agency at [International Actions for Reducing Mercury Emissions and Use](http://www2.epa.gov/international-cooperation/international-actions-reducing-mercury-emissions-and-use) (<http://www2.epa.gov/international-cooperation/international-actions-reducing-mercury-emissions-and-use>).

## Actions Addressing Mercury in Newborns

As noted previously, data on the levels of mercury in Minnesota newborns is limited, and there is no information on time trends to know whether the policies for reducing mercury in the environment are also working to reduce average exposure levels in pregnant women and newborns. The MDH Biomonitoring Program is conducting several studies to find out more about newborns' exposure. One study has compared mercury levels in newborn blood spots to levels found in matched cord blood samples. The investigators hope to learn whether newborn blood spots provide a viable way of monitoring mercury in a large, statewide sample, and tracking time trends. Another study is measuring mercury in newborns in four racial/ethnic communities in the state to find out whether some communities experience higher levels, the sources of exposure, and whether more targeted intervention may be needed. More information can be found at [Minnesota Biomonitoring: Chemicals in People](http://www.health.state.mn.us/divs/hpcd/tracking/biomonitoring/index.html) (www.health.state.mn.us/divs/hpcd/tracking/biomonitoring/index.html).

The MDH Fish Consumption Advisory Program provides safe eating guidelines and site-specific advice at [Fish Consumption Guidance](http://www.health.state.mn.us/divs/eh/fish/) (www.health.state.mn.us/divs/eh/fish/). Fish are an excellent source of low-fat protein and are also rich in the omega-3 fatty acids needed for proper development of the brain and nervous system in babies. In Minnesota, most fish are healthy to eat, but any fish could contain contaminants (like mercury) that can harm human health. Fish consumption advisories help people make wise choices about the fish they eat. Special advice and educational brochures are given to help pregnant women choose fish as part of a healthy diet and limit their mercury exposure to within safe levels for the developing fetus. The program also conducts biomonitoring and evaluates educational interventions for women of childbearing age to encourage healthy fish consumption.

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