

COSTS OF POLLUTION IN CANADA

Measuring the impacts on families,
businesses and governments



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The Conference Board was asked to review the methodology used in the preparation of the report *Costs of Pollution in Canada: Measuring the impacts on families, businesses and governments*, published by the International Institute for Sustainable Development. It is well understood that there are costs to pollution and environmental degradation. However, Canadians do not have a clear understanding of what these costs are. While there are numerous studies measuring the costs of individual pollutants, no single study to date has reviewed every pollutant to tabulate an overall cost. An estimate of the full cost of pollution would highlight this important issue, aiding Canadians and policy-makers in prioritizing and dealing with this problem. The purpose of the methodology we reviewed was to arrive at a comprehensive measurement of the economic costs of pollution based on a systematic review of the scientific literature.

The report, *Costs of Pollution in Canada: Measuring the impacts on families, businesses and governments*, applied a methodology used in health sciences literature to systematically review the literature on pollution. This methodology first identified all the literature based on predetermined keywords and on-line sources. The methodology then identified the most relevant literature based on a transparent screening criteria. The criteria used included categories such as the recency of the literature and the quality of the publisher. The literature was classified to determine gaps and areas for targeted searching, then was analyzed and summarized. The estimated costs of the pollution were converted to Canada and scaled appropriately. The results were then presented by impact type and by type of pollutant.

The approach used has significant benefits. In particular, it significantly reduces the subjective selection of the literature. By creating predetermined search and screening criteria, I am confident that all relevant literature was identified and the correct literature was selected. In tabulating the final results, the estimates were converted to a national Canadian estimate and a standard base year using conversion factors that are appropriate. In addition, we agree with IISD's decision to report the costs in three categories—costs imposed on human welfare, costs imposed on production and consumption, and costs imposed on value of assets. The dollar figures in each of the three categories are not directly comparable; therefore, retaining separate estimates for each category is the most appropriate approach to reporting the costs of pollution.

In summary, I am confident that the methodology was appropriate for this type of project.

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Helpful advice on the report was also provided by David Sawyer of EnviroEconomics Inc.

Every effort has been made to ensure that the report is free from errors in interpretation, analysis or presentation. Any errors that remain in spite of this are the sole responsibility of the IISD project team.



EXECUTIVE SUMMARY

Why This Report?

Canadians realize that clean water, air and land contribute to better health, greater enjoyment of life, more productive communities and a stronger economy. Likewise, they understand that contamination of the environment by pollution leads to a wide variety of costs. Pollution harms human health, damages forests and crops and degrades the quality of land and water—to name just some of its impacts. The result is higher costs for many things: medical care, raw materials, food and public services. In these and numerous other ways, pollution threatens not only Canadians' current well-being but also the prospects for sustaining that well-being into the future.

Despite pollution's widespread costs, Canadians are not adequately informed about them. Various studies have assessed the costs of specific pollutants (for example, additional hospital stays due to urban smog), but no single study covers them all. For many pollutants, no cost information is available at all. The result is an incomplete and complicated array of information that an average citizen would be hard-pressed to sort through.

With financial support from the Ivey Foundation, the International Institute for Sustainable Development reviewed and synthesized existing studies on the costs of pollution in an effort to improve the data available to Canadians. Our findings, which represent the most comprehensive assessment of pollution and its costs undertaken in Canada, are summarized here and outlined in detail in the main report. The methods used in compiling the report were scrutinized and approved by the Conference Board of Canada.

Our hope is that the report better equips Canadians, policy-makers and industry leaders to understand and make decisions about pollution. The challenge is to balance the trade-off between pollution's costs on the one hand and the benefits of the activities that lead to its creation on the other. The report shows that the costs involved are very significant. Allowing the costs to be obscured by poor data serves no one well.

Text Box ES1. What is pollution?

Pollution is any material or energy released to the environment—intentionally or accidentally—as a result of human activities. Examples include:

- Exhaust from the tailpipes of automobiles
- Sewage released to water bodies from treatment plants
- Crude oil spilled from a pipeline rupture
- Road salt running off roads and walkways into surface and groundwater
- Fertilizers running off farmland into surface and groundwater
- Waste heat released to water bodies from industrial cooling towers, and noise and light emitted from roads and buildings.

The Costs of Pollution—Overall findings

Pollution costs Canadian families, businesses and governments a startling amount every year.

We know from our review that these costs add up to **tens of billions of dollars at least**.

We cannot say what the full costs are because the data needed to measure the costs of many pollutants simply do not exist. We can say, though, that it is very likely that the pollutants that could not be measured would **add tens of billions more** to the annual cost.



The costs of pollution arise in three ways.¹

- First, pollution harms Canadians' health and well-being by lowering their enjoyment of life, making them sick and, in extreme cases, leading to premature death. These are the best studied and understood of pollution's costs. We estimate that they amounted to **at least \$39 billion in 2015, or about \$4,300 for a family of four. They were very likely much higher than this—perhaps twice as high—**because we were not able to measure the health and well-being impacts of many pollutants. In particular, we could not put a value on the costs of persistent organic pollutants. These include a number of chemicals that people are exposed to in everyday life: pesticides, plastic additives and flame retardants. Scientists believe these chemicals play a role in diseases like diabetes and obesity that affect thousands of Canadians, so the associated costs could be enormous.
- also costs families, businesses and governments money straight out of their pockets. When people get sick from pollution—perhaps with an asthma attack caused by smog—they need treatment. This can be costly. Medications, visits to the hospital, lost time at work: all these are a burden on households' incomes. Businesses and governments face costs too. Farmers lose money when their crops are damaged by air pollution. Extra money is needed to treat polluted water before it can be used to brew beer. Pollution dirties buildings and erodes infrastructure, adding to maintenance costs. Governments spend billions of dollars cleaning up sites contaminated by industrial pollutants from days past. These costs are not as well studied as those related to health and well-being, so we know less about them. **Those that could be measured amounted to \$3.3 billion in 2015.** Many important costs could not be measured, however, and **full impacts on income were likely in the tens of billions of dollars.** Put another way, **income costs likely reached upwards of 3 per cent of the combined net income of households, businesses and governments in 2015.**
- Finally, pollution reduces the value of the assets that make up Canadians' wealth. Cottage properties are less valuable when they sit on lakes that are thick with algae. Penthouse condos with views clouded by smog are worth less than those with clear vistas. Farmland falls in value when crops are harder to grow because of air pollution. Forests are less productive when damaged by acid rain. These wealth impacts are the least well understood of pollutions costs. **We simply do not know how much pollution costs us in terms of lost wealth** (though a few illustrative examples are laid out below). We do know that **there are trillions of dollars of assets at risk from pollution** and that it is very likely that these assets are significantly impacted by pollution today.



We Do Not Know Enough About the Costs of Pollution

More research is needed to fill the gaps in our understanding of pollutions' costs. The amounts of money involved are too big and the impacts on Canadians' lives too important to be left to guesswork. The only pollutant that is really well understood today is urban smog. Beyond that, we know far too little about the costs of pollution. In addition to persistent organic pollutants (noted above), we were unable to come up with costs for many other important pollutants. Though by no means the only missing pieces, filling the gaps below would be a good start on better understanding pollution and its costs in Canada.

¹ It must be noted that the costs in the three categories are not directly comparable and should not be added together. No overall "cost of pollution" is provided in this report for that reason.



- The costs of **greenhouse gas emissions** in terms of climate change and its impacts on the economy and the environment.
- The costs of **heavy metals** in terms of human health.
- The costs of **fertilizers and other nutrient runoff** in terms of freshwater “eutrophication” (or excessive growth of aquatic plants and algae).

Findings by Cost Category

Though we were not able to fully answer the question “What is the cost of pollution in Canada?” we nonetheless found solid evidence that pollution imposes significant costs on Canadians. Our findings are presented below, grouped by cost category:

- health and well-being costs
- lost income and increased expenses
- reduced asset values.²

The Health and Well-being Costs of Pollution

- **Criteria air pollutants:** Based on available data, the largest known direct health and well-being cost³ of pollution is that imposed on human health by so-called “common” air contaminants. Of these, fine particulate matter (PM_{2.5}) and ground-level ozone—the main elements of urban smog—are the most important. **Based on the most recent estimates of premature deaths and illness caused by PM_{2.5} and ground-level ozone in Canada, the direct welfare cost of these pollutants is estimated to have been \$36 billion in 2015, with a range of \$26 billion to \$47.5 billion.**
- **Pathogens:** Pathogens include bacteria, viruses and other microorganisms that cause disease directly as well as organisms that cause disease indirectly by the creation of toxins. In spite of their risk to human health, relatively little information was found regarding the economic cost of pathogens. **A tentative estimate of the cost of tap water-borne pathogens in 2015 is \$895 million based on Canadians’ spending on bottled water and water filtration devices. This cost would not include any health and well-being losses associated with exposure to other pathogens—such as the norovirus outbreak that plagued the British Columbia oyster farming industry in the winter of 2017—which are possibly somewhat larger.**
- **Pesticides and other persistent organic pollutants (POPs):** There is insufficient evidence at this time to estimate the health and well-being costs of pesticides and other POPs. Further research here should be considered a high priority, **as the cost of hormonal (endocrine) system disruption from pesticides and other POPs possibly runs to tens billions of dollars in Canada.**
- **Heavy metals:** There is insufficient evidence at this time to estimate the health and well-being impacts of heavy metals. The global cost of mercury emissions has been estimated to be on the order of \$20 billion to \$30 billion annually. What share of this cost might be imposed on Canadians cannot be determined given available data.
- **High-level nuclear wastes:** Evidence suggests that pollution from normally operating nuclear power plants likely imposes no health and well-being costs on Canadians today. Research on this topic is continuing,

² A specific approach has been adopted to discussing uncertainty in this report: “possibly” means < 50 per cent chance; “likely” means > 50 per cent chance; “somewhat larger” means < 100 per cent larger; “much larger” means > 100 per cent larger; “significant” means “at least on the order of tens of millions of dollars”; “very significant” means “at least on the order of billions of dollars.” These terms are intended to give the reader a rough sense of how much larger actual costs might be than those that can be measured based on available data and how likely it is that costs are this much larger. It should not be used to make quantitative estimates of missing values.

³ Health and well-being costs are termed “direct welfare” costs in the main report.



however, so it is not possible to conclude that the costs are zero. Of course, a major accident at a nuclear power plant could impose very substantial costs. Based on the cost of disasters in other countries, a major nuclear accident would impose costs on the order of hundreds of billions of dollars. The majority of these costs would likely result from health and well-being impacts on people displaced by the disaster rather than those who might die as a result of it.

- **Noise pollution:** Noise pollution is a part of daily life for nearly everyone who lives in an urban area. Transportation activities, especially road transport, are the biggest source, but construction and industrial activities also contribute. Studies around the world consistently show that noise pollution from transportation imposes health and well-being costs on the order of 0.1 to 0.5 per cent of GDP. **The annual costs to Canadians likely fall somewhere in the range of \$345 million to \$3 billion.**
- **Extreme weather:** Extreme weather events in the form of storms, floods, droughts, heat waves and cold snaps impose significant costs on Canadians from premature deaths, increased illness and disruption of daily life. Extreme weather events are increasing in frequency and severity as a result of climate change induced by emissions of greenhouse gases like carbon dioxide. Only the cost of premature deaths from climate change-related heat waves can be estimated today. These are **estimated to have been \$1.6 billion in 2015. The health and well-being costs of other extreme weather related to climate change are likely much larger** but further research will be needed before they can be estimated.
- **Lost recreational opportunities:** Pollution reduces Canadians' enjoyment of recreational opportunities. Freshwater lakes fouled by blue-green algae are unpleasant (and even dangerous) to swim, fish and boat in. Forests damaged by acid rain are less enjoyable as sites for hiking, camping and hunting. Air polluted by smog provides less beautiful vistas for tourists visiting iconic cultural or natural sites. **A tentative estimate of the cost of just the freshwater recreational opportunities lost in 2015 due to pollution is \$56 million.** A full assessment of the costs of pollution in terms of lost recreational opportunities in Canada is not possible given available data. **Total costs are possibly much larger.**
- **Reduced visibility:** Smog-filled air reduces visibility, which, in turn, reduces peoples' enjoyment of the world around them. Mountain views, whether enjoyed from homeowners' living rooms or the top of hiking trails, are less majestic through smoggy haze. Cityscapes are likewise less attractive when obscured by air pollution. **The estimated cost of the well-being losses from smog-reduced visibility in Canada in 2015 is \$438 million.**
- **Lost existence value:** For some people, the simple knowledge that the natural world is degraded by pollution is sufficient to impose welfare losses. Some feel that the environment and the species living in it have intrinsic value—that is, value beyond any use they might make of it—and that any damage humans do to it is wrong. The fact that damage is done, then, leaves these people less well off than they would be otherwise. **A tentative estimate of the cost of this loss due to pollution of freshwater in 2015 is \$87 million. Direct welfare losses associated with other forms of pollution are unknown but are likely much larger.** See Section 3.4.3 for further details for further details.

Lost Income and Increased Expenses Due to Pollution

- **Health care:** When people fall ill from pollution, it is not just their health and well-being (as considered above) that are affected. It also costs them money directly from their pockets. Salaries of health care workers, hospital operational costs, medical equipment and medications—all these must be paid for. These expenses are incurred by individuals and also by businesses and governments. **The estimated health care-related cost due to pollution in 2015 is at least \$2 billion.** This figure is conservative since it includes only the health care-related costs of PM_{2.5} and ground-level ozone. **The health costs of other pollutants, notably persistent organic pollutants (Text Box ES2), are likely much larger—possibly in the tens of billions of dollars.**



- Lost labour output:** Illness causes people to miss work, reducing their personal incomes and the incomes of the businesses they work for. Friends and family may also miss work to care for sick relatives. **The estimated value of lost labour output due to pollution in 2015 is at least \$800 million.** Again, this figure is conservative since it accounts only for lost labour output due to PM_{2.5} and ground-level ozone. The lost labour output due to other pollutants, notably persistent organic pollutants, is likely much larger—possibly in the tens of billions of dollars. Income Costs Due to Impacts on Produced Assets
- Acid rain and airborne particulate matter:** Acid rain and airborne particulate matter are the main contributors to building soiling and premature wearing of materials, both of which lead to increased maintenance costs for monuments, buildings and other infrastructure. The data available for Canada suggest their costs may be relatively low, though these data refer only to the cost of soiling of houses and only from some pollutants. Estimates for France and other European countries suggest much higher costs, though they are based on data that are often old and methodologically inconsistent. At this point, the costs of building soiling and premature wearing due to acid rain and particulate matter in Canada can only be said to be possibly significant.
- Road salt:** Bridges, buildings, vehicles and other produced assets are susceptible to deterioration due to road salt, which results in higher maintenance and replacement costs. About 7 million tonnes of road salt is applied annually in Canada. Based on a single American study from the early 1990s, an upper estimate on the cost of increased road maintenance due to salt use in 2015 in Canada is \$11 billion. The reliability of this estimate is very low and is not considered robust enough to report formally here; it is offered rather to give a sense of the order of magnitude of the possible costs, which are likely significant.
- Algal blooms:** Algal blooms on freshwater lakes and rivers polluted by phosphorous and nitrogen are a concern for the households, businesses and governments that rely on them as sources of raw water. Because algal blooms can produce toxins and impart unpleasant tastes and odours to water, higher levels of treatment are required if the water is to be used for human consumption. The blooms can also clog intake pipes, increasing operational costs. Evidence from one study of agricultural, industrial, recreational (golf courses) and municipal (drinking water) users of Lake Erie water suggests that the costs arising from severe blooms currently affecting Lake Erie are about \$4 million annually, all for drinking water treatment plants (other users have not reported increased costs). No basis for extrapolating this cost to other freshwater bodies in the country is available; the costs are possibly significant.

Text Box ES2. The possible costs of exposure to persistent organic pollutants

Persistent organic pollutants: The group of widely used chemicals known as persistent organic pollutants (POPs)—which includes a number of pesticides, fire retardants and plastic additives—is suspected to be a factor in a variety of common and costly illnesses, including obesity, neurological deficiencies and diabetes. Though the health care costs of exposure to most POPs cannot yet be accurately measured, scientists are moving closer to being able to value some of them. A European study found, for example, that the costs associated with POPs were likely no less than \$54 billion (and could be as great as \$264 billion) annually across the European Union (not including health and well-being costs). While these results are still too tentative to apply to Canada, they provide some evidence that POPs may impose health care costs of tens of billions of dollars in Canada. If the health and well-being costs of POPs were also taken into consideration, the costs of POPs could well turn out to be larger than any other pollutants.





- **Honeybee deaths:** Health Canada has linked the use of seeds coated with neonicotinoid pesticides with bee deaths, and the Province of Ontario has regulated use of these seeds following a 58 per cent loss of bee colonies over the 2013–14 winter. The income costs of bee colony losses have not been well researched, and the link with pesticide remains uncertain, so no estimate is possible here; the costs are possibly significant.
- **Acid rain:** Acid rain impacts aquatic and terrestrial environments in a variety of ways, including deaths of fish and other aquatic life and reduced tree growth. Despite considerable research into its ecological impacts, there has been little research into the economic costs of acid rain. The few estimates that have been made of these costs are based on data and methods that are out of date and/or inconclusive. As such, no estimate is possible here.
- **Reduced agricultural output:** Ground-level ozone reduces plant growth, which in turn reduces agricultural yields. **The estimated losses due to reduced agricultural yields are \$96 million in 2015.**
- **Ozone depletion:** Ozone depletion is the result of human emissions of “ozone-depleting substances” (ODS), that destroy ozone found in the upper atmosphere. Depletion of the ozone layer results in an increase in the amount of ultraviolet radiation reaching the earth’s surface. This has various human health and ecological impacts, though there remains a considerable degree of uncertainty regarding their exact nature. Given this uncertainty, it is not surprising that the economic costs of ozone depletion are not well understood. The few studies that exist, while offering useful insight into the possible magnitude of the costs, are not sufficient to draw firm conclusions. All that can be said here is that the annual costs of ozone depletion in Canada are likely significant and possibly very significant.
- **Spill cleanup costs:** When spills of oil and other materials occur, whether from pipelines, ships or other sources, considerable spending is devoted to limiting the spread of the material and removing it from the environment. Despite their potential ecological and economic impact, basic data on the number and volume of spills in Canada are incomplete, making it impossible to estimate of the cost of spills here. The potential magnitude of such costs is very significant, as large spills can be exceptionally costly to recover from. The total cost of the 1989 Exxon Valdez spill in Alaska is reported to have been US\$2.1 billion. The more recent (2010) blowout of the offshore Deepwater Horizon oil platform in the Gulf of Mexico has cost British Petroleum some US\$61 billion to date. Spills of this magnitude are, thankfully, infrequent. In Canada, the most serious spill in recent years was the 2014 derailment of a train carrying oil in the town of Lac Mégantic, Quebec. Fortunately, spills of this magnitude are infrequent and their high costs do not reflect the costs of spills on average. As noted, this cost cannot be calculated with available data.
- **Managing contaminated sites:** A large number of sites contaminated with residues from previous pollution emissions are found in Canada. These include former mines, industrial facilities, gas stations and military installations. Many have long been abandoned by their original owners. More than 22,000 sites fall under federal jurisdiction. The provinces/territories track the number of sites under their jurisdiction, though this information is harder to obtain. The number of sites falling under municipal and private responsibility is largely unknown. **It is estimated that average annual expenditures on sites under federal jurisdiction alone was \$283 million between 2005/06 and 2014/15.** The cost is likely to rise in coming years as a number of large sites move from relatively inexpensive assessment into the much costlier remediation stage. In addition to current spending, governments also acknowledge liabilities for the cost of future cleanup. The total liability for contaminated site cleanup recognized by the federal government was \$5.8 billion in 2015. An additional \$6.4 billion in liabilities was recognized by provincial governments. An unknown additional amount of liabilities is represented by sites under municipal and private responsibility.
- **Managing low-level nuclear legacy wastes:** Low-level nuclear legacy wastes include those from the early development of Canada’s nuclear industry. The largest concentration of these wastes is found in Port Hope, Ontario, which has been at the centre of the industry since its earliest days. Significant amounts of low-level wastes are also found at Atomic Energy of Canada Limited’s Chalk River, Ontario and Whiteshell, Manitoba



research facilities, with smaller amounts found at various other sites across the country. Responsibility for the long-term management of these wastes rests with Atomic Energy of Canada Limited through its subsidiary Canadian Nuclear Laboratories. **As of 2015, Atomic Energy of Canada Limited had recognized in its financial report plans for average annual spending on these wastes of \$121 million until the year 2164.**

Reduced asset values due to pollution

- **Freshwater algal blooms:** The losses in Lake Erie's value as a non-market (ecosystem) and market asset due to the algal blooms currently plaguing the lake (see above) are estimated to be \$3.8 billion and \$4 billion respectively. Unfortunately, no basis exists to extrapolate from these figures to losses in asset values for all degraded surface water bodies in Canada; such losses are likely much larger.
- **Forests and farmland:** No estimate of the loss of the value of forest and farmland assets was possible for this report, but an indication of what is at risk can be found in Statistics Canada's estimates of the value of Canada's commercial forests and farmland. In 2015, the agency estimated these to be worth, respectively, \$158 billion and \$376 billion. These are clearly very valuable assets, and they are both at risk from the impacts of pollution in the form of climate change, ozone depletion, acid rain and others.
- **Fossil fuels:** Even more valuable than Canada's farmland and timber are its deposits of fossil fuels. Here too there is a potential link to pollution, though less direct. As the world confronts climate change, the development of alternatives to fossil fuels in the form of solar, wind, hydro and other renewable forms of energy is rapidly increasing. One consequence of this may be that world oil prices, which have dropped significantly in recent years, will continue to face downward pressure. If so, high-cost oil producers, like Canada, may find it increasingly difficult to sell their oil at a profit. Declining oil prices have already driven the value of Canada's fossil fuel assets down by 95 per cent from their peak of \$1.1 trillion in 2008. If oil prices do not recover, this loss of wealth (about 13 per cent of Canada's total net worth) could be permanent.
- **Waterfront properties:** Waterfront property is more desirable when the quality of the nearby water bodies is good. The value of residential properties along Lake Erie's shoreline has been reduced by \$712 million as a result of algal blooms. There is insufficient evidence to extrapolate from this study to all lakefront property in Canada; however, the losses are likely significant.
- **Extreme weather:** The number and severity of extreme weather events are increasing as the climate changes and so too is the value of insurance payouts for damaged and destroyed property. Payouts for insured losses due to storms, floods and wildfires, including the 2016 Fort McMurray fire, have increased substantially since the 1980s, even after accounting for inflation and increases in the size of the insured asset base. Payouts have been above \$1 billion annually every year since 2009 with the exception only of 2015. Prior to 2009, they had been greater than \$1 billion only twice since 1983. Of course, severe weather is not solely attributable to climate change, but scientific understanding of the share of extreme weather events that can be attributed to the changing climate is improving. Nonetheless, climate change appears to be imposing significant and growing costs on Canada's produced asset base, and the losses are likely very significant.
- **Road salt:** Montreal's Champlain bridge is currently being replaced 50 years ahead of time in part because of excessive and unpredicted damage from road salt. The cost of this early replacement can be estimated by considering the interest that might have been earned by investing the funds required to replace the bridge in some other use for 50 years. Depending on the final cost to build the bridge, this loss of interest could amount to \$10 billion to \$17 billion. Overall, the losses due to impacts on all produced assets across the country are likely very significant, but they cannot be estimated based on existing data.



TABLE OF CONTENTS

1.0 INTRODUCTION AND SUMMARY OF FINDINGS.....	1
1.1 Summary of Findings	3
1.2 What Is Not Known About Pollution.....	4
2.0 POLLUTION AND ITS COSTS.....	6
2.1 What Is Pollution?	7
2.2 What Are the Costs of Pollution?.....	8
2.2.1 The Direct Welfare Costs of Pollution.....	10
2.2.2 Impacts of Pollution on Market Production and Consumption – Income costs.....	11
2.2.3 Impacts of Pollution on the Value of Produced and Natural Assets – Wealth costs.....	13
3.0 THE DIRECT WELFARE COSTS OF POLLUTION.....	14
3.1 Introduction.....	15
3.2 Summary of Findings – Direct welfare costs.....	15
3.2.1 Summary of Findings by Direct Welfare Cost.....	16
3.3 Human Health Costs of Pollution.....	20
3.3.1 The Health Impacts of Criteria Air Pollutants.....	20
3.3.2 The Health Impacts of Pathogens	28
3.3.3 Pesticides.....	35
3.3.4 Heavy Metals.....	36
3.3.5 High-Level Nuclear Wastes.....	38
3.3.6 Noise and Light Pollution	42
3.3.7 Extreme Weather.....	43
3.4 Non-Health Welfare Costs.....	45
3.4.1 Recreational Losses Due to Algal Blooms.....	45
3.4.2 Reduced Visibility.....	46
3.4.3 Lost Existence Value	47
4.0 THE INCOME COSTS OF POLLUTION.....	48
4.1 Introduction.....	49
4.2 Summary of Findings – Income costs of pollution	50
4.2.1 Summary of Findings by Income Cost.....	50
4.3 Income Costs of Human Health Impacts.....	55
4.3.1 Lost Labour Output – PM2.5 and ground-level ozone	55
4.3.2 Health Care Costs – PM2.5 and ground-level ozone.....	55
4.3.3 Lost Labour Output and Health Care Costs – Persistent organic pollutants.....	56



4.4	Income Costs of Impacts on Produced Assets.....	58
4.4.1	Excess Soiling and Premature Wearing.....	58
4.5	Income Costs of Impacts on Natural Assets.....	62
4.5.1	Honeybee Decline and Pesticides.....	62
4.5.2	Acid Rain.....	64
4.5.3	Reduced Agricultural Output.....	69
4.5.4	Ozone Depletion – Costs of increased UV-B radiation	70
4.6	Income Costs Due to the Need to Manage Pollution.....	73
4.6.1	Spill Cleanup Costs	73
4.6.2	Managing Contaminated Sites.....	74
4.6.3	Low- and Intermediate-Level Nuclear Wastes	79
4.6.4	Supplementary Information – Costs of efforts to minimize the quantity of pollution that enters the environment	81
5.0	THE WEALTH COSTS OF POLLUTION.....	82
5.1	Introduction.....	83
5.2	Summary of Findings	84
5.2.1	Summary of Findings by Wealth Cost.....	84
5.3	Wealth Costs of Pollution’s Impacts on Natural Assets	87
5.3.1	The Impacts of Eutrophication on Freshwater Lakes.....	87
5.3.2	Loss in the Value of Other Natural Assets – What could be at stake	89
5.4	Wealth Costs of Impacts on Produced Assets.....	91
5.4.1	Impacts of Water Pollution on Housing Values.....	91
5.4.2	Impacts of Extreme Weather on Produced Assets.....	92
5.4.3	Other Impacts on Produced Assets	93
	REFERENCES.....	94
	APPENDIX A. RESEARCH METHODOLOGY	114
	APPENDIX B. DETAILS OF KEY STUDIES AND MODELS	119



LIST OF FIGURES

Figure 1. Pollution pathways and costs.....	9
Figure 2. Steps in the impact pathway approach.....	20
Figure 3. Trends in criteria air contaminant emissions in Canada, 1990–2014.....	21
Figure 4. Ambient concentrations of ground-level ozone by region, 2000–2014.....	22
Figure 5. Ambient concentrations of PM _{2.5} , by region, 2000–2014.....	22
Figure 6. Peak 8-hour ozone concentrations, by region, 2000–2014.....	23
Figure 7. Air Pollution in China.....	24
Figure 8. Municipal Wastewater Treatment, by Level, 1983–2009.....	29
Figure 9. Risk to water from agriculture in Canada, 1981–2011.....	29
Figure 10. Shellfish Growing Area Quality, 2006–2010.....	31
Figure 11. Drinking Water Advisories in Canada, 2010–2015.....	31
Figure 12. Risk Ratings for INAC-Funded First Nations Water Systems.....	33
Figure 13. Nuclear waste storage sites.....	38
Figure 14. The costs of transportation noise in various countries.....	43
Figure 15. Losses of U.S. honeybee colonies, 2006/07–2015/16.....	63
Figure 16. Wet sulphate deposition (kg SO ₄ ²⁻ /hectare/year), 2012.....	65
Figure 17. Sugar maple health status, North American Maple Project, 1988–2007.....	66
Figure 18. Index of global use of ozone-depleting substances, 1986–2013.....	70
Figure 19. Antarctic ozone layer hole area, recent years and 2006–2015 trends.....	70
Figure 20. Catastrophic Insured Losses from Natural Disasters, Canada, 1983–2016.....	92
Figure 21. Nominal, inflation-adjusted and normalized trends in global insured losses due to natural disasters, 1980–2015.....	93
Figure 22. Nominal and normalized insured losses due to thunderstorms in North America, 1980–2015.....	93
Figure A1. Google Advanced Search Terms.....	115
Figure A2. Decision tree for systematic review methodology.....	117



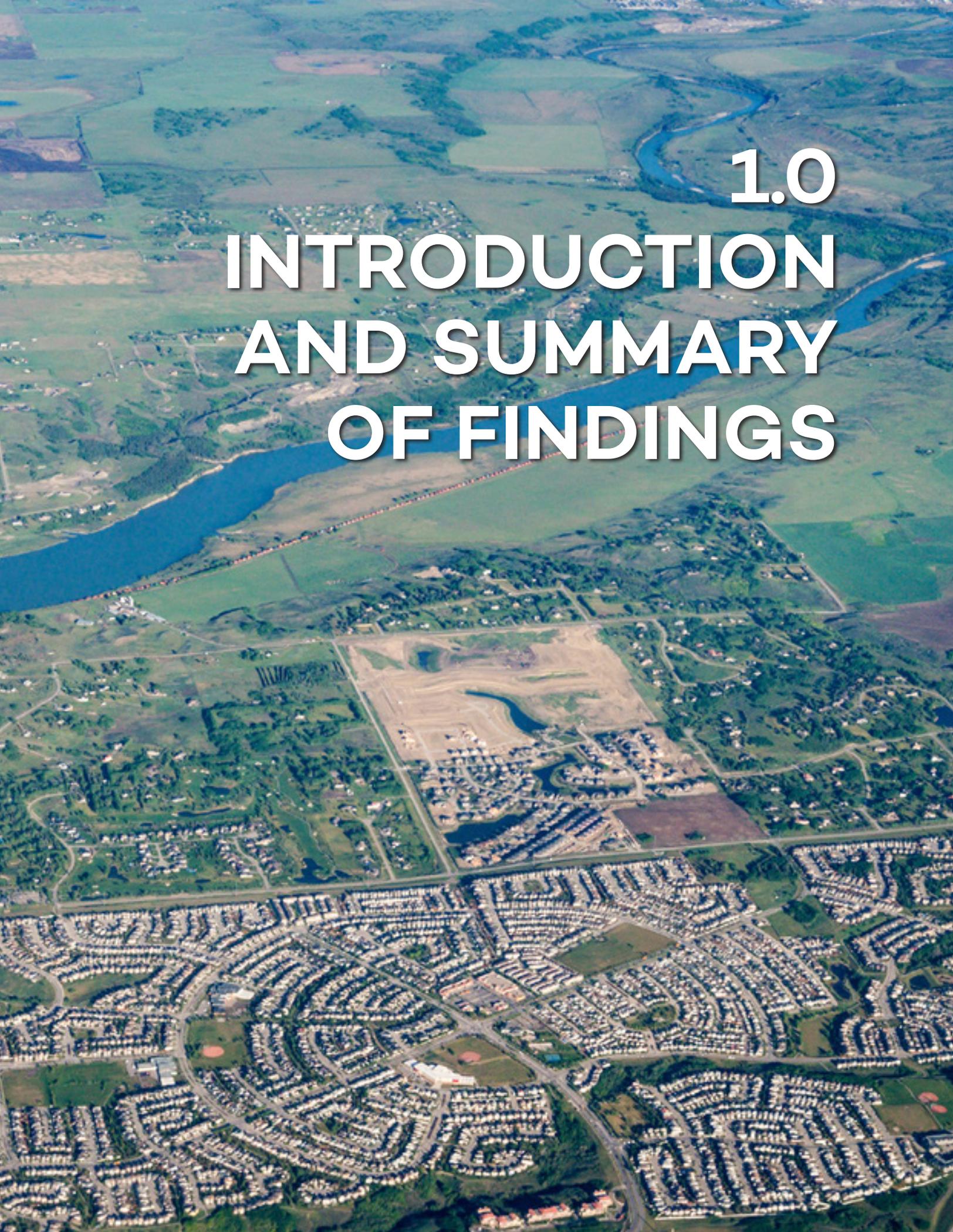
LIST OF TABLES

Table 1. Summary of 2015 direct welfare costs of pollution in Canada.....	19
Table 2. Potential cost of a large nuclear accident.....	40
Table 3. Summary of 2015 income costs of pollution.....	54
Table 4. Impacts of acid rain on aquatic animals.....	67
Table 5. Recreational fishing expenditures by province, 1975–2010 (thousand chained 2015 CAD).....	69
Table 6. Federal contaminated site under assessment/remediation and associated spending, 1995/96–2014/15 (CAD).....	75
Table 7. Reported contaminated site liabilities, provinces and territories - Most recent year.....	77
Table 8. Supplementary information - Pollution prevention expenditures, 2015.....	81
Table 9. Summary of 2015 wealth costs of pollution.....	86
Table 10. Costs of Lake Erie Algal blooms, 2015.....	89
Table A1. Overview of Literature Collection.....	116
Table A2. Overview of Screening Criteria.....	117
Table A3. Organizing classification for the chosen literature.....	119
Table B1. Health effects included in OECD (2016).....	122
Table B2. Monetized and non-monetized health impacts in ICAP.....	125
Table B3. Monetized and non-monetized health effects in AQBAT.....	127
Table B4. Crops included in VOICCE.....	128



Acronyms

AAFC	Agriculture and Agri-Food Canada	INES	International Nuclear and Radiological Event Scale
AECL	Atomic Energy of Canada Limited	IPCC	Intergovernmental Panel on Climate Change
AOAG	Alberta Office of the Auditor General	LLRW	Low-level radioactive waste
AQBAT	Air Quality Benefits Assessment Tool	MFSP	Mine Financial Security Program
AQVM	Air Quality Valuation Model	NAPS	National Air Pollution Surveillance
BP	British Petroleum	NASA	National Aeronautics and Space Administration
CCD	Colony collapse disorder	NASS	National Agricultural Statistics Service
CIHI	Canadian Institute for Health Information	NGO	Non-governmental organizations
CMA	Canadian Medical Association	NLLP	Nuclear Legacy Liabilities Program
CNL	Canadian Nuclear Laboratories	NPRI	National Pollutant Release Inventory
DEFRA	Department of Environment, Food and Rural Affairs	ODS	Ozone-depleting substances
DIAND	Department of Indian Affairs and Northern Development	OECD	Organisation for Economic Co-operation and Development
EDC	Endocrine-disrupting compounds	OHIP	Ontario Health Insurance Plan
EEA	European Energy Agency	OMA	Ontario Medical Association
EGS	Ecosystem goods and services	PBO	Parliamentary Budget Office
EPA	Environmental Protection Agency	PD	Parkinson's disease
FAR	Fraction of attributable risk	PHAC	Public Health Agency of Canada
FCSAP	Federal Contaminated Sites Action Plan	PMRA	Pest Management Regulatory Agency
GAINS	Gas and Air Pollution Interactions and Synergies	PPP	Purchasing power parity
GBD	Global Burden of Disease	SCSIE	Soiling Cleaning Savings Impact Estimator
GDP	Gross domestic product	SHS	Survey of household spending
IAEA	International Atomic Energy Agency	UNDP	United Nations Development Programme
IBC	Insurance Bureau of Canada	UNEP	United Nations Environment Program
ICAP	Illness cost of air pollution	USDA	United States Department of Agriculture
IER	Integrated exposure-response	VIEW	Visibility Impacts Estimator of Welfare
IHME	Institute of Health Metrics	VOC	Volatile organic compounds
IISD	International Institute for Sustainable Development	VOICCE	Value of Ozone Impacts on Canadian Crops Estimator
ILRW	Intermediate-level radioactive waste	VSL	Value of a statistical life
INAC	Indigenous and Northern Affairs Canada	WHO	World Health Organization
		WTP	Willingness to pay

An aerial photograph showing a large residential development in the foreground, characterized by dense rows of houses and winding streets. In the middle ground, there is a golf course with a prominent sand trap and a small pond. A wide river flows through the background, curving to the right. The surrounding landscape is a mix of green fields and some industrial or undeveloped areas.

1.0

INTRODUCTION AND SUMMARY OF FINDINGS



1.0 INTRODUCTION AND SUMMARY OF FINDINGS

Canadians understand that a clean environment is vital to their well-being. They realize that clean water, air and land contribute to better health, greater enjoyment of life, more productive communities and a stronger economy. The reasons for this are many. Fresh air is healthier and more enjoyable than smoggy air. Clean rivers and lakes offer pleasing places to swim and boat without having to worry about what pollutants might be in the water. Healthy forests and wetlands provide opportunities to experience nature up close, not to mention sustainable sources of timber and free water-filtration services. Jobs are created when tourists visit Canada to enjoy the country's unspoiled natural beauty. All of this contributes to what makes life in Canada exceptional. Put simply, each of us, our families, our society and our economy are stronger when we enjoy the benefits of a clean environment.

In contrast, when the environment is contaminated by pollution, a wide variety of costs are imposed on individuals, families, society and the economy. Pollution harms human health, damages forests and crops and degrades the quality of land and water—to name just a few impacts. The result is higher costs for many things: medical care, raw materials, food and public services. As such, pollution threatens not only Canadians' current well-being but also the prospects for sustaining that well-being into the future.

Despite pollution's many costs, Canadians are not adequately informed about them. While various studies have assessed the costs of specific pollutants (for example, additional hospital stays due to urban smog), no single study covers them all. For many pollutants, no cost information is available at all. The result is an incomplete and complicated array of information that an average citizen would be hard-pressed to sort through.

“ Despite pollution's many costs, Canadians are not adequately informed about them. ”

The absence of complete information on the costs of pollution in Canada (or anywhere for that matter, as this is not a uniquely Canadian problem) means that Canadians are not well-equipped to make decisions about the related issues. For those concerned about pollution, poor information makes it harder to draw the case for policy measures to control it. Those not aware of (or not concerned about) pollution's costs are denied information that might prompt them to pay more attention.

The purpose of this report is to address these shortcomings. With financial support from the Ivey Foundation, the International Institute for Sustainable Development (IISD) reviewed a wide range of existing studies on the costs of pollution. The findings of this review, which represents the most comprehensive assessment of pollution and its costs undertaken in Canada, are summarized in this report.

The methodology used in the review is explained in detail in Appendix A. Briefly, it involved a systematic review of published studies from universities, government agencies, international organizations, think-tanks, research organizations, civil society organizations and other sources deemed credible. The review focused on Canadian studies but made use of results from other countries where relevant. It covered, to the extent possible, all kinds of pollutants and all kinds of costs. Only *current* costs (that is, costs imposed on individuals, families, businesses and governments today) were considered. Future costs of pollution—for example, the costs to future generations of climate change caused by emissions of greenhouse gases—were outside the scope of the review.



The remainder of this report is structured as follows.⁴

- The findings of the review are summarized in the remainder of this chapter. Readers interested in just the high-level conclusions may focus their attention on this chapter alone.
- Chapter 2 discusses the definitions of pollution and costs that have been used in the study. Readers not familiar with these concepts would benefit from reading this chapter before delving into the rest of the report.
- Chapter 3 presents the detailed findings of the review regarding the costs of pollution in terms of reductions in Canadians' health and well-being (**direct welfare costs**).
- Chapter 4 presents the findings regarding lost revenues and increased costs for individuals, households, businesses and governments (**income costs**).
- Chapter 5 presents the findings regarding the lost value of assets (such as houses, infrastructure and freshwater lakes) due to pollution (**wealth costs**).
- Finally, two appendices provide additional technical details regarding the methodology used in the study and some of the more common approaches to valuing the cost of pollution used by researchers.

Since each of the cost categories considered in the review (direct welfare costs, income costs and wealth costs)⁵ is distinct, no “total cost of pollution” is offered in the report. Rather, costs are estimated for each category and presented separately.⁶ As will be seen, the costs in each category are very significant, even though many pollutants could not be assessed based on existing studies. **The costs presented should be taken, therefore, as a lower bound on the total costs of pollution in Canada. The actual costs are likely to be much higher.**

The fact that the findings here are incomplete—though the most complete ever compiled for Canada—provides an opportunity to highlight areas where more research is required to assess the costs of pollution. This is done at the end of this introductory chapter.

1.1 Summary of Findings⁷

Based on the review undertaken for this report, the costs of pollution in Canada can be said with a high degree of certainty to be very significant.

It is likely that the **direct welfare costs** of pollution alone amount to tens of billions of dollars annually. **Based on a thorough review of available data, the best estimate of the direct welfare cost of those impacts that can be valued today is \$39 billion⁸. The full direct welfare cost of pollution is likely to have been much larger than this, possibly twice as large, as a number of important impacts cannot be valued today.**

Since welfare costs are all borne by individuals and families, they can be put into more familiar terms by comparing them with household earnings. **Taking \$39 billion as the most likely minimal estimate of the direct welfare costs of pollution, the average Canadian bore costs of at least \$1,100 in 2015. A family of four would**

⁴ Note that the report has been written so that each of the substantive chapters (Chapters 3, 4 and 5) can be read as stand-alone sections. For this reason, those reading the full report will notice a certain amount of repetition of key points from chapter to chapter.

⁵ These cost categories are defined in detail in Chapter 2.

⁶ Just as an individual would not add her annual income to the value of her house (the former representing a flow of money over a period and the latter a store of money at a point in time) to understand her financial situation but, instead, would consider each source of economic well-being separately, so too should the costs of pollution be considered separately. Doing otherwise would amount to “adding apples and oranges.”

⁷ A specific nomenclature has been adopted to discuss uncertainty in this report. The nomenclature is not based on a quantitative assessment of uncertainty but rather on the authors' judgement derived from the review of published studies. The terms in the nomenclature have the following meanings: “**possibly**” (< 50 per cent chance); “**likely**” (> 50 per cent chance); “**somewhat larger**” (< 100 per cent larger); “**much larger**” (> 100 per cent larger); “**significant**” (at least on the order of tens of millions of dollars); “**very significant**” (at least on the order of billions of dollars).

⁸ All monetary figures in 2015 Canadian dollars unless otherwise indicated.



have borne costs of no less than \$4,300, or 3 per cent of household income.⁹ The *total* direct welfare costs of pollution per family was *likely much larger than this*.

As for **income** costs, **those that could be measured amounted to \$3.3 billion in 2015**. Many important costs could not be measured, however, and **full income costs were likely to have been much larger than this—likely in the tens of billions of dollars**, making them possibly as large as direct welfare costs. These costs are borne jointly by individuals, families, businesses and governments, **possibly reaching as much as 3 per cent of their combined income¹⁰ in 2015**.

Measuring the **wealth** costs of pollution proved to be the most challenging part of the review and only a few illustrative estimates are possible. One of them concerns the algal blooms that have affected Lake Erie in recent years. These were found to reduce the lake's value as an ecosystem by \$3.8 billion and its value as a source of market goods and services by a further \$4 billion. Houses along the lake's shoreline, whose values are contingent on the quality of the lake, were found to have lost more than \$0.7 billion in value due to the blooms. Many other freshwater lakes in Canada are similarly affected by algal blooms, meaning that these figures likely underestimate the actual costs of the blooms significantly. **Overall, Canada has trillions of dollars of produced and natural assets at risk from pollution. Though no estimate of the current loss in value of these assets due to pollution was possible, it can be said that this loss is likely to be very significant.**

Much more is said about the costs of pollution in the chapters that follow. Readers wishing just an overview of the costs in each of the three categories are invited to review the summary sections found at the beginning of Chapters 3, 4 and 5. Those interested in the details will find them following the summaries in each chapter.

1.2 What Is Not Known About Pollution

Despite a thorough review of relevant scientific and economic studies, there remain many gaps preventing a full estimate of the cost of pollution in Canada. Only air pollution has been thoroughly studied, and then only for certain pollutants.¹¹ Beyond air pollution, surprisingly little is known about pollution's costs, in spite of the wide range of pollutants Canadians are exposed to and the numerous ways in which their welfare is impacted. Some of the more important gaps identified through this review are listed below. Though they are by no means the only gaps, filling these four would be a good start on better understanding pollution and its costs in Canada and beyond.

Climate change: First on the list of gaps is the cost of climate change induced by human emissions of greenhouse gas pollution. Climate change is already affecting individual welfare (e.g., illness and premature deaths due to heat waves) as well as incomes (e.g., lost agricultural production due to drought and heat) and asset values (e.g., destruction of infrastructure due to extreme weather events). Scientific capacity to attribute specific impacts to climate change is improving, but uncertainty remains; only heat waves can be attributed to climate change with sufficient certainty to permit valuing their costs today. As climate change takes further hold, its impacts and the associated costs are likely to grow. Gaining a better understanding of them is key to understanding the full costs of pollution.



⁹ As measured by primary household income from Statistics Canada.

¹⁰ As measured by net national income from Statistics Canada.

¹¹ Specifically, fine particulate matter and ground-level ozone.



Persistent organic pollutants: Persistent organic pollutants (POPs) are a group of compounds that include pesticides, plastic additives, fire retardants and a variety of other chemicals common in everyday life. They are all very long-lived, meaning that they tend to accumulate in the environment over time. Scientific understanding of the relationship between POPs and human health is still evolving, but there is growing evidence they are linked with a number of widespread diseases. These include diabetes, obesity, infertility, neurological deficits and some forms of cancer—diseases that affect thousands of Canadians. Though it is not yet clear what share of the incidence of these diseases is due to exposure to POPs, scientists increasingly believe that POPs play a major role in these diseases. Since these diseases are common—and their consequences significant—the costs associated with them are large. If even a relatively small fraction of their incidence is attributable to POPs, POPs could be among the costliest of pollutants. Given this, more study is called for to both further the understanding of the links between POPs and disease and to improve the estimates of the associated costs.



Heavy metals: Both the scientific understanding of the impacts of heavy metals on humans and the environment and, especially, the understanding of the costs of these impacts require improvement. No estimate of their cost at all was possible for this study.

Freshwater eutrophication: Pollution from surface runoff, especially from farmland, is an increasing concern for the quality of lakes and rivers. Excess nutrients entering water bodies from fertilizers, sewage and urban runoff encourage the growth of aquatic plants far beyond their natural levels, a process known as eutrophication. These plants choke out other aquatic life and severely degrade water quality. Some of them (blue-green algae) are even toxic to humans and animals. The costs of eutrophication have been studied for only a few lakes, and there is insufficient evidence today to put a value on the problem at the national level, despite an increasing number of affected water bodies.



2.0 POLLUTION AND ITS COSTS



2.0 POLLUTION AND ITS COSTS

2.1 What Is Pollution?

Pollution is defined in this report as any material or energy released to the environment—intentionally or accidentally—as a result of human activities. For material or energy to be considered pollution, it must have at some point been under human control (for example, in a manufacturing plant or a household) and then have fallen out of human control because it was either intentionally or accidentally released into the environment. Examples of pollution include:

- Exhaust gases emitted to the atmosphere from the tailpipes of automobiles
- Biological wastes released to water bodies from sewage treatment plants
- Crude oil spilled as a result of a pipeline rupture
- Road salt running off roads and walkways into surface and groundwater
- Fertilizers running off farmland into surface and groundwater
- Waste heat released to water bodies from industrial cooling towers, and
- Noise and light emitted from roads and buildings.



All of the above fit the definition of pollution because they originate from materials/energy that were at one point used in human activities and then intentionally or unintentionally (in the case of the pipeline rupture) allowed to enter the environment.

Pollution also includes secondary or by-product materials that are the result of transformations of the materials originally released to the environment; for example, ground-level ozone, a major constituent of urban smog, is not released directly by human activity but results from the transformations of other pollutants that are.

Potentially harmful materials or energy found in products that remain under active use or storage in the economy are not considered pollution; for example, a household thermometer containing mercury is not considered pollution so long as the thermometer is being used by the household. Such materials may become pollution once the products are discarded however. The mercury in a broken thermometer disposed of down a sink drain will likely become pollution, for example.

Waste materials that are no longer being used but are kept under active management in secure storage facilities—such as municipal solid wastes disposed of in managed landfill sites and nuclear wastes housed in specialized containment facilities—are also not considered pollution. Any materials that leak out of such storage sites—such as methane that escapes from landfill sites into the atmosphere—is, however, considered pollution. Materials discarded into sites that are not actively managed are considered pollution from the moment of disposal; for example, solid waste disposed of in an open-pit landfill with no human management is pollution.

Pollution can be the result of current or past human activities. Automobile exhaust is pollution due to a current activity. Contamination found in soil around former industrial sites is pollution due to a past activity.



2.2 What Are the Costs of Pollution?

Figure 1 portrays the links between the generation of pollution, the efforts to manage it, the amount that ultimately impacts “receptors” (human beings, produced assets and natural assets) and the costs imposed directly on human welfare and on the economy by those impacts.

For the purposes of this report, the costs of pollution are classified using an economic rather than a biophysical framework; **in other words, they are classified according to the consequences of the costs in economic terms rather than by who or what bears them.** This perspective is chosen because it places the costs in a framework that facilitates their comparison with other economic costs and benefits. Within this economic framework, the costs of pollution fall into three distinct categories.

The first is the set of costs related to the **direct impacts of pollution on human welfare.** Direct welfare impacts are those related to the burden that pollution imposes on health and other aspects of human well-being that are not associated with economic activities. They include suffering due to premature death (mortality) and increased illness (morbidity) caused by pollution, as well as the costs associated with other non-health losses of life satisfaction; lost enjoyment of recreational opportunities due to water and air pollution, for example.

The second category is costs related to the **impact of pollution on the production and consumption of market goods and services.** These costs come in the form of either reduced income or increased expenditures (or both) for individuals, businesses and governments. For example, lower crop productivity in the presence of ground-level ozone impacts the value of income earned by farmers. It might also increase their costs if they require additional fertilizers or other inputs to maintain harvests. Similarly, the increased costs to individuals who fall ill from pollution and must buy medication as a result are an example of an impact on individuals and families.

Production and consumption impacts are related by the fact that they all affect national income, either the amount of income generated by the economy or the way in which that income is spent to meet individuals’ needs and wants. For this reason, they are referred to in this report as the income costs of pollution.

The final cost category is the **impact of pollution on the value of produced and natural capital assets.** Produced capital includes assets like buildings, bridges, homes and other built assets. Natural capital includes waterbodies, agricultural land, forests, the atmosphere and other ecosystems. Produced and natural assets have value because they are integral to producing the goods and services that people enjoy—both market goods and services, like food, clothing and transportation, and non-market goods and services, like wild food, clean air, flood protection and wilderness experiences. Pollution impacts the value of assets either by reducing their capacity to produce useful goods and services, as in the case of lakes and forests degraded by acid rain, or, more extremely, through their outright destruction, as in the case of buildings destroyed by extreme weather events induced by climate change. These impacts are all related by the fact that they affect the wealth of the nation.¹² For this reason, they are referred to in this report as the wealth costs of pollution.

It must be noted that the costs in the three categories are not directly comparable and should not be added together. No overall “cost of pollution” is provided in this report for that reason.

Direct welfare costs are both similar to and distinct from income-related and wealth-related costs. They are similar in the sense that all costs ultimately affect welfare, including income- and wealth-related costs. Individuals are less well off (that is, their welfare is reduced) with less income and wealth, just as they are less well off if they are sick or die prematurely.

¹² Wealth, or the value of all the nation’s assets, is basis on which national income is produced. Wealth and income are closely related. Wealth can be thought of like savings in a bank, whereas income is the value of the interest that is earned off those savings each year. At the national level, wealth is the value of all assets and income is the money that people and businesses earn by using those assets.

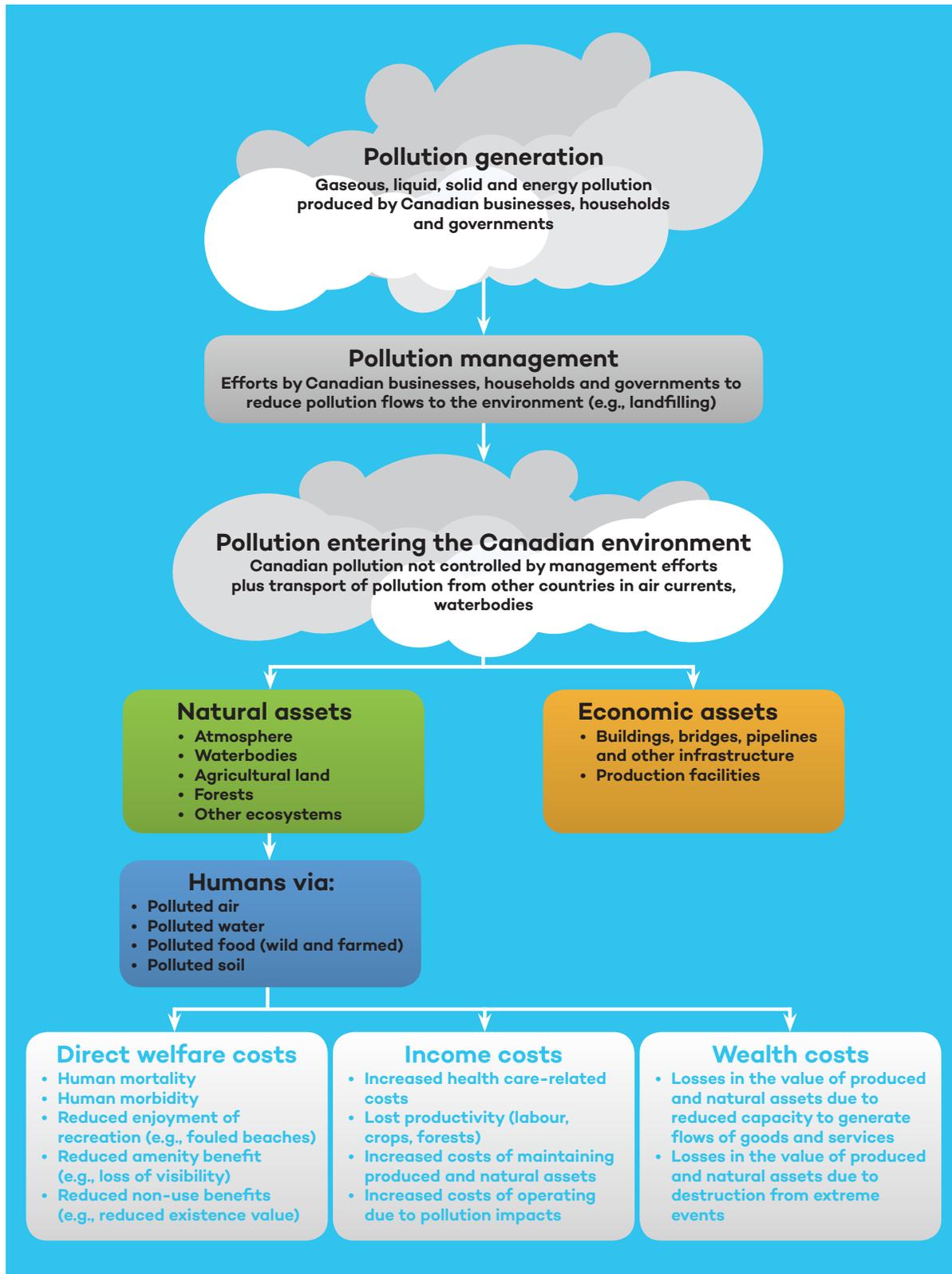


Figure 1. Pollution pathways and costs



What distinguishes direct welfare costs from income- and wealth-related costs is that direct welfare costs need not involve the market. Pollution causes mortality, morbidity and other loss of welfare all without mediation by the market. That is why these impacts are termed “direct” welfare costs. Income- and wealth-related costs also impact welfare but, in contrast, do so indirectly. These costs are felt first in reductions in market income and wealth. These changes, other things being equal, then lead to welfare declines.

One consequence of direct welfare costs not requiring market mediation is that there are usually no market prices available to value them.¹³ As a result, their values are generally not directly comparable with income- and wealth-related costs, which are always valued using market prices.¹⁴ The absence of market prices for direct welfare costs forces economists to adopt alternative approaches to their valuation. These approaches often involve asking individuals to state directly how they value different costs and benefits. The nature of these “stated preference” valuation methods is such that they often produce values that are incommensurable with market valuations.¹⁵

It should be noted that even though they both rely on market prices, income- and wealth-related costs are also not directly comparable with each other, since they reflect different economic concepts. As noted, the costs imposed on production and consumption affect national income, which is a flow over a given period. Losses in asset values, in contrast, affect national wealth, which is a stock at a point in time. Therefore, they should be considered separately, in the same way that an individual would not add her annual income to the value of her house in assessing financial position but would consider each figure on its own.

Each of the cost categories is now discussed in more detail.

2.2.1 The Direct Welfare Costs of Pollution

Humans are exposed to pollution via various channels: the air they breathe, the water they drink, the food they eat and the land they live on. The most serious impacts of this exposure on human welfare are those associated with premature death (mortality) and the pain and suffering associated with additional illness (morbidity).

The most frequently studied mortality and morbidity impacts are those associated with air pollution. Exposure to air pollution—especially fine particulate matter and ground-level ozone—is known to result in increased respiratory, cardiac and other illnesses in certain individuals. In some instances, especially among the very young



“ Humans are exposed to pollution via various channels: the air they breathe, the water they drink, the food they eat and the land they live on. ”

¹³ This is not always true. Some direct welfare costs can be valued using prices observed in the market. The loss of a recreational experience can be valued, for example, using information about the market expenditures, such as travel, undertaken in order to enjoy them.

¹⁴ An exception is losses in the value of natural assets that provide non-market ecological goods and services. These are not mediated by the market and are sometimes valued using stated preference methods.

¹⁵ The distinction between market (or “revealed preference”) and stated preference valuations is in their treatment of what economists call “consumer surplus.” Consumer surplus is the amount that some consumers are willing to pay for a good or service over and above what the market forces them to pay. Market prices, because they reflect the willingness to pay of the marginal consumer, exclude consumer surplus. As a result, they understate the welfare benefits of consumption. Stated preference methods, on the other hand, usually result in valuations that include consumer surplus and, therefore, more closely reflect true welfare values.



and the elderly, this exposure can contribute to premature death. Though other forms of pollution can have equally devastating effects, there has been much less study of mortality/morbidity impacts beyond air pollution.

Mortality, for obvious reasons, imposes greater costs than additional morbidity. The loss of a human life, especially when premature and preventable, imposes immeasurable costs on both the victim and those around him/her.

Though the cost of the loss of a human life is immeasurable in any actual instance, it is accepted practice in a variety of contexts to value the loss of a “statistical” life in monetary terms.¹⁶ Economists have devised means of determining this value by considering the willingness to pay (WTP) of individuals to avoid small changes in the risk of dying. The resulting values do not represent the value of any real individual’s life (which, as noted, is immeasurable) but rather an estimate of the collective willingness to pay to avoid the death of a representative individual. In most developed countries, this “value of a statistical life” (VSL) is found to be on the order of several million dollars.

Similarly, economists can estimate the monetary value of pain and suffering due to illness by assessing WTP to avoid an increased risk of such pain and suffering.

These statistical values of mortality and morbidity can be used to estimate the welfare cost of pollution by assessing the additional deaths and disease associated with a given level of pollution and multiplying these by the value of a single death or additional case of disease.

In addition to its impacts on mortality and morbidity, pollution can directly affect welfare by reducing the capacity of natural assets to yield welfare-enhancing benefits for humans. For example, polluted lakes and rivers are less enjoyable for swimming, boating, fishing and bird watching than pristine ones. Smoggy air reduces the enjoyment of scenic views. For some people, welfare losses are associated simply with knowledge of the evidence of pollution’s impacts. For example, just knowing a natural icon like Lake Erie is substantially degraded by pollution (as is currently the case due to phosphorus pollution) can induce welfare losses in people who have never visited it and never will.

2.2.2 Impacts of Pollution on Market Production and Consumption – Income costs

The impacts of pollution on market production and consumption—its **income costs**—fall into several categories:

- Lost production and/or increased costs due to impacts on human health
- Lost production and/or increased costs due to impacts on produced assets
- Lost production and increased costs due to impacts on natural assets, and
- Increased costs due to the need to limit the amount of pollution that reaches humans and produced/natural assets.

As noted above, these costs are related to one another by the fact that they all affect national income in one way or another.

2.2.2.1 Income Costs Due to Human Health Impacts

In addition to their direct welfare costs, which were discussed above, the human health impacts of pollution affect production and consumption. Humans who die or fall ill from exposure to pollution are unable to contribute to the economy for as long or as fully as those who do not. Economic production is therefore lower than it would be in the absence of pollution. In addition, there are expenses associated with the medication and medical services required to treat those who are ill. These costs may be imposed on the sick individual (costs of uninsured medication and treatments), on the government (public health care) and on businesses (coverage of insured expenses).

¹⁶ For example, damages in legal proceedings that involve premature death are sometimes assessed based on the estimated value of an individual life.



2.2.2.2 Income Costs Due to Impacts on Produced Assets

Just as humans are exposed to pollution through various pathways, produced assets are also impacted by pollutants that travel through the air, water and soil.

The primary produced assets at risk are buildings, factories, homes, bridges and other built infrastructure—including structures of cultural significance such as monuments and historic buildings. A highly visible result of their exposure to pollution is excess soiling, which results from pollution particles carried by air and precipitation that adhere to buildings and other structures. Such soiling requires surfaces such as windows and exterior walls to be cleaned more often than otherwise. Another less visible but potentially more serious impact is premature wearing, which occurs when pollutants cause materials to break down sooner than they would otherwise (for example, peeling of painted surfaces, corrosion of metals and weakening of plastics and stone). Premature wearing leads to additional costs for maintenance (such as more frequent painting) and reduces the useful lifespan of structures through weakening of their constituent materials.



“ Assets are degraded by pollution when it reduces their capacity to function normally. ”

In addition to increased costs for the maintenance of produced assets, pollution can impose increased costs for their operation. For example, drinking water treatment plants may be impacted by pollution because the processes rely on require raw input water of a certain quality. If raw water quality declines due to increased pollution, the cost of producing potable water may increase.

2.2.2.3 Income Costs Due to Impacts on Natural Assets

The natural assets impacted by pollution are the water bodies, forests, farmland, atmosphere, soil and other parts of the environment into which pollution is released directly or eventually settles after being transported by air or water currents.

The cost of this exposure comes partly in reductions of natural assets’ capacities to produce goods and services that are valued by humans.¹⁷ For example, forests impacted by acid rain are less productive as sources of timber for harvesting and offer less attractive recreation and viewing opportunities. Similarly, agricultural land exposed to ground-level ozone has a reduced capacity to produce crops. Fish, wildlife and plants that ingest pollutants can pass them on to humans that consume them, making them less valuable as sources as food. Excess greenhouse gases in the atmosphere reduces its ability to regulate the earth’s climate and maintain weather patterns within the range to which society is adapted. This, in turn, can lead to reductions in the production of crops, timber, fish and a range of ecological services.

The income costs of natural assets’ exposure to pollution also come in terms of increased costs to businesses that rely on them—for example, increased fertilizer costs to farmers to boost crop production or increased harvest effort on the part of forestry companies to obtain a given volume of timber.

¹⁷ In addition, there are obvious impacts beyond those of concern to humans. Non-human species that live in ecosystems can suffer significantly from the impacts of pollution, as in the case of birds, marine mammals and other aquatic life soiled following spills of oil in waterbodies. The well-being impacts on non-human lives cannot be valued in monetary terms and are therefore beyond the scope of this study. The cost of the efforts that human undertake to minimize the impacts of pollution on the environment and its non-human inhabitants is, however, within scope.



2.2.2.4 Income Costs Due to the Need to Manage Pollution

Finally, the need to limit the amount of pollution that reaches human, economic or natural receptors increases costs for businesses, governments and individuals in two ways: the costs of limiting the impact of accidental releases of pollutants, including:

- Costs of containing the spilled material
- Costs of removing the spilled material from living and non-living objects that come into contact with it (such as removing oil from birds and beaches)
- Legal costs of the spill (such as fines and lawsuits)
- Lost economic output for the organization responsible for the spill;

and the costs of remediating polluted sites resulting from prior human activities, including:

- Costs of removal of the pollution from the site (which often resides in the soils and groundwater around where the activity took place)
- Costs of treating the contaminated soil/water to render it safe.

2.2.3 Impacts of Pollution on the Value of Produced and Natural Assets – Wealth costs

The impacts of pollution on the value of produced and natural assets are associated with both **degradation** and **destruction** of assets. As noted earlier, these impacts are related by the fact that they reduce the value of national wealth—they are therefore referred to here as **wealth costs**.

Assets are **degraded** by pollution when it reduces their capacity to function normally. For example, acid rain impacts aquatic ecosystems by lowering their pH and rendering them less suitable as habitat for marine organisms. This, in turns, reduces their capacity to provide recreational opportunities and other ecosystem services, making them less valuable from a human perspective. Acid rain also impacts economic assets like bridges and buildings by corroding the materials they are made from.

Even if the value of an asset is not directly affected, it may lose value if its surroundings become polluted. For example, a cottage on the shore of a pristine lake will drop in resale value if the lake becomes polluted even though the pollution does not impact the cottage itself. Similarly, the value of cropland is contingent upon appropriate levels of warmth and moisture from the atmosphere, both of which are subject to disruption by climate change.

Sometimes degradation due to pollution can be so severe that an asset is effectively **destroyed**. For example, the degradation of forests and aquatic ecosystems by acid rain can, in some cases, be severe enough to consider the impacted forest and lakes “dead.” Another example is the pollution of freshwater lakes by phosphorus and nitrogen, leading to their eutrophication—or excess growth of aquatic plants. A famous case that led to the near-loss of a major natural asset was that of Lake Erie in the middle part of the last century. Eutrophication from inadequately treated sewage became so bad that the lake was considered “dead” in the 1970s.¹⁸

Today, the effects of climate change mean that pollution—more specifically, emissions of greenhouse gases—threatens the existence of a much wider range of produced and natural assets. Among the many impacts of climate change are increases in the frequency and intensity of extreme weather events (extreme heat, cold, precipitation and winds). When produced and natural assets like houses, power grids, roads and forests are found in the path of such events, they can be destroyed. Climate change, especially prolonged drought and high temperatures, can also lead to conditions that favour wildfires. These too can destroy assets found in their way. Though the attribution of any single extreme weather event to climate change is difficult, progress in this direction is being made.

¹⁸ Regulations imposed in the 1970s to control phosphorus loadings to Lake Erie from wastewater treatment plants were successful in reducing eutrophication, and the lake had regained its health by the 1990s. It is facing another crisis today, this time as a result of phosphorus loadings from fertilizers applied to cropland in the lake’s basin.

3.0 THE DIRECT WELFARE COSTS OF POLLUTION





3.0 THE DIRECT WELFARE COSTS OF POLLUTION

3.1 Introduction

In this chapter, the **direct welfare costs** of pollution are considered. These include pollution's impacts on the full range of what people find valuable (apart from what they purchase with their paycheques). These impacts range from scenic vistas diminished by smoggy haze or walks in the park ruined by litter to more serious impacts resulting in chronic illness or even premature death. Though welfare costs are not tangible—and many people may not be accustomed to thinking of them in monetary terms—that does not mean they have no value. However, measuring their value and expressing it in monetary terms can be challenging.

Direct welfare costs are measured by observing choices that people make in their daily lives and inferring how they value the things that pollution impacts, or by asking them directly how they value the impacts of pollution in controlled surveys. How much are people willing to pay for clean parks and communities or for scenic views or good health? Understanding the answers to these questions allows economists to estimate the direct welfare costs of pollution.

The most commonly studied direct welfare cost of pollution is premature death. Humans value life greatly, and the premature death of any person comes at an obviously immeasurable cost for that person. Though immeasurable in actual cases, economists have found means of expressing this cost using statistical “value of life” measures.

Along with premature death, pollution can also cause acute and chronic non-fatal illnesses. Illness has a number of obvious economic costs (which are considered in Chapter 4), including the costs of treating sick people and the cost of lost economic output. But illness also has a direct welfare impact on individuals, as pain and suffering reduce the enjoyment of life.

The direct welfare costs of pollution extend beyond health impacts as well. Smog reduces visibility, ruining the enjoyment of scenic views. Litter reduces the pleasure taken from a walk in a park. For some people, the simple knowledge that natural places are polluted can directly reduce welfare even if they never have visited them or never will.

3.2 Summary of Findings – Direct welfare costs¹⁹

The available evidence suggests that pollution imposes significant direct costs on the welfare of Canadians. **Based on a thorough review of available data, the direct welfare cost of those impacts that can be valued today is estimated to have been at least \$26 billion in 2015 and as much as \$50 billion. The best**

“The direct welfare costs of pollution extend beyond health impacts as well. Smog reduces visibility, ruining the enjoyment of scenic views.”



¹⁹ A specific nomenclature has been adopted to discuss uncertainty in this report. The nomenclature is not based on a quantitative assessment of uncertainty but rather on the authors' judgement derived from the review of published studies. The terms in the nomenclature have the following meanings: “possibly” (< 50 per cent chance); “likely” (> 50 per cent chance); “somewhat larger” (< 100 per cent larger); “much larger” (> 100 per cent larger); “significant” (at least on the order of tens of millions of dollars); “very significant” (at least on the order of billions of dollars). In cases where order of magnitude (millions, billions) estimates can be given with some degree of certainty, they have been. This nomenclature is intended to provide readers with a rough sense of how much larger actual costs might be than those that can be measured based on available data and how likely it is that costs are this much larger. It should not be used to make quantitative estimates of missing values.



estimate of the actual 2015 costs of this subset of pollution impacts is \$39 billion.²⁰ The full direct welfare cost of pollution is likely to have been much larger than this, possibly twice as large, as a number of important impacts cannot be valued today.

Importantly, the figure of \$39 billion excludes the human health costs of pesticides and other “persistent organic pollutants” (POPs). While the science required to estimate the direct welfare costs of POPs is still emerging, tentative steps in that direction are being taken. Based on current evidence, these costs could be of the same order of magnitude as those for urban smog (tens of billions of dollars). This is a significant finding, as smog is the pollutant currently thought to have the greatest direct welfare costs.

Also significant are the exclusions of the costs of heavy metals and the impacts of climate change on extreme weather (aside from heat waves). In the case of climate change, the possibility for significant welfare costs is substantial, as flooding, major storms and heat waves—all of which can be tied in part to climate change—can impose major welfare costs in terms of loss of life, illness and dislocation.

Taking \$39 billion as the most likely *minimal* estimate of the direct welfare costs of pollution, the average Canadian borne costs of at least \$1,100 in 2015. A family of four would have borne costs of no less than \$4,300, or 3 per cent of household income.²¹ The total direct welfare costs of pollution per family was likely much larger than this.

Each of the direct welfare costs of pollution in Canada is discussed briefly below and then summarized in Table 1 at the end of this section. They are then discussed in much greater detail in the remainder of the chapter, where they are divided into two categories: impacts on human health (Section 3.3) and other direct welfare impacts (Section 3.4).

3.2.1 Summary of Findings by Direct Welfare Cost

- **Criteria air pollutants:** Based on available data, the largest known direct welfare cost of pollution is that imposed on human health by so-called “common” (or criteria) air contaminants.²² Of these, fine particulate matter (PM_{2.5}) and ground-level ozone—the main elements of urban smog—are the most important. **Based on the most recent estimates of premature deaths and illness caused by PM_{2.5} and ground-level ozone in Canada, the direct welfare cost of these pollutants is estimated to have been \$36 billion in 2015, with a range of \$26 billion to \$47.5 billion.** This cost does not include the health impacts of other criteria air contaminants, though it is believed that PM_{2.5} and ground-level ozone are responsible for the majority of human health impacts. See Section 3.3.1.1 for further details.
- **Pathogens:** Pathogens include bacteria, viruses and other microorganisms that cause disease directly as well as organisms that cause disease indirectly by the creation of toxins. The main pollution-related sources of pathogens are human and animal wastes that enter water bodies from sewage, farm manure and landfill sites. The main concern regarding toxins is those from cyanobacteria (blue-green algae) blooms caused by eutrophication of water bodies due to excess nitrogen and phosphorus loadings. In spite of their risk to human health, relatively little information was found regarding the economic cost of pathogens. **A tentative estimate of the cost of tap water-borne pathogens in 2015 is \$895 million based on Canadians’ spending on bottled water and water filtration devices. This cost would not include any direct welfare losses associated with exposure to algal bloom toxins or pathogens from other pollution sources, which are possibly somewhat larger.** See Section 3.3.2 for further details.

²⁰ This figure has been arrived at as follows: \$36 billion (criteria air contaminants) + \$0.895 billion (pathogens) + \$1.6 billion (extreme weather) + \$0.056 billion (recreational activities) + \$0.438 billion (visibility) + \$0.087 billion (existence value). No estimate for the cost of noise pollution has been included since a central value for that cost could not be determined.

²¹ As measured by primary household income from Statistics Canada.

²² In Canada, criteria air pollutants include: sulphur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM₁₀ and PM_{2.5}), volatile organic compounds (VOCs), ammonia (NH₃), carbon monoxide (CO) and ground-level ozone (O₃) (Environment and Climate Change Canada, n.d.)



- Pesticides and other POPs:** There is insufficient evidence at this time to estimate the direct welfare costs of the human health impacts of pesticides and other POPs. Data from the Pest Management Regulatory Agency of Canada suggest that most reported exposure to pesticides is not the result of pollution but of unintended exposure during production, use or storage of pesticides. Of course, most exposure to pesticide pollution goes unreported because it occurs at low levels as the result of consuming food or water containing pesticide residues or from outdoor activities in areas where residues are present. The welfare costs of this exposure are unknown but scientists are moving toward being able to value it. **In particular, the cost of endocrine disruption from pesticides and other POPs possibly runs to tens billions of dollars in Canada.** See Section 3.3.3 for further details.
- Heavy metals:** There is insufficient evidence at this time to estimate the direct welfare costs of the human health impacts of heavy metal pollution. Though estimates of the welfare costs of certain heavy metals are available on a cost-per-unit-of-emission basis, the estimates are not specific to Canada and they are derived from only a few studies. Moreover, Canadians' exposure to heavy metal pollutants such as a mercury is related not just to emissions in Canada but also to long-range transport of the pollutants from other parts of the globe. A tentative estimate of the global cost of mercury emissions alone would be on the order of \$20 billion to \$30 billion. What share of this cost might be imposed on Canadians cannot be determined given available data. See Section 3.3.4 for further details.
- High-level nuclear wastes:** Available evidence suggests that pollution from normally operating nuclear power plants likely imposes no direct welfare costs on Canadians today. Though some studies have pointed to an increase in rates of childhood leukemia for those living in the vicinity of nuclear power plants, the majority of studies find no evidence to support this link. Research on this topic is continuing, so it is not possible to conclude here that the costs are zero. Of course, a major accident at a nuclear power plant could impose very substantial costs. Fortunately, no such accident has happened in Canada and only a few have occurred worldwide. Based on evidence from those that have occurred, a major nuclear accident would impose direct welfare costs on the order of hundreds of billions of dollars. The majority of these costs would likely result from impacts on people displaced by the disaster rather than those who might die as a result of it. See Section 3.3.5 for further details.
- Noise pollution:** Though not usually a focus of public attention, noise pollution is estimated to impose substantial direct welfares costs on Canadians. Noise pollution is to some degree a part of daily life for nearly everyone who lives in an urban area. Transportation activities, especially road transport, are the biggest source, but construction and industrial activities also contribute. Studies around the world consistently show that noise pollution from transportation imposes direct welfare costs on the order of 0.1 to 0.5 per cent of GDP. **The annual costs to Canadians likely fall somewhere in the range of \$345 million to \$3 billion.** See Section 3.3.6 for further details.
- Extreme weather:** Extreme weather events in the form of storms, floods, droughts, heat waves and cold snaps impose significant welfare costs on Canadians from premature deaths, increased illness and disruption of daily life. While not a form of pollution, extreme weather is, increasingly, an indirect result of pollution. More specifically, extreme weather events are increasing in frequency and severity as a result of climate





change induced by emissions of greenhouse gases like carbon dioxide. While no individual extreme event can be attributed with certainty to climate change, scientists are increasingly able to assess the percentage of such events that are driven by it. This is particularly the case for heat waves, half of which are determined to the result of climate change today. Based on this, the estimated welfare cost (mortality only) of pollution-related extreme weather (heat waves) in Canada is estimated to have been \$1.6 billion in 2015. The total cost of heat waves including morbidity is likely somewhat larger. The direct welfare costs of other extreme weather related to climate change are likely much larger. See Section 3.3.7 for further details.

- **Lost recreational opportunities:** In addition to the direct loss of welfare from health impacts, pollution also reduces Canadians' enjoyment of life in other ways. One of these is reduction in the quality of recreational opportunities. Freshwater lakes fouled by blue-green algae are unpleasant (and even dangerous) to swim, fish and boat in. Forests damaged by acid rain are less enjoyable as sites for hiking, camping and hunting. Air polluted by smog provides less beautiful vistas for tourists visiting iconic cultural or natural sites. **A tentative estimate of the cost of just the freshwater recreational opportunities estimated to have been lost in 2015 due to pollution is \$56 million.**



- **A full assessment of the costs of pollution in terms of lost recreational opportunities in Canada is not possible given available data. Total costs are possibly much larger.** See Section 3.4.1 for further details.
- **Reduced visibility:** Smog-filled air reduces visibility, which, in turn, reduces peoples' enjoyment of the world around them. Majestic mountain views, whether enjoyed from homeowners' living rooms or the top of hiking trails, are less majestic through smoggy haze. Cityscapes are equally less attractive when obscured by air pollution. **The estimated cost of the associated direct welfare losses in Canada in 2015 is \$438 million.** See Section 3.4.3 for further details.
- **Lost existence value:** For some people, the simple knowledge that the natural world is degraded by pollution is sufficient to impose welfare losses. Some feel that the environment and the species living in it have intrinsic value—that is, value beyond any use they might make of it—and that any damage humans do to it is wrong. The fact that damage is done, then, leaves these people less well off than they would be otherwise. **A tentative estimate of the cost of this loss due to pollution of freshwater in 2015 is \$87 million. Direct welfare losses associated with other forms of pollution are unknown but are likely much larger.** See Section 3.4.3 for further details.

“ In the case of climate change, the possibility for significant welfare costs is substantial, as flooding, major storms and heat waves—all of which can be tied in part to climate change—can impose major welfare costs in terms of loss of life, illness and dislocation. ”



Table 1. Summary of 2015 direct welfare costs of pollution in Canada

Category	Estimated direct welfare cost in 2015	Reliability of estimate	What is and is not covered
 Criteria air pollutants (PM_{2.5} and ground-level ozone)	Central estimate: \$36 billion Range: \$26 billion to \$47.5 billion	High	Represents the cost of PM _{2.5} and ozone in terms of premature mortality and morbidity; other criteria air pollutants are excluded but are likely much smaller.
 Pathogens (tap water-borne)	Central estimate: \$895 million; possibly somewhat larger Range: Unknown	Low	Represents the cost of tap water-borne pathogens; the cost of other pathogens is excluded.
 Pesticides and other persistent organic pollutants	<i>Unknown</i> ; likely significant; possibly very significant	n/a	Data are insufficient to value pollution by pesticides and other persistent organic pollutants in Canada today. Based on available evidence, their cost is likely hundreds of millions of dollars and possibly billions to tens of billions of dollars.
 Heavy metals	<i>Unknown</i> ; likely significant; possibly very significant	n/a	Data are insufficient to value heavy metal pollution in Canada today. A tentative estimate of the global cost of mercury pollution alone is \$20 billion to \$30 billion. The share of this cost imposed on Canadians is unknown.
 High-level nuclear wastes	<i>Unknown</i> ; likely not significant under normal conditions; likely very significant in the event of a major nuclear accident	n/a	Some evidence points to increased rates of childhood leukemia in the vicinity of nuclear power plants, but most studies do not support this conclusion. The main concern is the possibility of a major nuclear accident, which could impose costs of hundreds of billions of dollars. No such accident has occurred in Canada and only a few have occurred worldwide.
 Noise pollution	Central estimate: unknown Range: \$345 million to \$3 billion	Medium	No central estimate is available. The low end of the range is a “very conservative” estimate from Transport Canada and the high end based on a European average.
 Extreme weather due to climate change	Central estimate: \$1.6 billion (likely somewhat higher) for mortality from heat waves due to climate change; unknown but likely much larger for other extreme weather due to climate change Range: unknown	Medium	Costs for heat waves are based on an assumed share of heat waves attributable to climate change of 50 per cent; represents the cost of mortality only; morbidity costs are excluded. Scientists are not yet able to attribute other extreme weather events (e.g., flooding) to climate change with sufficient certainty to quantify their costs.
 Recreational activities (freshwater recreation)	Central estimate: \$56 million; possibly much larger Range: unknown	Low	Represents the cost of lost freshwater recreation due to poor water quality. The costs of other lost recreational opportunities are excluded.
 Visibility	Central estimate: \$438 million Range: unknown	Low	Represents the cost of lost visibility due to all sources of particulate matter and ground-level ozone. Other forms of air pollution do not significantly affect visibility.
 Existence value	Central estimate: \$87 million due to pollution of fresh water; likely much larger for other forms of pollution Range: unknown	Low	Represents the loss of welfare for those who intrinsically value the environment (non-users) associated with pollution of fresh water. Non-user direct welfare losses associated with other forms of pollution are unknown but likely much larger.



3.3 Human Health Costs of Pollution

Health impacts of pollution come via various pathways, including the air we breathe, the water we drink and the food we eat. Air pollutants such as fine particulate matter can find their way deep into our lungs, causing respiratory diseases and even premature death. Toxic chemicals can work their way through the food chain, contaminating fish and other food and causing a variety of health effects.

Health effects are broadly classified into premature mortality (death) and morbidity (illness) effects. Premature mortality is obviously a single health “endpoint,” although with multiple pollution-related causes. Morbidity, on the other hand, involves a wide number of health endpoints, from respiratory and cardiovascular illnesses to developmental impacts. Morbidity and mortality can also be classified as resulting from either acute or chronic exposure to pollution. Acute illness or death is that caused by sudden changes in pollution exposure. Chronic effects are those that surface slowly over years of exposure to pollution. Certain pollutants, such as ground-level ozone, can have both acute and chronic impacts.

In order to be assessed, the impact of pollution on a given health endpoint must be clearly understood. Changes to health happen for many reasons, and the impact of pollution must be isolated from other sources of health impacts, including other pollutants. Epidemiological studies²³ of pollution attempt to link changes in ambient pollution levels with increases (or decreases) in specific health endpoints. The relationships between a certain concentration of pollution and a corresponding health endpoint are known as concentration-response (or dose-response) functions.

Estimation of the cost of pollution often relies on what is known as the “impact pathway” (or “damage function”) approach. Impact pathway analysis is a bottom-up approach in which pollution costs are estimated by following the pathway from emissions via changes in the quality of air, soil and water to physical health impacts (using concentration-response functions) before being expressed in monetary benefits and costs (ExternE, n.d.). The approach can be used to estimate changes to health, visibility, ecosystem functions and other impacts associated with pollution. It is a standard method of assessing the costs of pollution and is used by Environment and Climate Change Canada, the United States Environmental Protection Agency (EPA) and other environmental agencies around the world (for example, Regulations Amending the Off-road Small Spark-ignition Engine Emissions Regulations, 2016; EPA, 2014). The main steps in the impact pathway approach are illustrated in Figure 2.

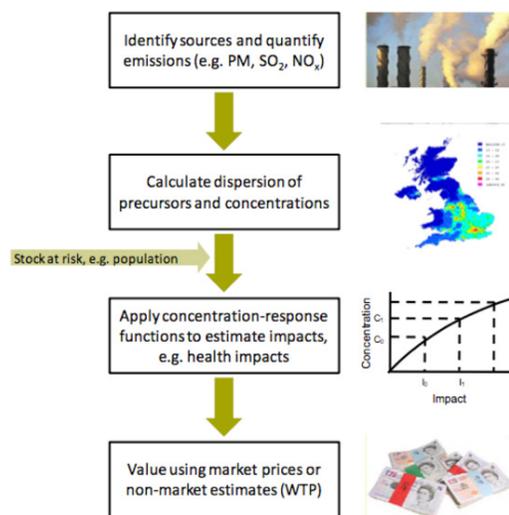


Figure 2. Steps in the impact pathway approach
Source: DEFRA, 2013.

3.3.1 The Health Impacts of Criteria Air Pollutants

Based on the data available today, air pollution by so-called “common” (or “criteria”) pollutants has the greatest impact on health endpoints of any type of pollution (World Health Organization [WHO] & Organisation for Economic Co-operation and Development [OECD], 2015). It is not clear, however, whether this is objectively true or simply a result of the fact that the health impacts of air pollution have been studied more closely than any other. More is said on this point in the discussion of the health impacts of persistent organic pollutants (Section 4.3.3).

²³ The science that deals with study of the incidence, distribution, causes and control of diseases is known as *epidemiology*. It is the source of much of the research used in measuring the cost of pollution.



In Canada, criteria air pollutants include (Environment Canada, 2013a):

- Sulphur oxides (SO_x)
- Nitrogen oxides (NO_x)
- Particulate matter (PM₁₀ and PM_{2.5})²⁴
- Volatile organic compounds (VOCs)
- Ammonia (NH₃)
- Carbon monoxide (CO)
- Ground-level ozone (O₃).

Of these, SO_x, NO_x, PM₁₀, PM_{2.5}, VOCs, NH₃ and CO are all released directly to the atmosphere from human activities. Ground-level ozone, in contrast, is not released directly but is formed in the atmosphere as a result of chemical reactions involving other pollutants (Text Box 1). Particulate matter is unique in that it is both released directly and formed as the result of secondary reactions (Text Box 2).

Emissions of most criteria air pollutants in Canada have been trending downward since 1990 (Figure 3). The exceptions are ammonia and fine particulate matter, emissions of which remained above or close to their 1990 levels in 2014 (the most recent year for which data are available). The increase in ammonia emissions is attributed to increased agricultural fertilizer use and larger livestock populations. In the case of PM_{2.5}, the relatively stability is attributed to emissions from so-called “open sources” such as agriculture and unpaved roads. Emissions of PM_{2.5} from other sources (e.g., fossil fuel and firewood combustion) have trended downward over time (Environment and Climate Change Canada, 2016a).

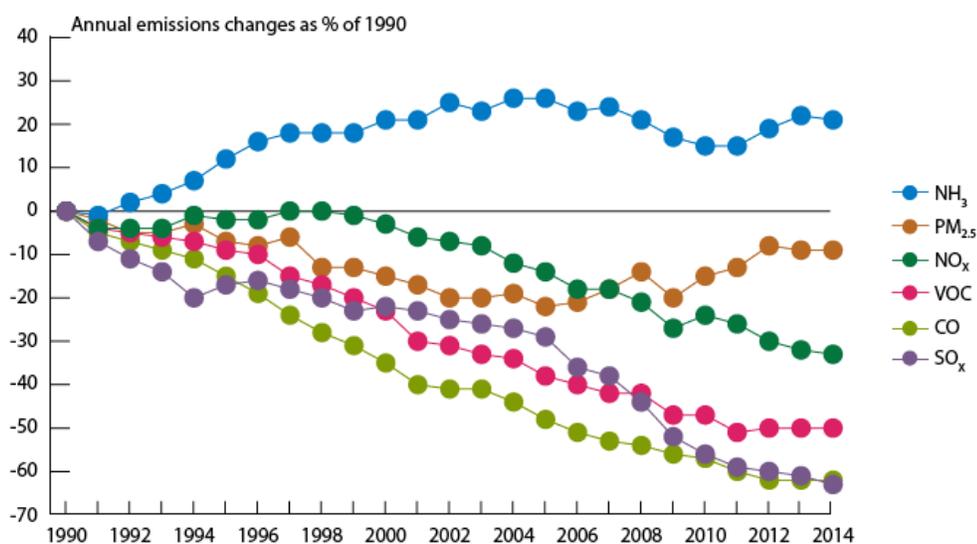


Figure 3. Trends in criteria air contaminant emissions in Canada, 1990–2014

Source: Environment and Climate Change Canada, 2016a.

²⁴ Particulate matter is generally divided into two categories, coarse (PM₁₀) and fine (PM_{2.5}). The numbers 10 and 2.5 refer to the size of the particles measured in micrometers (millionths of a meter). Separate categories have been established because studies have shown that PM_{2.5} is able to penetrate further into individuals’ airways and, therefore, has greater potential for damaging health.



A similar story emerges when the ambient concentrations of criteria air pollutants are considered, with SO_x , NO_x and VOCs showing declines from 2000 to 2014 but $\text{PM}_{2.5}$ and ground-level ozone (a secondary pollutant) showing little change over time (Figure 4 and Figure 5).²⁵ Average annual ambient $\text{PM}_{2.5}$ concentrations are below or, in the case of southern Quebec, at the level established as the Canadian air quality standard. There is no standard for average annual ground-level ozone concentrations, but there is one for the peak 8-hour concentration. In general, between 2000 and 2014, peak 8-hour ground-level ozone concentrations were close to or above this standard in all regions of the country, most notably in the densely populated regions of southern Quebec and Ontario where the majority of Canadians live (Figure 6). As discussed below, studies indicate that $\text{PM}_{2.5}$ presents the greatest health risk of all criteria air contaminants. The fact that concentrations of $\text{PM}_{2.5}$ are not decreasing in Canada is, therefore, reason for concern.

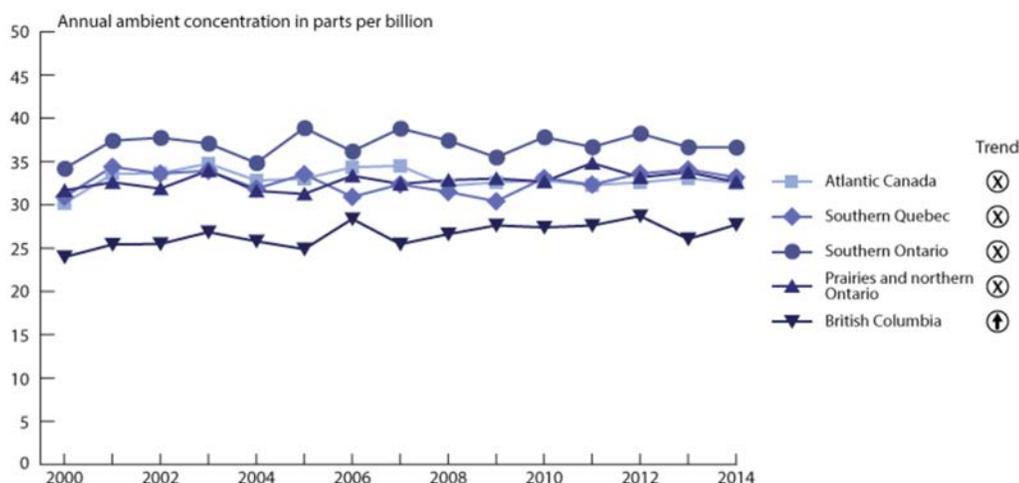


Figure 4. Ambient concentrations of ground-level ozone by region, 2000–2014

Source: Environment and Climate Change Canada, 2016b.

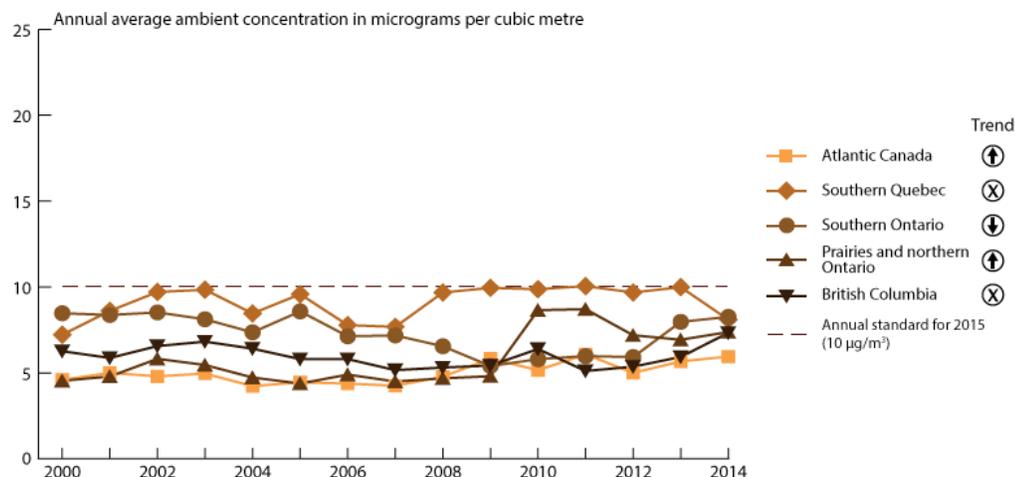


Figure 5. Ambient concentrations of $\text{PM}_{2.5}$ by region, 2000–2014

Source: Environment and Climate Change Canada, 2016c.

²⁵ Note that no ambient concentration for ammonia is measured since it is a highly reactive compound and does not remain in the atmosphere for long. Rather, it mainly contributes to the formation of secondary $\text{PM}_{2.5}$ through reactions with SO_x and NO_x .

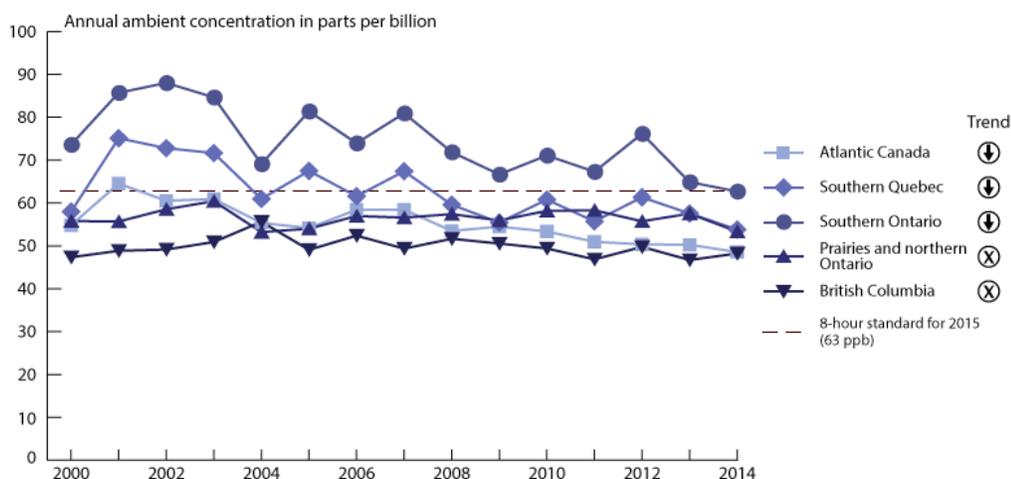


Figure 6. Peak 8-hour ground-level ozone concentrations, by region, 2000–2014

Source: Environment and Climate Change Canada, 2016b.

While the individual health risks due to criteria air pollutants are relatively low, the large number of people exposed to them means the overall societal health cost is very large (Department of Environment and Conservation, 2005). Criteria air pollutants cause a number of negative health effects, including cardiovascular and respiratory illnesses that can lead in some cases to premature mortality. Outdoor air pollution²⁶ is now the fourth-leading mortality risk worldwide, behind only metabolic, dietary and smoking risks (World Bank and Institute for Health Metrics and Evaluation, 2016). Urban populations are most at risk, as many human activities that are sources of criteria air pollutants occur in towns and cities (e.g., fuel use, chemical production and use and construction).

Scientific studies have determined that the most harmful of the criteria air pollutants is PM_{2.5} (Text Box 2), as its fine particles can find their way deep into respiratory tracts (WHO, 2016). Ground-level ozone, NO_x and SO_x also contribute significantly to the health impacts, though the effects of NO_x and SO_x have been less well studied. However, PM_{2.5} contributes the largest share of quantifiable impacts by far. As a result, PM_{2.5} impacts are sometime used as proxies for the health impacts of air pollution as a whole (WHO & OECD, 2015). Most major studies consider both PM_{2.5} and ground-level ozone however.

Scientific understanding of the health impacts of PM_{2.5} and ground-level ozone is constantly evolving. Emission monitoring methods have improved, including the use of remote sensing satellite technology, which has in turn improved models of ambient air quality. Epidemiological understanding of the links between air pollution and health endpoints has also improved. This has resulted in the use of new, more accurate concentration-response functions. As the understanding of air pollution’s effects on the human body has increased, new diseases (e.g., lung cancer) have been included as health endpoints (WHO & OECD, 2015).

“ Criteria air pollutants cause a number of negative health effects, including cardiovascular and respiratory illnesses that can lead in some cases to premature mortality. ”

²⁶ In some developing countries, where cooking over open wood fires remains common, indoor air pollution from criteria air pollutants—especially particulate matter—remains a concern. In Canada, criteria air contaminant exposure occurs mainly outdoors.



As a result of these improvements in scientific understanding, the estimated number of cases of morbidity and mortality due to exposure to air pollution has increased. The latest figures from WHO (2014) suggest that they were responsible for 3.7 million premature deaths worldwide in 2012. WHO's previous estimate (for 2008) had been 1.3 million deaths. Another authoritative source, the *Global Burden of Disease* study of the Institute of Health Metrics and Evaluation, also recently increased its estimates of premature worldwide mortality caused by PM_{2.5} and ground-level ozone, rising from 0.8 million in 2000 to 3.4 million in 2010 (WHO & OECD, 2015).



Figure 7. Air Pollution in China

Such elevated rates of death mean that unless action is taken to reduce ambient levels of PM_{2.5} and ground-level ozone, one person will die prematurely every 5 seconds from outdoor air pollution by the middle of the century (OECD, 2016). About 87 per cent of the world's population now live in countries in which ambient pollution levels exceed air quality guidelines set by the World Health Organization (World Bank & Institute for Health Metrics and Evaluation, 2016). China and other developing countries are particularly affected due to their large share of the global population and often poor air quality (Figure 7).

Future improvements in the understanding of the health impacts of air pollution are likely. Data gathering techniques and availability are liable to improve, whether relating to emissions or to hospital stays. New diseases are liable to be linked to air pollution. And health impacts are liable to be linked to different air pollutants. Studies currently focus on the health impact of PM_{2.5} and ozone, but there is increasing evidence that other air pollutants such as nitrogen dioxide have a direct independent impact (WHO & OECD, 2015).

The improving estimates of the health impacts of air pollution show that previous estimates of mortality and morbidity were too low. More recent estimates from the OECD (2016) and World Bank & Institute for Health Metrics and Evaluation (2016) that take advantage of the latest data suggest that the magnitude of the health effects and costs of air pollution are greater than previously thought. The estimates for Canada presented below are derived from these recent studies. Earlier estimates, such as those from the Canadian Medical Association (2008), are no longer considered valid (Text Box 3).





Text Box 1. Ground-level ozone

Ground-level (or tropospheric) ozone is different from the ozone found naturally in the stratospheric ozone layer. Unlike stratospheric ozone, which plays a vital role in supporting life by limiting solar radiation hitting the earth, ground-level ozone does not occur naturally and is harmful to humans, plants and animals (Environment and Climate Change Canada, 2016d).

Ground-level ozone is a secondary pollutant (that is, it is not emitted directly from human activities) formed as a result of chemical reactions between so-called “precursor” pollutants. The most important of these are NO_x and VOCs, which are emitted from the production, distribution and use of fossil fuels, firewood combustion, and evaporation of fuels and solvents. While NO_x emissions are largely of human origin, VOCs come from both human and natural sources. NO_x and VOCs react in the presence of sunlight to create ozone and other pollutants. The rate of ozone formation is related to both the concentrations of precursors atmosphere and to meteorological characteristics such as wind, humidity and temperature. Near the ground, where the precursor pollutants are emitted, ground-level ozone concentrations can be high and pose a threat to human health, the environment and the economy. Ozone and its precursors can be transported over long distances (Environment and Climate Change Canada, 2016d; EPA, 2014).

Exposure to ozone has been linked to premature mortality and a range of morbidity endpoints such as hospital admissions and asthma symptom days. Morbidity impacts of ozone include hospital and emergency department visits for illnesses such as asthma and chronic obstructive pulmonary disease and respiratory symptoms such as coughing and wheezing (EPA, 2014). Research suggests there may be no safe minimum level of human exposure to ground-level ozone (Bell, Peng, & Dominici, 2006).

In addition to its effects on human health, ozone can impact vegetation and decrease the productivity of some crops. It can also injure flowers and shrubs and may contribute to forest decline. Ozone can damage textiles, plastics and rubber, accelerate fading of dyes and speed deterioration of some paints and coatings.

Though the emissions of the precursor pollutants NO_x and VOCs are declining in Canada, average annual concentrations of ground-level ozone have remained more or less constant in most regions since 2000 (with the exception of British Columbia, where they have increased) (see Figure 4). Peak 8-hour concentrations declined slightly in most regions (except the Prairies and British Columbia) but remained at or near the national standard everywhere in 2014. Prior to 2014, they had been consistently above the national standard in the heavily populated region of southern Ontario and occasionally above the standard elsewhere (see Figure 6). Significantly, ground-level ozone concentrations in Canada’s largest city, Toronto, exceeded the national standard for ozone in every year from 2002-2012 (Pugliese, Murphy, Geddes, & Wang, 2014).

Text Box 2. What is $\text{PM}_{2.5}$?

The most damaging of the criteria air pollutants is $\text{PM}_{2.5}$, which comprises solid or liquid particulate matter with a diameter of less than 2.5 micrometres, or about one-thirtieth the width of a human hair. Because of their small size, these particles are capable of penetrating deep into the respiratory tract (World Bank & Institute for Health Metrics and Evaluation, 2016).

$\text{PM}_{2.5}$ is emitted directly to the atmosphere from motor vehicles, power plants, wood stoves and fireplaces, forest fires, waste burning, agricultural tilling and some industrial processes (AirNow, 2017). It also forms in the atmosphere as a secondary pollutant through chemical and physical reactions involving different precursor gases, such as SO_x , NO_x and ammonia. Some natural dust also contributes to $\text{PM}_{2.5}$. Particles can be transported long distances in the atmosphere (EPA, 2012).

The chemical makeup of $\text{PM}_{2.5}$ varies depending on the source. It often consists of carbon, sulphate, and nitrate compounds but also may include toxic substances such as heavy metals.

Several studies have also shown a connection between PM exposure and infant mortality (EPA, 2012).

People with heart or lung diseases, older adults and children are most likely to be affected by exposure to $\text{PM}_{2.5}$. However, even healthy individuals may feel temporary symptoms when exposed to high levels. Both long-term and short-term exposure can result in morbidity/ mortality. Numerous studies connect particulate pollution with a variety of health issues, including:

- Irritation of the eyes, nose and throat
- Coughing, chest tightness and shortness of breath
- Reduced lung function
- Irregular heartbeat
- Asthma attacks
- Heart attacks.



3.3.1.1 The Direct Welfare Costs of PM_{2.5} and Ground-Level Ozone in Canada

The most recent studies dealing with the cost of criteria air pollutants in Canada are *The Economic Consequences of Outdoor Air Pollution* (OECD, 2016) and *The Cost of Air Pollution: Strengthening the Economic Case for Action* (World Bank & Institute of Health Metrics and Evaluation [IHME], 2016).²⁷ Both of these are global studies using recent estimates of mortality and morbidity due to criteria air pollutants. The OECD study assessed the mortality and morbidity impacts of both PM_{2.5} and ground-level ozone. The World Bank and IHME study focused only on mortality costs and only on those associated with PM_{2.5}. Each of the studies and their results for Canada are discussed further below.

To estimate the direct welfare costs of PM_{2.5} and ground-level ozone exposure, the OECD study used the impact pathway approach to link air quality to mortality and morbidity endpoints via concentration-response functions.

The OECD's estimate of the number of premature mortalities due to PM_{2.5} and ground-level ozone was based on data from the 2013 *Global Burden of Disease* database produced by the IHME (Brauer et al., 2016; Forouzanfar et al., 2015). The OECD developed its own baseline estimate of the value-of-a-statistical life (VSL) for use in valuing premature mortality (US\$3 million in 2005 prices). This value was transferred to individual countries using country-specific exchange rates based on purchasing power parity. The country-specific VSL was then applied to the OECD's estimated number of premature deaths in each country. For Canada, the OECD's country-specific VSL was US\$3.4 million (2005 prices), equivalent to \$4.8 million in 2015 after taking currency conversion and inflation into account (OECD, 2014).

The number of deaths estimated by the OECD to be attributable to PM_{2.5} and ground-level ozone in Canada in 2010 was 8,000 based on the 2013 version of the *Global Burden of Disease* database.²⁸ Particulate matter accounted for by far the largest share of these deaths. Combining this figure with its Canada-specific VSL estimate of US\$3.4 million, the OECD estimated the direct welfare costs of mortality in Canada due to PM_{2.5} and ground-level ozone to have been US\$20 billion in 2010 (2010 prices).

The latest figures available on-line from the *Global Burden of Disease* database (which were not available when the OECD published its study) indicate that 7,712²⁹ deaths were attributable to PM_{2.5} and ground-level ozone in Canada in 2015, with lower and upper limits of 5,590 and 10,280 deaths. Multiplying these figure by the value of \$4.8 million calculated above as the Canada-specific VSL for 2015 gives \$37 billion as a central estimate of the mortality costs of PM_{2.5} and ground-level in 2015, with a range of \$27 billion to \$49 billion.

Turning to the recent study from the World Bank and IHME (2016), its focus was only on the mortality costs and only those associated with PM_{2.5}. Morbidity costs and the effects of ozone were set aside because mortality costs due to PM_{2.5} have been shown to be the largest portion of health costs and the methods and data are best established for mortality and PM_{2.5}. Like the OECD study (see above), the World Bank and IHME report used the 2013 *Global Burden of Disease* database for its estimate of the number of premature deaths caused by PM_{2.5} (9,466 deaths in 2013). The corresponding estimate of direct welfare costs was US\$40.4 billion (2011 prices). The report does not mention the Canada-specific VSL used in these calculations but implicitly it must have been about US\$4.3 million (2011 prices) in 2013, which equates to \$4.5 million in 2015 after taking currency conversion and inflation into account. This is quite close to the value of \$4.8 million used in the OECD study.

As noted, the latest figures from the *Global Burden of Disease* database (which were not available when the World Bank and IHME published their study) indicate that 7,712³⁰ deaths were attributable to PM_{2.5} and ground-level ozone in Canada in 2015, with lower and upper limits of 5,590 and 10,280 deaths. Multiplying these figure by the

²⁷ See Appendix B for a description of the methods used in these studies.

²⁸ The most recent *Global Burden of Disease* database estimate for deaths from PM_{2.5} and ground-level ozone in Canada for 2010 is 6,977.

²⁹ It is not clear why the current figure from the *Global Burden of Disease* database for 2015 is lower than the OECD's figure for 2010.

³⁰ Again, it is not clear why the current figure from the *Global Burden of Disease* database for 2015 is lower than the OECD's figure for 2010.



implicit Canada-specific VSL value of \$4.5 million used by the World Bank and IHME gives \$35 billion as a central estimate of the mortality costs of PM_{2.5} and ground-level in 2015, with a range of \$25 billion to \$46 billion.

“ Data gathering techniques and availability are liable to improve, whether relating to emissions or to hospital stays. New diseases are liable to be linked to air pollution. And health impacts are liable to be linked to different air pollutants. ”

Averaging the results obtained using the latest figures from the Global Burden of Disease database in combination with the OECD and World Bank/IHME Canada-specific VSL gives a central estimate of the 2015 mortality costs of PM_{2.5} and ground-level ozone pollution of \$36 billion with upper and lower bounds of \$26 billion and \$47.5 billion.

Neither study provides estimates of the cost of morbidity associated with PM_{2.5} and ground-level ozone. The OECD study estimates this cost but does not provide details for Canada, while the World Bank and IHME’s study does not consider this cost at all. Elsewhere, however, (OECD, 2014; Hunt Ferguson, Hurley, & Searl, 2016) it has been reported that the welfare costs of morbidity associated with air pollution are about 10 per cent of the mortality costs. Applying this share to the figures above gives a central estimate of about \$3.6 billion for morbidity costs of PM_{2.5} and ground-level ozone in Canada in 2015, with a range of \$2.6 billion to \$4.75 billion. Combined with the estimates of mortality costs further above, a central estimate of both the mortality and morbidity welfare costs associated with PM_{2.5} and ground-level ozone in 2015 is about \$40 billion with a range of about \$29 billion to \$53 billion.

To put these costs in perspective, they can be compared with net national income,³¹ the closest thing to a measure of welfare available from the national accounts. In 2015, Canadian net national income was \$1,614 billion (Statistics Canada, 2016a), meaning that the direct welfare costs of PM_{2.5} and ground-level ozone were equal to about 2.5 per cent of net national income in 2015. This is half of the 5 per cent average the OECD study estimated for all its member states, reflecting the relatively better air quality in Canada compared to many OECD countries.

It should be noted that that these figures represent a lower bound on the direct welfare costs of criteria air pollutants, since they do not reflect pollutants other than PM_{2.5} and ground-level ozone. The additional costs imposed by other pollutants are not known, but current epidemiological evidence suggests PM_{2.5} is responsible for the greatest share of costs. It should also be noted that these costs do not reflect additional health care spending and lost economic output for those made ill by air pollution. These costs are discussed in the next chapter, which deals with the income-related costs of pollution.

Prior to the release of the OECD and World Bank/IHME studies, the most reliable estimate of the direct welfare costs of PM_{2.5} and ground-level ozone in Canada was a study from the Canadian Medical Association (CMA) (2008). As noted earlier, this study was based on earlier epidemiological data that predicted much lower rates of mortality and morbidity than the most recent estimates from the *Global Burden of Disease database*. The CMA study also used a VSL figure considerably lower than more recent studies. The results of the CMA study are compared with those calculated here in Text Box 3.

³¹ Net national income is equal to GDP less the consumption of produced capital adjusted for foreign investment flows.



Text Box 3. Earlier estimates of the direct welfare impacts of criteria air pollutants in Canada

The Canadian Medical Association (CMA) released *No Breathing Room: National Illness Costs of Air Pollution* in 2008 (CMA, 2008). The study used a custom-built illness cost of air pollution (ICAP) model to estimate the health effects and costs of air pollution (see Appendix B for a description of the model). The model was originally developed for the Ontario Medical Association, but was later expanded by the CMA to cover all provinces. The ICAP model has since been discontinued.

Both PM_{2.5} and ground-level ozone impacts were modelled in ICAP for mortality and a number of morbidity endpoints. The costs of morbidity were divided into pain and suffering (direct welfare costs) and lost productivity and increased health care spending (income costs). The model followed the impact pathway approach, linking emissions to health endpoints using concentration-response functions. Mortality was valued using a VSL of \$2.4 million (2006 prices) (DSS, 2005; CMA, 2008).

The total number of premature mortalities in Canada due to air pollution was estimated to be 2,682 in 2008 and 3,233 in 2015. These are much lower than the current estimates available from the *Global Burden of Disease* database (7,712 deaths in 2015), reflecting the fact that the CMA estimates were based on now-outdated epidemiological data. The estimated economic cost of these deaths was about \$9 billion in 2015 (adjusted to account for inflation), much lower than the \$40 billion calculated here based on the most recent mortality estimates and VSL values. Reduced welfare due to the pain and suffering associated with morbidity was estimated to be \$475 million in 2015 (adjusted for inflation), again much lower than the \$3.6 billion estimated here.

3.3.2 The Health Impacts of Pathogens

Pathogens are compounds of living origin that cause disease in humans and animals. They include bacteria, viruses and other microorganisms that cause disease directly, as well as organisms that cause disease indirectly by the creation of toxins.

Not all pathogens found in the environment are the result of pollution. Those that are pollution-related are mainly related to pollutants that enter surface, ground and coastal waters from urban areas and farmland. The main concerns are:

- Pathogens associated with human, animal and food wastes that enter water bodies directly from sewage, farm manure and landfill sites.
- Toxins produced by algal blooms that are caused by eutrophication of surface waters as result of waste nutrients (nitrogen and phosphorus) entering lakes, rivers and oceans.
- Methemoglobinemia, or blue-baby syndrome, associated with nitrates found in drinking water.

Each of these is discussed further below.

3.3.2.1 Direct Pathogens

Bacteria, viruses and other microorganisms that can directly cause a range of morbidity and even mortality are commonly found in human, animal and food wastes. While proper management of these wastes will prevent most pathogens from entering the environment, such management is not perfect.

For example, modern sewage treatment plants and landfill sites are capable of preventing most pathogens associated with municipal sewage and solid wastes from being released to the environment. But not all sewage and solid wastes are treated in such facilities. According to Environment and Climate Change Canada (2016e), 3 per cent of Canadian homes connected to municipal sewer systems in 2009 (the most recent year for which data are available) saw their wastes sent directly into the environment without treatment. Another 16 per cent received only primary treatment—which does not remove pathogens—before release and a further 13 per cent of households managed

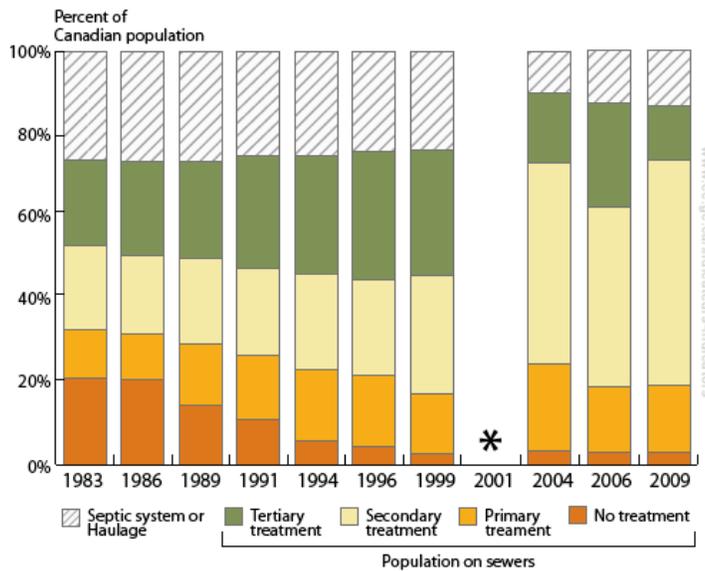


Figure 8. Municipal Wastewater Treatment, by Level, 1983–2009

Source: Environment and Climate Change Canada, 2016e.

However, this risk has actually been increasing in recent decades. Environment and Climate Change Canada (2016f) notes that “greater application of fertilizers and manures on farms in recent decades has increased the opportunities for agricultural nitrogen and phosphorus, as well as bacteria, to reach water bodies.” In 2011, the risk of water quality impacts from agriculture actually fell below its target level (Figure 9).

Farmland is not the only source of animal wastes entering the environment. Runoff from rain and snow on urban areas containing wastes from pets and wild animals is also a source. In some towns and cities, such runoff is captured in storm sewers and processed in sewage treatment plants or storm-water treatment facilities before being released to the environment, reducing the chance that pathogens will reach water bodies. This is not the case everywhere across the country, however. No data are available to measure the share of urban runoff that is treated before release.

Once pathogens find their way into the environment, humans are at risk of exposure through a variety of pathways. The most likely routes are recreational activities in and around contaminated waters and consumption of contaminated shellfish and/or drinking water (Text Box 4).³³

their own sewage using private septic systems, where the quality of treatment is difficult to judge (Figure 8).³² So, while the risk of pathogens entering the environment from municipal sewage is low, it is not zero.

No data are available on the level of treatment available in Canadian landfill sites, though most larger towns and cities are today served by sites designed to prevent “leachate” from escaping from the landfill and entering surrounding surface and groundwater.

As with municipal wastes, the risk of pathogens from animal manure and other farm wastes entering the environment can also be minimized if properly managed. Farmers have a variety of manure management methods at their disposal, and the risk of water contamination from agricultural activities is relatively low in Canada.

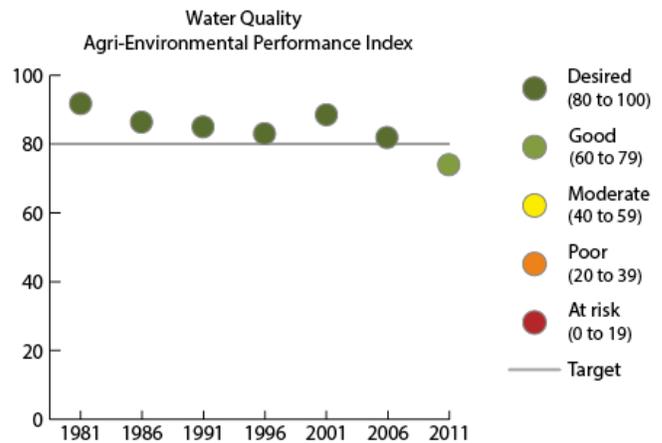


Figure 9. Risk to water from agriculture in Canada, 1981–2011

Source: Environment and Climate Change Canada, 2016f.

³² The data in Figure 8 illustrate several of the weaknesses characteristic of environmental statistics in Canada (and elsewhere). They are not up-to-date, with the most recent figures dating from 2009, and they are difficult to compare over time because of concerns about data quality and changes in collection methods. Though data on sewage treatment levels exist prior to 2004, there is a clear break in the time series between 1999 and 2004 that renders comparison over time impossible.

³³ Shellfish that feed by filtering water can collect and concentrate bacteria and viruses from the waters to levels high enough to cause illness in humans who eat them.



Text Box 4. Norovirus and the British Columbia oyster industry

An outbreak of norovirus began plaguing the British Columbia oyster industry in December 2016. While the outbreak had not resulted in any deaths at the time of completion of this report, it remained a serious public health issue. As of March 28, 2017, 321 cases of gastrointestinal illness had been reported across three provinces (Public Health Agency of Canada [PHAC], 2017).

This was not the first outbreak of oyster-borne norovirus in B.C., with one having occurred in 2004 as well. It was, however, the largest such outbreak in the province's history (Hui, 2017). On top of its unusual duration and severity, scientists are uncertain about its cause. The outbreak was most likely the result of contamination of shellfish farms by human sewage, though the specific source of the contamination had not been discovered as of March 2017 (Pynn, 2017). Seven oyster farms had already been closed due to contamination by that point (PHAC, 2017), with others closing voluntarily (Hui, 2017).

The prolonged outbreak presents a financial challenge to the oyster industry. The Canadian industry is worth \$11.7 million a year, with 60 per cent based in B.C. (Hui, 2017). Sales of oysters are declining as the outbreak continues. Some oyster farms have reported an almost total stop to sales, resulting in layoffs and reduced hours. (Hui, 2017). However, for oyster farmers on the East Coast, the outbreak in B.C. has meant a short-term boom in sales. Despite the short-term gain, East Coast oyster farms remain concerned that the prolonged outbreak will damage public trust in the safety of the industry as a whole (Collins, 2017). The total economic impact of this outbreak will not be known until it has been controlled.



The risks associated with contaminated recreational waters are generally managed by local health authorities, whose responsibility it is to post warning signs to keep bathers out of water where pathogen levels are high.

There is little information on the degree to which pathogens in recreational waters actually lead to human morbidity and mortality in Canada and even less on the associated costs. Except in rare cases, morbidity associated with exposure to contaminated recreational water is generally not severe. Typical concerns include mild cases of gastrointestinal illness, infections of the eyes and ears, and skin irritations. People affected may not even know what has caused their illness. Even if they are ill enough to visit a doctor, exposure to water-borne pathogens may not always be identified as the cause.

In a study of the impact of water-borne pathogens on bathers at two southern California beaches, Dwight et al. (2005) estimated the economic burden from morbidity associated with exposure to polluted recreational marine waters. Using data on morbidity combined with estimates of mean annual salaries and medical costs, they estimated that exposure to polluted waters at Newport and Huntington beaches (south of Los Angeles) generated an average of about 75,000 episodes of gastrointestinal illness and respiratory, eye, and ear infections per year. This morbidity burden translated into an annual cost of US\$3.3 million (2001 prices) in terms of lost worker productivity and increased health care costs. The authors made no estimate of the lost welfare due to pain and suffering associated with this morbidity. As direct welfare costs are often higher than income-related costs, the welfare costs could be assumed to be equal to at least US\$3.3 million. Considering that the United States has thousands of public beaches frequented by millions of visitors per year, it is clear that the economic costs of polluted recreational waters could run into the hundreds of millions of dollars per year in the United States. Translating the costs from this study to other U.S. or Canadian beaches is not possible, since the number of cases of morbidity is a function not just of the number of recreationists but also of the concentration and type of pathogens in the water.

The risks associated with shellfish are managed by the Canadian Shellfish Sanitation Program led by the Canadian Food Inspection Agency in partnership with Environment and Climate Change Canada and Fisheries and Oceans Canada. If unsafe bacteria levels are measured in shellfish and/or if shoreline investigations show pollution concerns, shellfish harvesting in the growing area will be restricted or prohibited. Between 2006 and 2010 (the most recent



year for which data are available) the share of shellfish growing areas in the Atlantic, Quebec and Pacific regions that were either approved or conditionally approved for harvest either remained stable or increased, though more than 4,000 square kilometres of growing areas were either restricted or conditionally restricted in 2010.

The risks associated with consumption of contaminated drinking water are managed by local governments for Canadians with municipal water supplies. Most drinking water in Canada is of high quality, and the risk of exposure to pathogens is low. It is not zero, however, as the need to issue boil-water advisories from time to time proves. In 2015, 10 per cent of households in Canada reported that they had been notified of a boil-water advisory. Households in Manitoba (36 per cent) were most likely to have reported one (Statistics Canada, 2016b). According to Environment and Climate Change Canada (2016h), roughly one quarter of advisories are issued because of concerns related to microbiological contamination of water (Figure 11). The situation on First Nations communities is, in general, considerably worse than that for the general population (Text Box 6).

Illness from contamination of drinking water is not common in Canada. Nonetheless, Canadians remain concerned about the quality of the tap water they drink and many choose to minimize their consumption of tap water. According to Statistics Canada (2016b), 19 per cent of Canadian households reported drinking primarily bottled water at home in 2015, down from 23 per cent in 2013 and 30 per cent in 2007. The reasons for the downward trend in bottled water consumption are not clear but may have something to do with fading memories of the Walkerton tragedy in Ontario in 2000, in which seven people died and hundreds fell ill from drinking water contaminated with bacteria from cow manure (Text Box 5).

Choosing bottled water over tap water is just one way Canadians modify their behaviour in response to concerns about the quality of drinking water. Another is to treat drinking water before consuming it. Just over half of all households (51 per cent) did so in 2015 (up from 47 per cent in 2007). “Brita” style jug filters were the most common method of treating drinking water, with 25 per cent of households reporting their use. More sophisticated filters attached directly to taps or water lines were the second-most common method, used by 18 per cent of

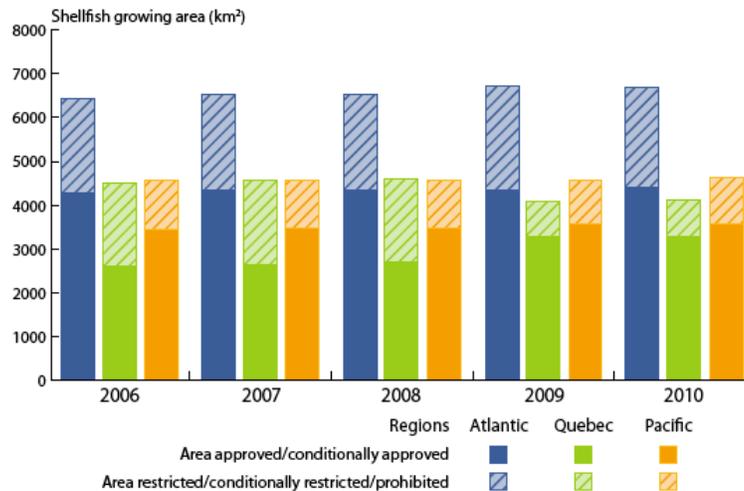


Figure 10. Shellfish Growing Area Quality, 2006–2010

Source: Environment and Climate Change Canada, 2016g.

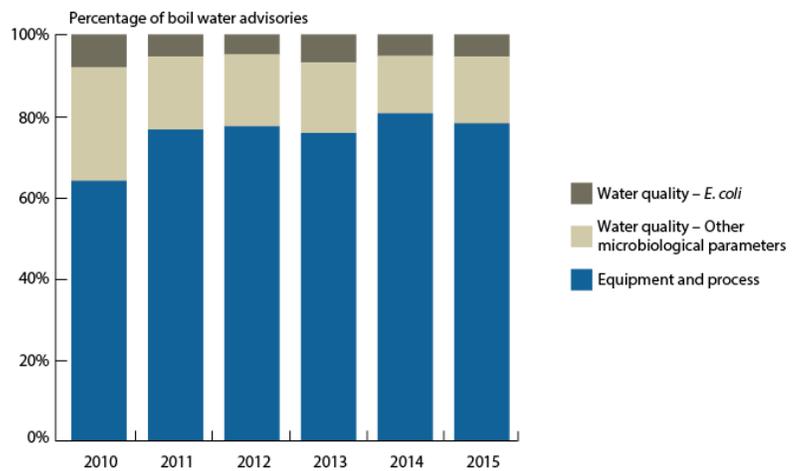


Figure 11. Should be Drinking Water Advisories in Canada, 2010–2015

Source: Environment and Climate Change Canada, 2016h.



households. Boiling water to make it safe to drink was reported by 12 per cent of households in 2015 (Statistics Canada, 2016b).

Dupont and Jahan (2012) have estimated that the spending of Canadian households on bottled water and water filtration devices (with the goal of avoiding possible negative health impacts of contaminated water) equated to an average willingness to pay for improved water quality of about US\$19 (2010 prices) per person (about \$27 in 2015 after taking inflation into account). This figure is supported by the finding of Beaumais, Briand, Millock, and Nauges (2010) that households across 10 medium- and high-income countries (including Canada) were willing to pay on average 7.5 per cent of the median household water bill for improved water quality. Statistics Canada (2017a) reports that the average household spending on water and sewerage in Canada was \$350 in 2015, which would imply a willingness to pay of \$26.25 (this figure is likely on the high side, since it reflects spending not just on water supply but also sewerage).

Dupont and Jahan's figure is also supported by the results of a study to estimate the benefits of water quality improvements in the Grand River watershed in southern Ontario that found a willingness to pay equal to 19 per cent of the average water bill (Brox, Kumar, & Stollery, 1996). The higher willingness to pay found by Brox et al. compared with the results of Beaumais et al. (7.5 per cent of the median water bill) may reflect the fact that the former were working in the context of a single, highly industrialized and relatively affluent watershed whereas the latter considered willingness to pay across a number of countries with varying levels of water quality and economic circumstances.

The data used in Dupont and Jahan's study were collected just a few years after the Walkerton tragedy, which elevated the issue of drinking water quality in the minds of many Canadians, especially in Ontario. More recent evidence suggests that Canadians' confidence in the quality of their drinking water may be increasing. As noted, Statistics Canada (2016b) data show that the number of Canadians minimizing their consumption of tap water is on the decline. The share of households reporting tap water as their primary source of drinking water increased from 59 per cent in 2007³⁴ to 69 per cent in 2015, suggesting growing confidence in tap water. However, a greater percentage of Canadians were found to be treating their drinking water prior to consumption (47 per cent in 2007 versus 51 per cent in 2015).



Photo courtesy of Alberta Venture

“ In 2015, 10 per cent of households in Canada reported that they had been notified of a boil-water advisory. ”

Assuming that Canadians' confidence in their drinking water has improved by about 6 per cent (the difference between the increase in the number of people drinking tap water and the number of people treating their drinking water), the average willingness to pay found by Dupont and Jahan might be adjusted downward from \$27 per person to \$25 per person. Given a 2015 population estimate of 35,848,600, this would equate to an annual willingness to pay of about \$895 million for the health benefits of improved drinking water quality.

³⁴ 2007 is the first year following the Walkerton tragedy for which Statistics Canada collected such data.



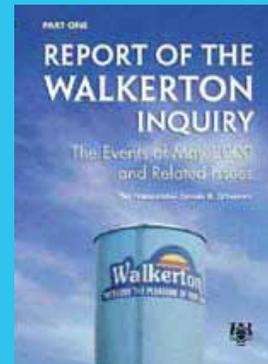
Text Box 5. The Walkerton Tragedy

The most famous case of waste-related pathogens impacting human health in Canada is that of the so-called Walkerton tragedy. In May 2000, seven people in the small town of Walkerton in southern Ontario died and some 2,300 became ill from drinking municipally supplied tap water that had been contaminated with *Escherichia coli* O157:H7 and *Campylobacter jejuni*, both bacteria with the ability to cause severe gastrointestinal illness.

The direct cause of the contamination was determined to be cattle manure spread near one of the three groundwater wells the Walkerton Public Utilities Commission used to supply water to the town. The indirect causes of the tragedy were, however, very much human. Following a criminal trial and a public inquiry, it was determined that negligence on the part of the water treatment plant operators coupled with cutbacks in the provincial water-quality assurance systems had been the real causes of the tragedy.

A study of the economic consequences of the tragedy undertaken for the public inquiry determined that the costs in terms of human welfare amounted to about \$91 million, using a figure of \$8 million for the value of a statistical life and a “rough estimate” of \$15,000 per case of gastrointestinal illness (Livernois, 2002b). The costs in terms of impacts on market consumption were estimated to be \$64.5 million (Livernois, 2001a).

Fortunately, a drinking water tragedy of Walkerton’s scale and cost has not been witnessed since. This is not to say that one will not. Though low for most Canadians, the risk of contamination of drinking water from agricultural activities is growing due to increased numbers of livestock on farms (Environment and Climate Change Canada, 2016i). The risk is also much greater for Canadians living in Indigenous communities (Text Box 6).



Text Box 6. Water Quality on First Nations Reserves

Two-thirds of all First Nation communities in Canada have been under at least one drinking water advisory at some time in the last decade. Data show that 400 out of 618 First Nations in the country had some kind of water problem between 2004 and 2014. The longest running advisory is in the Neskantaga First Nation in Ontario, where residents have been required to boil their water for 20 years (Levasseur & Marcoux, 2015). In the summer of 2015, advisories were in place in 114 First Nations (McClearn, 2016).

Indigenous and Northern Affairs Canada (INAC) conducts regular performance inspections to determine the risk levels of INAC-funded water and wastewater systems. Of the 719 INAC-funded First Nations water systems inspected in a 2011 “national assessment”, 525 systems (73 per cent) were found to be of either medium or high risk for producing unsafe drinking water (Figure 12). Systems at higher risk tend to be in smaller and more remote communities, so the share of the First Nations population at medium or high risk was smaller than this.

The evidence shows that improvements are being made but that there remains considerable work to be done. Though the share of systems assessed as low risk grew considerably between 2011 and 2015, 43 per cent of systems (304 of 699) remained in the medium- or high-risk categories in 2014/15.

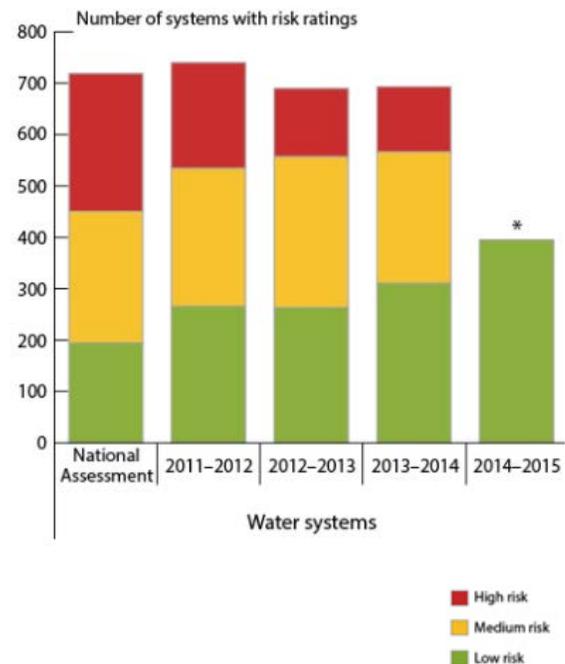


Figure 12. Risk Ratings for INAC-Funded First Nations Water Systems

Source: Environment and Climate Change Canada, 2016j.



3.3.2.2 Toxins

A serious consequence of the pollution of surface water bodies is excess growth of aquatic plants, a process known as eutrophication (see Section 5.3.1 for further details). Under natural conditions, nutrients are in limited supply in aquatic ecosystems, and plant growth is kept in check. When pollutants containing nitrogen and phosphorus (e.g., municipal sewage and fertilizer runoff) enter water bodies, aquatic plant growth can exceed its natural level. If sufficient nutrients are available, plant growth will occur to the point where water bodies become choked with plant biomass.

The consequences of eutrophication are numerous. Here, the main concern is excess growth of various forms of algae that have the ability to produce compounds that are toxic to humans and animals. These include so-called “blue-green algae,” which are actually not algae at all, but cyanobacteria that form in large masses, or blooms, in surface fresh and salt waters.

Lake Erie has been particularly affected by blue-green algae in recent years, with large blooms of *Microcystis aeruginosa* and other cyanobacteria forming in the lake’s western basin every summer. *Microcystis aeruginosa* produces the liver toxin *Microcystin*, the symptoms of which can include skin irritation, nausea, vomiting and, in rare cases, acute liver failure.

A study carried out in 2015 for Environment and Climate Change Canada considered the economic costs of algal blooms on Lake Erie (Midsummer Analytics and EnviroEconomics, 2015). It found no that human deaths had been reported as a result of the blooms. Nor was there evidence of morbidity impacts on Canadian users of the lake, though it was noted that unreported (or incorrectly diagnosed) cases of illness were possible. Moreover, the authors concluded that the number of any such cases is likely to be small today and in the future. Public health authorities are careful to post signs warning people to stay out of the water when blooms are present. In addition, the blooms themselves are unsightly. Most people would be sensible enough to steer well clear of the water when a bloom is present.

Algal blooms also affect ocean waters, where they produce a variety of toxins that can be concentrated in filter-feeding shellfish. If eaten, contaminated shellfish have the potential to cause gastrointestinal illness, paralysis, memory loss, brain damage and death. Available data from the Public Health Agency of Canada (PHAC) suggest that the number of cases of shellfish poisoning in Canada is low, though only paralytic shellfish poisoning is treated as a nationally reportable disease. No cases of paralytic shellfish poisoning were reported to PHAC between 2007 and 2014 (PHAC, 2016). Two deaths were reported in Alaska in 2010 (McColl, 2016). There have been no cases of amnesic shellfish poisoning since the illness was first reported in 1987 (Lefebvre & Robertson, 2010).



Though shellfish toxin poisoning is extremely rare, the risks are increasing as coastal algal blooms increase in extent and frequency. For example, in the summer of 2015, an unprecedented toxic bloom of the marine diatom *Pseudo-nitzschia*, stretching from central California to the Alaska Peninsula, resulted in significant impacts to coastal resources and marine life. *Pseudo-nitzschia* produces the neurotoxin that leads to amnesic shellfish poisoning (domoic acid). In this massive bloom, the largest and longest-lasting in at least the past 15 years, domoic acid concentrations in Monterey Bay, California, were 10 to 30 times the level that would be considered high for a



normal *Pseudo-nitzschia* bloom. The blooms were suspected in the unusual deaths of 30 large whales, though no conclusive evidence was found of a link. The full economic impact of these closures is still being calculated (National Ocean Service, 2016).

3.3.2.3 Methemoglobinemia

Methemoglobinemia is a disorder in which the ability of blood to transport oxygen to the body is disrupted. In infants, it can be caused or exacerbated by the ingestion of water containing nitrate ions (NO_3^-) (Fertwell, 2004). Nitrate can be present in water from nitrogen-containing precipitation or dust falling on surface water, from industrial and sewage treatment plant effluents and, most importantly, from the runoff of nitrogen-containing commercial fertilizers or manure into water bodies.

Nitrate is found in both untreated surface and groundwater across Canada and in treated drinking water. Though the levels in both untreated and treated water are generally below the Canadian drinking water standard of 45 mg NO_3^- per litre, there is ample evidence that levels in both untreated and treated water occasionally exceed this standard in specific locations and that nitrate pollution is increasing over time. Nitrate levels are generally higher in groundwater than in surface water and are highest around agricultural areas (Health Canada, 2013a).

There is no evidence of any infant deaths from nitrate-induced methemoglobinemia in Canada in recent decades. The last reported death in North America was a Wisconsin infant who died in 1987 (Johnson et al., 1987). There is evidence, however, that non-fatal cases of the illness occur but go either undiagnosed or unreported (Johnson et al., 1987).

3.3.3 Pesticides

Pesticides have a number of adverse health effects. Exposure to pesticide can result in acute poisoning, which in turn may result in hospitalization or even death. There are also many chronic impacts from pesticide exposure, including neurological effects, respiratory and reproductive effects, and cancer (Pimentel, 2005). Health impacts are most prevalent among farmers and farm workers. Neurological effects include memory loss, language problems, and learning impairment, as well as organophosphate-induced delayed polyneuropathy. Respiratory impacts include asthma, chronic sinusitis, and chronic bronchitis. Pesticides have also been linked to sterility. Many insecticides and herbicides are also carcinogens, with farm workers being more susceptible to certain forms of cancer. The health effects of pesticides are more acute in children than among adults. This is in part due to the higher metabolic rate of children.



The Pest Management Regulatory Agency (PMRA) began collecting pesticide incident reports in 2007. These reports identify the risks to humans, domestic animals and the environment posed by pesticides. They aid in the development of risk reduction measures, such as better labelling, and the development of new regulations. Both Canadian and U.S. incident reports are collected by the PMRA.

From 2007 to 2014, 12,585 incident reports were submitted to the PMRA. Pesticide incidents are classified into death, major, moderate, and minor. Minor incidents are those that are minimal and resolve quickly without medical



intervention. Moderate incidents are more pronounced and may require some form of medical treatment, while major incidents may be life-threatening or result in chronic disability (PMRA, 2014).

In 2014, the most recent year for which data are available, the PMRA received 1,884 incident reports, with 216 human incident reports in Canada. The majority of pesticide incident reports related to domestic animals and most of the incidents involved products that can be purchased and used by the general public (PMRA, 2014).

The most common form of exposure was inhalation or skin contact. Itchy skin was the most commonly reported symptom, with gastrointestinal, nervous and muscular symptoms also regularly reported. Six of the human incident reports in Canada were major in severity or involved a death, with four of these determined to be directly related to pesticide exposure.

Of the 29 incidents classified as “major or death” in 2014, 19 were considered by the PMRA to be unrelated to the reported pesticide exposure.³⁵ Four of the remaining 10 serious incidents occurred in Canada. All of them occurred as a result of contact with pesticides during their production, use or storage, so none could be considered an impact of pesticide pollution. Many of the moderate and minor incidents did, however, involve exposure to pesticide pollution (e.g., drift of aerosols containing pesticides from the site of application to nearby residences). The one serious incident that resulted in death involved an individual who died after accidentally drinking a pesticide that was being improperly stored in a beverage container, so was not pollution-related.

The data contained in the PMRA incident reports provide evidence that pesticide pollution does have an impact on human welfare in Canada, but the impact might be low. Most reported pesticide incidents are not pollution-related (but related to the handling of pesticides in production, use or storage), and most are rated as minor or moderate by the PMRA. A fuller investigation of the PMRA database, which is large, was beyond the scope of this report.

Of course, not all exposure to pesticide pollution is reported to the PMRA. Much exposure simply goes unnoticed, as it occurs at low levels through the consumption of food or water containing pesticide residues or from outdoor activities in areas where residues are found on plants or in the soil. Though the direct welfare costs of this exposure are unknown, scientists are getting closer to being able to quantify it. Section 4.3.3 below discusses the possible costs of one health impact of pesticides and other persistent organic pollutants (disruption of the human endocrine system). Though the results are tentative, the costs of endocrine disruption from POPs may be on the order of tens billions of dollars annually, putting it on par with the costs of PM_{2.5} and ground-level ozone, the pollutants currently thought to have the greatest direct welfare costs.

3.3.4 Heavy Metals

Heavy metals are a group of elements including arsenic, cadmium, chromium, nickel, mercury and lead. These metals are emitted as pollutants from fuel combustion, leach out of solid waste and are used in some industrial processes. Heavy metals can be emitted into the air where inhalation can cause negative health impacts. They are also released to soil and water where they concentrate in organisms or water, and ingestion is the primary impact pathway. This complexity makes estimating the health impacts of heavy metals difficult. Arsenic, cadmium, chromium and nickel are considered to be carcinogenic, while lead and mercury’s main health effects are related to brain toxicity (Rabl, Spadaro, & Zoughaib, 2008).

Heavy metals are also found in airborne particulate matter, and therefore contribute to the impacts of PM, including cardiovascular and bronchovascular health impacts. As a result, valuing heavy metals on their carcinogenic and neurotoxic impacts alone risks underestimating the impact. However, valuing both the impact of particulate matter and heavy metals risks double counting these impacts, although the European Energy Agency has concluded that this risk is small (European Energy Agency, 2014).

³⁵ In total, 6 of the 29 incidents classified as “major or death” occurred in Canada.



Mercury is a toxic element found throughout the environment, and is naturally emitted by volcanoes and from the ocean. However, 50 to 80 per cent of total emissions are the result of human activity, including fossil fuel combustion, industrial leaks and disposal or incineration of waste (EPA, 2011). There are three common forms of mercury: pure (or elemental) mercury, organic mercury and inorganic mercury. Methyl mercury, an organic compound, is of the greatest concern for human health, as it builds up in plants and animals and can move up the food chain (Products Containing Mercury Regulations, 2014).

Mercury has a complex set of pathways through the environment and can change forms several times. Elemental mercury—Hg(0)—is commonly emitted from human activities and has a lifetime of one to two years in the atmosphere. Hg(0) can also evaporate after it has been deposited on land or water, returning to the atmosphere to continue travelling. These characteristics make mercury a global pollutant. Attention must be therefore paid to emission levels worldwide rather than just local emissions (Spadaro & Rabl, 2008). More than 95 per cent of mercury pollution deposited in Canada originates from foreign sources. Mercury concentrations in the Arctic are of particular concern, as global atmospheric cycles tend to concentrate in polar regions (Products Containing Mercury Regulations, 2014).

The primary health effect pathway of mercury is through the consumption of fish with high levels of methyl mercury (Text Box 7). This compounds the ability of mercury to travel across the globe, as the international fish trade spreads the pollutant (Belhaj et al., 2008). Exposure to mercury causes a number of health impacts, including brain, nerve, kidney, lung or cardiovascular damage. Low levels of methyl mercury exposure can impact the development of the brain, with children and fetuses being particularly sensitive (Products Containing Mercury Regulations, 2014).

Lead has a number of harmful health effects, with infants and children being most susceptible. Health effects include disruption of brain development, brain degeneration, cardiovascular, liver and reproductive impacts. Disrupted brain development is the primary concern, as is the case with mercury. It can lead to reduced IQ and attention-related behaviours. Evidence of lead poisoning is detectable in children and infants even at the lowest measurable levels of lead. This has led to the conclusion that there is no safe threshold for adverse health effects (Health Canada, 2013b).

The other common heavy metals (cadmium, chromium, nickel and arsenic) are carcinogenic. Their health impacts vary based on whether the pollutant is inhaled or ingested. Cadmium, chromium and nickel are only known to be carcinogenic through inhalation (Rabl, Spadaro, & Zoughaib, 2008).

Estimating the health impact cost of mercury and lead is commonly done by linking exposure to reductions in IQ. Reduced IQ is linked to lower educational success and loss of earnings (Belhaj et al., 2008). A recent regulatory impact assessment for mercury emissions in Canada used an estimate of \$6,110 per kg (2012 prices) as the

Text Box 7. Mercury contamination at Grassy Narrows

Grassy Narrows First Nation has long dealt with mercury contamination. A Reed Paper chemical plant in Dryden, Ontario dumped mercury directly into the English-Wabigoon River system from 1962 to 1970. Mercury accumulated in the fish, resulting in widespread mercury poisoning among the people of Grassy Narrows. Reed Paper, the Great Lakes Forest Company and the federal and provincial governments agreed in 1985 to a payout of \$17 million to compensate them for the health impacts of the contamination. The closure of the local fishery also resulted in significant job and economic losses (Galloway, 2017).

The end of direct dumping did not end the community's struggle with mercury contamination, however. A report released in February 2017 shows that water downstream of the mill still has mercury levels 130 times higher than upstream. Ninety per cent of people in Grassy Narrows suffer from mercury poisoning, including those born after the dumping ended.

Evidence points to a point-source of mercury at the mill site that is still leaching into the river. The Province of Ontario has agreed to remediate the site by removing the contaminated material at the point-source as well as mercury from the water (Galloway, 2017). As of early 2017, the only spending was \$300,000 that had been dedicated to further testing (Porter, 2016).



estimate of the health cost of mercury (Products Containing Mercury Regulations, 2014). Due to the global spread of mercury, Spadaro and Rabl (2008) have suggested a global average cost estimate of US\$3,400 per kg (2005 prices). The European Energy Agency (EEA, 2014) estimated the global cost of mercury as 2,860 euros per kg. UNEP (2013) estimates that global mercury emissions to air and water were roughly 3,000 tonnes in 2010, suggesting that the global cost of mercury emissions in that year was on the order of \$20 to \$30 billion depending on which estimate of the cost per kg is used.

Based on Environment and Climate Change Canada (2017a) estimates, Canadian mercury emissions were at least 3.9 tonnes in 2014 (the last year for which data are available), or about 0.1 per cent of global emissions. However, given global atmospheric transport of mercury and the fact that much of Canadians' exposure to mercury is through consumption of fish, much of it imported, it is not clear that Canadian emissions and Canadians' exposure to mercury are closely correlated. For this reason, no estimate of the cost of mercury pollution in Canada is proposed here.

The EEA (2014) has estimated the following European average costs for other heavy metals: lead – 965 euros per kg) arsenic – 349 euros per kg; cadmium –29 euros per kg; chromium –38 euros per kg and nickel – 3.8 euros per kg (2005 prices). No studies were found with costs specific to Canada. Again, given this limited evidence base, no cost for the impacts of these pollutants in Canada is proposed here.

3.3.5 High-Level Nuclear Wastes

Canadian nuclear power accounts for about 16 per cent of the country's electricity production. In total, 19 reactors are currently in operation, 18 of which are located in Ontario. Nuclear power plant waste is dealt with by the Nuclear Waste Management Organization. Roughly 1,500 tonnes of used fuel (high-level nuclear waste) are disposed of per year in Canada (World Nuclear Association, 2016a). For now, this waste is stored and managed in seven different facilities, including nuclear reactor sites in Ontario, Quebec, and New Brunswick, and two laboratories managed by Atomic Energy of Canada Limited, one in Manitoba and one in Ontario (Figure 13). Waste is stored for 7 to 10 years in water-filled pools. Once the heat and radioactivity of the waste has decreased, it is moved into dry storage containers that have a minimum life span of 50 years (Nuclear Waste Management Organization, n.d.a). A solution for the long-term storage of Canada's nuclear power plant waste is currently being considered (Text Box 8).

“ Heavy metals can be emitted into the air where inhalation can cause negative health impacts. They are also released to soil and water where they concentrate in organisms or water, and ingestion is the primary impact pathway. ”



Figure 13. Nuclear waste storage sites

Source: Nuclear Waste Management Organization, n.d.a.



Text Box 8. Long-term storage of high-level nuclear waste in Canada

Radioactive waste remains harmful long after the 50-year lifespan of dry containment, so a long-term storage plan is required. The Canadian government began a process in 2007 to develop a phased management plan for the long-term storage of high-level nuclear waste. The plan involves deep-rock burial of nuclear waste at a site with suitably stable geology and a willing community host. Waste will be buried 500 to 1,000 metres deep in the Canadian Shield. A process to choose a site for burial was started in 2010 (Nuclear Waste Management Organization, n.d.b).

Site selection is guided by a two-stage process consisting of an initial screening and a detailed evaluation to ensure that the chosen site will protect the environment, human health and the well-being of the host community. The initial screening criteria are:

- The site must have available land of sufficient size to accommodate the surface and underground facilities.
- This available land must be outside protected areas, heritage sites, provincial parks, and national parks.
- This available land must not contain known groundwater resources at the repository depth that could be used for drinking, agriculture, or industrial uses, so that the repository site is unlikely to be disturbed by future generations.
- This available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.
- This available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe.

Any area that meets these initial criteria must then undergo a more detailed evaluation to ensure that the site is able to safely contain the nuclear waste, and that the community accepts and supports the project (Nuclear Waste Management Organization, n.d.c). There are currently nine communities undergoing assessment: Blind River, Central Huron, Elliot Lake, Hornepayne, Huron-Kinloss, Ignace, Manitouwadge, South Bruce, and White River (Nuclear Waste Management Organization, 2016).

Health risks due to the storage of nuclear power plant waste are uncertain and depend on the effectiveness of their management. As noted, waste nuclear fuel is currently managed on-site at nuclear power stations in Canada as part of normal operations. This will change as the country moves forward with plans for deep-rock burial. Any health impacts of this decision are, obviously, not yet known. Risks from storage can be minimized if storage sites are permanently maintained in good condition, a costly endeavour (see Section 4.6.3 for further discussion of the costs of long-term management of nuclear wastes).

The evidence regarding the health impacts of normally operating nuclear power plants is inconclusive. Though some studies suggest an increase in the rate of childhood leukemia for those living with 5 kilometres of nuclear power stations, there is not agreement on the cause of the increase (Baker & Hoel, 2007; ExternE, 1995; Kaatsch et al., 2008; Little, McLaughlin, & Miller 2008; National Research Council, 2010; Ontario Hydro, 2003; Rabl & Rabl, 2013; US Department of Energy & Commission of European Communities, 1994).

Of course, large-scale accidents at nuclear power plants have the potential to impose great health costs. Fortunately, there have been relatively few such accidents since the beginning of the nuclear age. In the roughly 70 years that nuclear power plants have been in operation around the world, there have been three incidents (Hasegawa et al., 2015) at civilian nuclear power plants rated 5 or more (out of a maximum of 7) on the *International Nuclear and Radiological Event Scale* (INES) of the International Atomic Energy Agency (IAEA)³⁶ (IAEA, n.d.):

³⁶ Though the International Atomic Energy Agency has created the *International Nuclear and Radiological Event Scale* for the purpose of communicating nuclear accidents, the agency does not appear to maintain a public list of such events. Thus, Wikipedia is used here as the source. A number of the incidents listed in Wikipedia for which no INES level is provided appear to have been INES level 5 or above.



- 1979 (INES level 5) – Partial meltdown at the Three Mile Island power plant in Pennsylvania, United States. No immediate radiation-related injuries or fatalities and no evidence of long-term health effects (Talbot et al., 2003).
- 1986 (INES level 7) – Complete meltdown of the Chernobyl nuclear power plant in Pripyat, Ukraine (see Text Box 9 for a discussion of the health impacts of this disaster).
- 2011 (INES level 7) – Partial meltdowns in multiple reactors at the Fukushima I Nuclear Power Plant in Japan as a result of an offshore earthquake and subsequent tsunami. No immediate radiation-related injuries or deaths were reported, but considerable morbidity and mortality associated with displacement of residents from the contamination zone (World Nuclear Association, 2017). A study by researchers at Stanford University (McClure, 2012) puts the probable eventual global health burden due to cancer associated with the accident at 180 non-fatal cases of cancer and 130 cancer deaths. Most of the radioactivity released during the accident ended up in the ocean, keeping the population exposed to high doses of radiation relatively small.

Fortunately, no serious nuclear power plant accident has occurred in Canada since the 1950s.³⁷ It is worth asking, however, what the economic costs might be if one were to occur. Though there is relatively little evidence to look to, as serious nuclear accidents are rare anywhere, Rabl and Rabl (2013) have made an attempt based on the events at Three Mile Island, Chernobyl and Fukushima. Assuming a total of 10,000 worldwide deaths and 500,000 evacuees per large accident, they estimated total costs of about 354 billion euros (\$574 billion) not including pain and suffering associated with morbidity due to radiation or evacuation. Of this, only about 5 per cent is health related (cancer deaths); the rest is related to other economic impacts (Table 2).

Table 2. Potential cost of a large nuclear accident

Impact		Estimated cost in billions of euros (\$)
	Mortality due to cancer (10,000 deaths assumed worldwide)	18.8 (30)
	Replacement of reactors	30 (49)
	Cleanup	30 (49)
	Evacuation (500,000 persons)	250 (405)
	Loss of agricultural output	7.5 (12)
	Lost electric power	18 (29)
Total		354 (574)

Source: Rabl and Rabl, 2013.

³⁷ Accidents involving research reactors at Atomic Energy of Canada Limited’s Chalk River research station in Ontario occurred in 1952 and 1958. They would have been rated INES level 5 had the rating system existed then. In neither case did any immediate deaths result and, according to follow-up studies conducted by Atomic Energy of Canada Limited, there is no evidence of long-term illness among those involved in the cleanup of either accident (Werner, Myers, & Morrison, 1983).



Text Box 9. The Chernobyl Disaster

The immediate health consequences of the Chernobyl nuclear accident are well documented. Two plant workers died on the night of the accident from the effects of acute radiation poisoning. Acute radiation poisoning was eventually confirmed in 134 additional cases. Of these, 28 people died within a few weeks of the accident (World Nuclear Association, 2016b).

As for longer-term health effects, there remains considerable debate except in the case of thyroid cancer (Cardis, Howe et al., 2006). As of 2002, nearly 5,000 cases of thyroid cancer were observed—mostly in children, adolescents and young adults—in Belarus, Ukraine and the most contaminated regions of Russia (Cardis, Howe, et al., 2006). Of these cases, 15 had proven fatal. By 2006, the number of cases had risen to

6,000 (no additional deaths had been reported) and was expected to continue rising (Gronlund, 2011). In Belarus, the rate of childhood thyroid cancer increased from about 0.03–0.05 cases per 100,000 prior to the disaster to 4 per 100,000 by 1995. By 2002, it had fallen back to pre-disaster levels while the rates for adolescents and young adults had climbed, reflecting the aging of those who were exposed to radiation at the time of the disaster (Cardis, Howe, et al., 2006).

The evidence for other forms of cancer is less clear. In a study authored by some 30 experts from around the world, Cardis, Howe, et al. (2006), concluded that “no clearly demonstrated increase in the incidence of cancers [other than thyroid] can be attributed to radiation exposure from the accident.” However, “the absence of a demonstrated increase in total cancer risk is not proof that no increase has, in fact, occurred.” The researchers found some evidence of links to childhood leukemia in the Ukraine, though it was inconclusive, in part, because of problems with the study design. They also found evidence of links to increased levels of breast, bladder and kidney cancers, though it was also inconclusive, again in part because of problems in study design. They also noted that “because most radiation-related solid cancers [that is, those involving tumours] continue to occur decades after exposure and because only 20 years [had] passed since the accident [at the time of the study], it [was] too early to evaluate the full radiological impact of the accident” (Cardis, Howe, et al., 2006, p. 136).

The number of cancer cases and deaths that will ultimately result from the Chernobyl disaster can only be predicted on the basis of modelling. Different researchers come to different conclusions. In a different study, Cardis, Krewski et al. (2006) suggest the totals could reach 2,400 cases of leukemia (1,650 deaths), 4,450 cases of breast cancer (2,100 deaths), 15,700 cases of thyroid cancer (no estimate of death since thyroid cancer is generally not fatal) and 22,800 (14,100 deaths) for other cancers (for a total of 45,350 cancer cases and 17,850 deaths). The Union of Concerned Scientists puts the figures somewhat higher than this, at 53,000 cases and 27,000 deaths from all cancers excluding thyroid cancer (for which no estimate is given) (Gronlund, 2011). Yet another authoritative study, this one undertaken by a number of multilateral organizations including the World Health Organization working together as The Chernobyl Forum, put the probable total number of eventual deaths at 4,000 (The Chernobyl Forum, 2006).

Alongside the cancer-related illness associated with the disaster are the long-term mental health effects on those who lived through it and its aftermath. Some 350,000 people were eventually relocated to lessen their radiation exposure, though it is not clear the relocations were always effective (WHO, IAEA, & UNDP, 2005). The Chernobyl Forum health report concluded in 2005 that “the mental health impact of Chernobyl is the largest public health problem unleashed by the accident to date.” (Chernobyl Forum, 2006, p. 36).





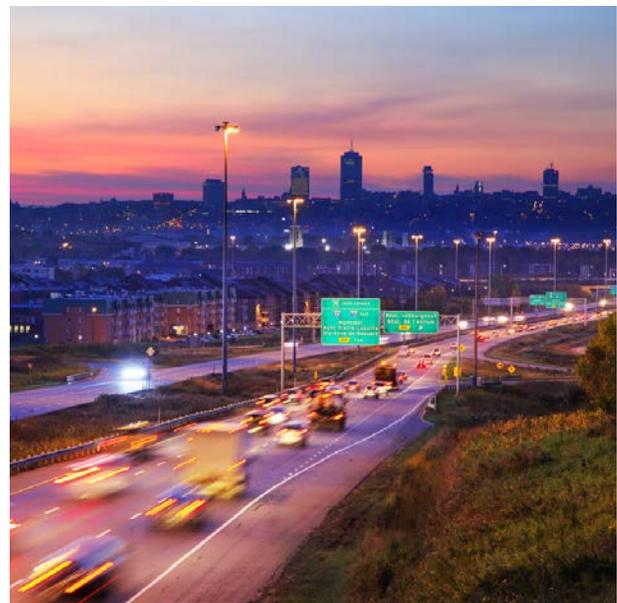
3.3.6 Noise and Light Pollution

The economic cost of noise pollution has been widely investigated, though most studies were carried out in the 1980s and 1990s. The cost of light pollution has not been nearly as thoroughly investigated. The few studies focusing on it mainly consider its costs in terms of the energy required to power street lights in urban areas.

Noise pollution and light pollution differ significantly in that the former has no external benefits (that is, no one other than the person producing it benefits in any way from noise) whereas the latter has significant external benefits. This means that all noise is pollution, but that only some light is pollution. This may explain why less effort has been invested in studying the economic costs of the latter.

The most studied type of noise pollution is that from road traffic, likely because it affects almost everyone to some extent. Several factors affect the amount of noise emitted by traffic and its costs (Victoria Transport Policy Institute, 2017):

- **Vehicle type:** Motorcycles, heavy vehicles (trucks and buses), and vehicles with faulty exhaust systems tend to produce high noise levels.
- **Engine type:** Older diesel engines tend to be the noisiest, followed by gasoline and natural gas, hybrid, and electric vehicles being quietest.
- **Traffic speed:** Lower speeds tend to produce less engine, wind and road noise.
- **Topography:** Engine noise is greatest when a vehicle climbing an incline.
- **Aggressive driving:** Engine noise is greater with faster acceleration and harder stopping.
- **Pavement type and condition:** Certain pavement types and smoother road surfaces emit less noise.
- **Distance and barriers:** Noise declines with distance and is reduced by structures, walls, trees, hills and sound-resistant design features such as double-paned windows.



Railways and airplanes also contribute to transportation noise pollution, but the automobiles, trucks, buses and motorcycles that travel the nation's roads are by far the largest sources. Other sources include construction activities and industry.

In a study of the cost of noise from motor vehicles in the U.S., Delucchi and Hsu (1998) concluded that the cost could range from US\$100 million to US\$40 billion annually (1991 prices), with the actual value unlikely to “exceed \$5 billion to \$10 billion annually,” or about 0.08 per cent to 0.16 per cent of 1991 US GDP. A variety of factors accounted for the wide range of their estimates, including assumptions about thresholds, interest rates, noise attenuation, housing density, traffic speeds and other costs of noise.

In its study *Estimates of the Full Cost of Transportation in Canada*, Transport Canada (2008) estimated the cost of noise related to transportation in Canada to be about \$260 million in 2000 (\$345 million in 2015). This figure was, the study noted, considerably lower as a fraction of GDP than most similar estimates for other industrialized nations (see Figure 14). The average value for OECD countries in the early 1990s was reported to be about 0.15 per cent of GDP (Victoria Transport Policy Institute, 2017), which would amount to about \$3 billion (Statistics Canada,



2016c) in Canada in 2015. Transport Canada acknowledges that “the level of uncertainty is high” in its estimate of noise-related costs and that the costs are “very conservative.” Thus, \$345 million might be taken as a lower bound on the direct welfare costs of noise and \$3 billion could be taken as an upper bound.

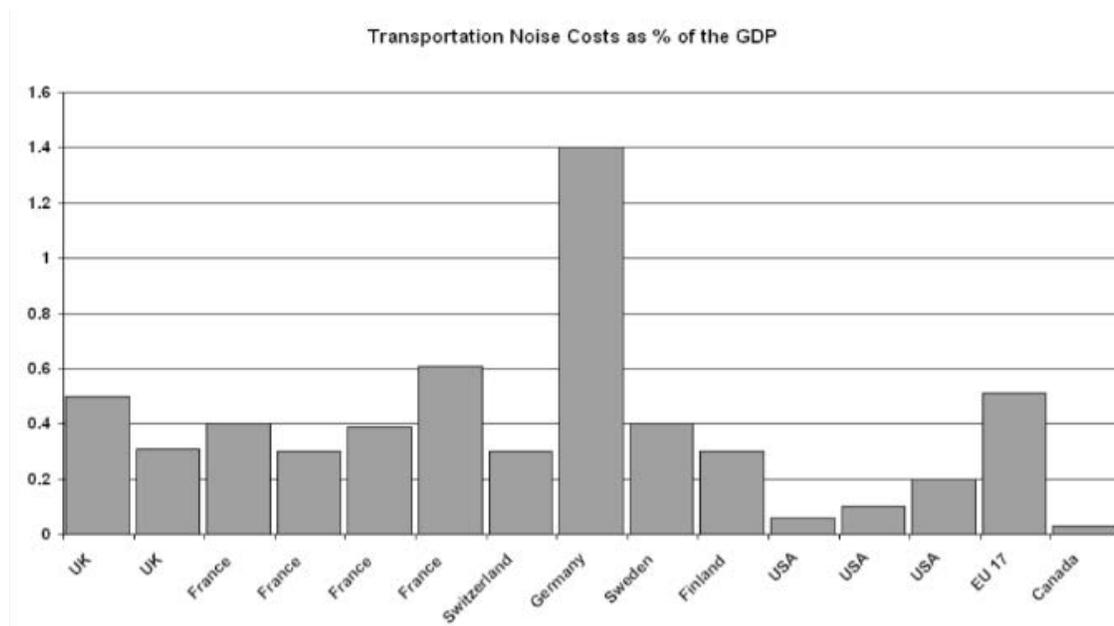


Figure 14. The costs of transportation noise in various countries

Source: Transport Canada, 2008.

3.3.7 Extreme Weather

Extreme weather events, such as floods, hurricanes and heat waves, can result in deaths and other human health impacts. Of course, not all extreme weather events can or should be attributed to pollution as weather extremes occur naturally, but it is clear that anthropogenic climate change is increasing both the frequency and severity of some extremes (National Academies of Sciences, Engineering and Medicine, 2016).

Probabilistic event attribution is a method for assessing the relationship between climate change and extreme weather. Of course, it is all but impossible to state with certainty that a specific event has been caused by climate change. Natural variability is and always will be an important factor. Probabilistic event attribution speaks instead to trends, such as the severity and intensity of extreme weather (National Academies of Sciences, Engineering, and Medicine, 2016).

Using probabilistic event attribution, it is in principle possible to estimate the socioeconomic impacts of extreme weather. However, in spite of advances in the understanding of the links between climate change and extreme weather, current uncertainties and shortcomings make impact valuation difficult except in a few instances (Otto, James & Allen, 2014). Climate change and extreme weather can be most confidently linked when the mechanisms that cause the extreme weather are well understood. Confidence is improved when that mechanism is linked to a known impact of climate change, such as increased temperatures. Non-meteorological factors, including human interference, reduce the confidence of attribution.

Confidence of attribution is highest for extreme heat, followed by extreme cold, drought and rainfall events. Attribution of wildfires to climate change is difficult due to the non-meteorological factors that impact regularity and severity.



Climate change is likely to increase the severity and frequency of extreme heat events. The Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report assessed increases in heat waves due to climate change for North America and stated (with "medium confidence") that it is very likely that heat waves will happen more frequently and be more severe in the future (Collins et al., 2013; Hartmann et al., 2013).

A recent study (Gasparrini et al., 2015) estimated that roughly 0.25 per cent of deaths between 1986 and 2009 were due to extreme heat in Canada. Not all these deaths are attributable to climate change, as heat waves happen naturally. Attribution studies have been able to assess the impact of climate change on the severity and frequency of heat waves with relatively high confidence however. The "fraction of attributable risk" (FAR)³⁸ for extreme heat events is found to be very likely greater than 0.5 (Stott et al., 2015).

According to Statistics Canada (2016d), there were an estimated 269,012 deaths in 2015/16. Based on the research by Gasparrini et al. (2015), 0.25 per cent (673) of these deaths could be attributed to extreme heat. Using a FAR of 0.5, half of these deaths (336) can be attributed to climate change.

Applying the average 2015 VSL used by the OECD (2016) and World Bank and IHME (2016) in their studies of the costs of air pollution (Section 3.3.1.1) of \$4.65 million, **the total direct welfare cost of extreme heat mortality in Canada in 2015 is estimated to have been \$1.6 billion.**

Extremely cold weather is common in Canada, and it results in more deaths in the country than hot weather (Gasparrini et al., 2015). It is not yet possible to attribute extreme cold events to climate change with confidence, so no estimate of the costs of these deaths is given here. Trends indicate that extreme cold events are both less frequent and less severe than in past decades, as nighttime temperatures have generally increased across North America since the 1950s (Seneviratne et al., 2012). Natural variability can explain extremely cold winters, such as that in 2014, but such winters are less common and severe than in the past (National Academies of Sciences, Engineering, and Medicine, 2016). As a result, climate change may reduce the health costs of extreme cold events, rather than increase them.

Few studies have looked at trends in extreme snow and ice events. Those that did look found mixed evidence for a trend in the frequency or severity of these events (National Academies of Sciences, Engineering, and Medicine, 2016). As with extreme cold, attribution of these events to climate change is not yet possible with confidence, so no estimate of their direct welfare costs is given here.



“ Climate change and extreme weather can be most confidently linked when the mechanisms that cause the extreme weather are well understood. ”

³⁸ The FAR expresses the fraction of risk of a particular threshold being exceeded (e.g., a positive temperature departure associated with a heat wave) that can be attributed to a particular influence. For example, if the probability that a particular threshold being exceeded has increased by a factor of 4 as a result of human influence on climate, FAR=0.75, and three quarters of the risk of that event is attributable to human influence. In this case, under the current climate, on average three quarters of such events could be blamed on human influence. Such a result does not indicate that human influences were responsible for 75 per cent of the observed event magnitude, however, nor does it discriminate which specific events would not have happened, but rather that the probability of exceeding a particular threshold has increased (Stott et al., 2016).



Droughts are more complex than extreme temperature events, making it more difficult to link them to climate change. The availability of water is driven not only by meteorological factors but also by water use and hydrological factors. The IPCC states (with “high confidence”) that there has been a likely decrease in dryness in central North America since the 1950s (Hartmann et al. 2013). Again, attribution of droughts to climate change is not yet possible with confidence and no estimate of the associated direct welfare costs is possible here. The welfare costs are likely low in any case, as deaths and illness are not generally associated with drought in Canada.

On the opposite side of drought is the prospect of extreme rainfall and flooding. Increased severity and frequency of extreme rainfall has been linked to climate change, with confidence highest in North America and Europe (Hartman et al. 2013). At the same time, modelling precipitation patterns is difficult, and the attribution of precipitation extremes to climate change is not straightforward. Water vapour in the atmosphere is expected to increase at a rate of 6-7 per cent per degree Celsius of temperature rise with climate change. A simple estimate then would be that extreme rainfall events would increase at about the same rate (National Academics of Science, Engineering, and Medicine, 2016). Such events, which can cause both death and significant dislocation of people, have the potential for significant direct welfare costs. No estimate of them is possible here, however, given the difficulties in event attribution.

Finally, wildfires, while not weather events per se, are influenced by climate and also present a substantial threat to human life. Attributing wildfires to climate change is particularly difficult due to the role that humans play in starting and fighting fires and managing forests. Forest health and local weather patterns play a role alongside broader climate trends. Though an upward trend in forest area burned in Canada is not apparent, the length of the average global “fire weather” season has increased by 19 per cent since the 1990s (National Academics of Science, Engineering, and Medicine, 2016). Again, there is potential for significant direct welfare costs due to death and dislocation.

3.4 Non-Health Welfare Costs

In addition to the direct welfare costs of climate change related to human health discussed in the preceding sections, non-health welfare losses are also evident. Those related to lost recreational opportunities, reduced enjoyment of clear visibility and the intrinsic value of the environment are discussed below.

3.4.1 Recreational Losses Due to Algal Blooms

Pollution can reduce the enjoyment of recreational activities by degrading the quality of the sites people visit to spend their leisure time. Particularly noteworthy in this regard is the impact of pollution on water quality, as many recreational activities³⁹ take place on or near waterbodies.

In a study of the impact of algal blooms on Lake Erie (Midsummer Analytics and EnviroEconomics, 2015), Environment and Climate Change Canada found that the blooms imposed costs of \$21 million annually (2015 prices) in lost recreational opportunities on the 893,000 Canadian households living within 50 kilometres of the lake’s shore. This was equivalent to average cost per household of about \$23.50.

Though Lake Erie is perhaps the best known affected lake, algal blooms affect a large and increasing number of freshwater lakes in Canada (Winter et al., 2011; Pick, 2016). This “rise of slime” has been most dramatic in large inland lakes found along the edge of the Canadian Shield: Lake Champlain, Lake Ontario, Lake Erie, Lake of the Woods and Lake Winnipeg. Lake Winnipeg has the dubious distinction of being called “Canada’s sickest lake” (Pick, 2016). Smaller lakes are also affected. Winter et al. (2011) report that the number of Ontario lakes observed to have algal blooms increased steadily from nearly zero in 1994 to almost 50 in 2009. In Quebec, about 150 waterbodies

³⁹ Sunbathing, swimming, boating, fishing, camping, birdwatching, hiking, canoeing and hunting can all take place on or near waterbodies.



have been reported to have visible blooms annually since 2007, up from 21 in 2004 (Ministère du développement durable, environnement et lutte contre les changements climatiques, 2016).

The reasons for the increase in numbers of lakes fouled by algal blooms is not only increased loadings of nutrients to freshwater ecosystems, but also climate change (which leads to warmer water) and invasive species (which changes lakes' ecological systems⁴⁰). Blooms are persisting much later in the year—even into December—than in the past as well.

Environment and Climate Change Canada (2016k) reports that 18 per cent of 172 river water sites where human activity is most intensive were in “poor” or “marginal” condition in the 2010 to 2012 period⁴¹ (Environment and Climate Change Canada, 2016k). Assuming that these rivers are representative of broader freshwater quality in the densely populated parts of Canada (where most recreation takes place) and that water of poor or marginal quality is not well suited to recreation, it might be assumed that 18 per cent of Canadian households⁴² currently experience losses in the value of recreational experiences due to pollution of surface freshwater bodies. **Assuming that these losses are similar to those faced by households living near Lake Erie (\$23.50 annually per household, as noted above), the total loss in recreational welfare could amount to \$56 million annually.** This would not reflect losses in the value of recreation due to other types of pollution (e.g., air pollution or solid wastes).

3.4.2 Reduced Visibility

Air pollution concentrations have an impact on visibility in both residential and recreational settings. Reduced visibility in residential settings impacts peoples' daily lives, while reduced visibility at recreational sites impacts their enjoyment of their leisure time. Visibility reductions in these two settings have different costs, as people's willingness to pay to avoid visibility reductions in the two settings is different (EPA, 2011).

In a study of transportation activity in Canada, Sawyer et al. (2007) estimated the loss in direct welfare due to reduced visibility from air pollution caused by transportation to be \$165 million annually (2000 prices).⁴³ According to Environment Canada (2014), reduced visibility is mainly associated with particulate matter and ground-level ozone. Transportation was responsible for about 9 per cent of total particulate matter in 2014, not including “open” sources⁴⁴ (Environment and Climate Change Canada, 2017b). Ground-level ozone is not emitted directly from transportation but is formed in the atmosphere from other pollutants that are, most importantly NO_x and VOCs (see Text Box 1 for further details).



⁴⁰ The presence of zebra mussels in some lakes, for example, has resulted in clearer water, which promotes plant growth by permitting sunlight to penetrate more deeply into the water column.

⁴¹ Water quality is assessed in terms of its suitability for the protection of aquatic life. “Poor” quality means that water quality *usually* exceeds guidelines and/or exceeds guidelines by a considerable margin. Marginal quality means that water quality *often* exceed water quality guidelines and/or exceeds guidelines by a considerable margin.

⁴² Statistic Canada reports that there were 13.3 million Canadian households in 2011 (<http://www.statcan.gc.ca/tables-tableaux/sum-som/101/cst01/famil66-eng.htm>).

⁴³ See Appendix B for a description of the VIEW model used to compile these estimates.

⁴⁴ Open sources include farms, construction sites, road dust, coal transportation, open burning of wastes (e.g., yard wastes), mine tailings and prescribed burning of forests to prevent forest fires. These are excluded here because they mostly affect air quality outside of populated areas and therefore have limited direct welfare impacts.



Transportation was responsible for about 53 per cent of NO_x and 22 per cent of VOC emissions in 2014, again not including open sources (Environment and Climate Change Canada, 2017b). Given these shares, a conservative factor by which to increase transportation's impact on visibility to account for non-transport sources of NO_x and VOCs would be 2. Using this factor, the total cost of reduced visibility due to all sources of air emissions in Canada would be \$330 million (2000 prices). Adjusting this for inflation gives a figure of \$438 million in 2015 as the estimated cost of visibility loss in Canada due to particulate matter and ground-level ozone.

3.4.3 Lost Existence Value

There is a large literature demonstrating that individuals experience direct losses in welfare when features of the natural environment they care about are degraded (Krutilla, 1967; Brookshire, Eubanks, & Randall, 1983; Aldred, 1994). This is understandable when the feature in question is something the individual interacts with directly; perhaps during a recreational activity, as discussed above. It occurs, however, even in cases where the individual does not directly use the feature of the environment in question and may never intend to. The simple knowledge that something of value is threatened is enough to cause a loss in utility for many non-users. Evidence that these losses are real is demonstrated by the express willingness of non-users to pay for initiatives to improve the quality of degraded environmental features they don't use and never intend to visit.

In its study of algal blooms on Lake Erie (Midsummer Analytics and EnviroEconomics, 2015), Environment and Climate Change Canada found that the losses in water quality on the lake imposed costs of \$94 million annually on non-users living within 100 kilometres of the lake's shoreline, or about \$36.30 for each of the 2.6 million impacted households. This represents the loss in welfare associated with people's knowledge that the lake is in a threatened state even though they make no direct use of the lake.

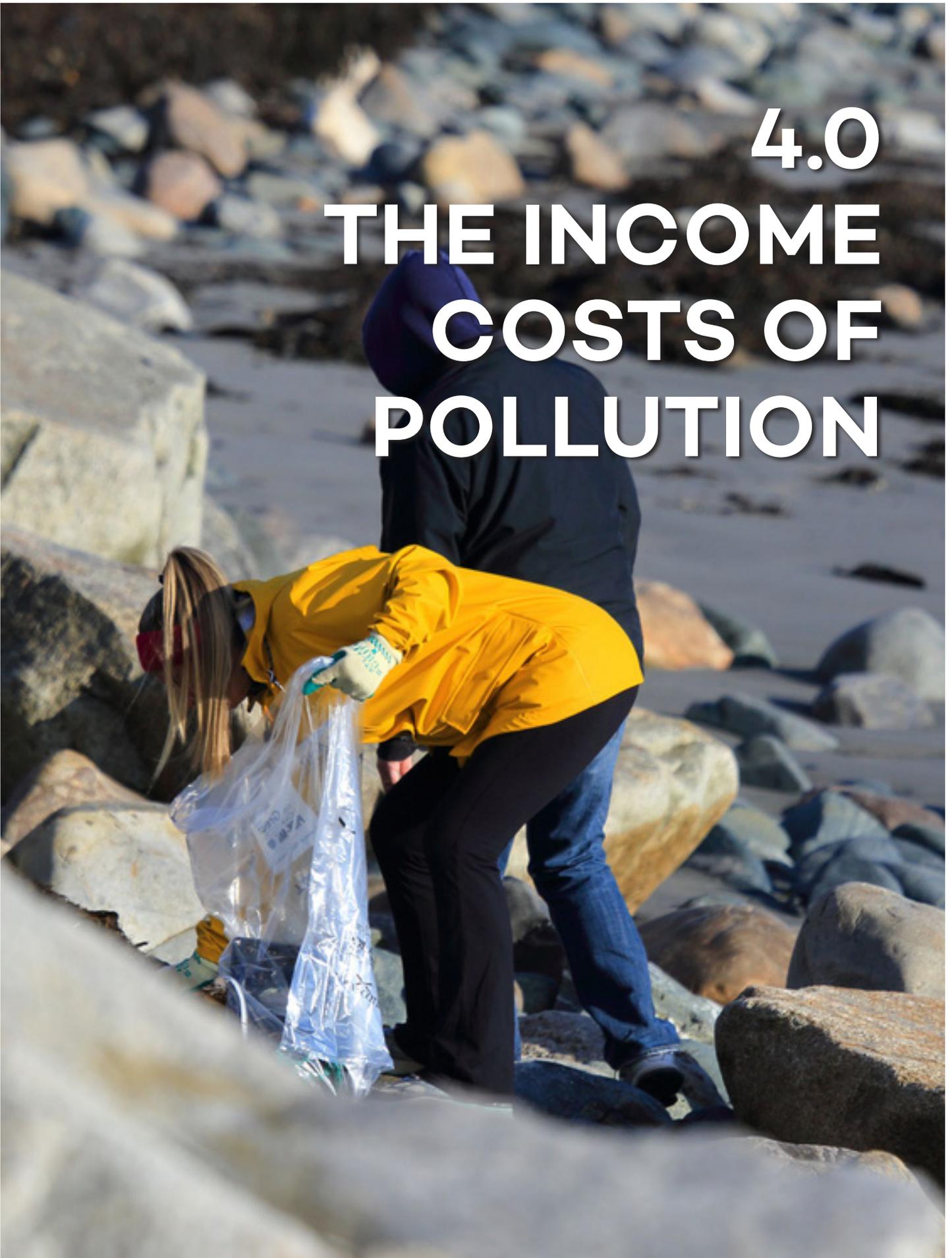
Using the same argument as for recreation above, this figure translates to a tentative estimate of \$87 million annually in lost non-use welfare associated with surface freshwater quality degradation for all households across Canada.⁴⁵

When combined with the figure above for the loss in the value of recreational experiences (\$56 million annually), a total of \$143 million in annual direct welfare losses could be associated with surface freshwater degradation across the country. This figure corresponds well with the willingness of households to pay for improved surface water quality estimated by Environment Canada (Fisheries Act: Wastewater systems effluent regulations, 2012) in the course of developing new wastewater treatment regulations for the country. The estimated present value of household willingness to pay was \$1.7 billion (2011 prices) over a 25-year period at an 8 per cent discount rate. The present value of \$143 million per year with the same parameters is about \$1.5 billion (2015 prices).

The above costs do not include direct welfare losses from other impacts of pollution on the existence value of ecosystems. Acid rain, climate change and toxic chemicals all have the potential to degrade ecosystems, for example. The cost of these in terms of terms of lost non-use welfare is unknown.

⁴⁵ 18 per cent of water bodies degraded sufficiently to cause direct welfare losses for 13.3 million households, each losing \$36.30 dollars annually.

4.0 THE INCOME COSTS OF POLLUTION





4.0 The Income Costs of Pollution

4.1 Introduction

In this chapter, the costs of pollution related to impacts on production and consumption of market goods and services are considered. These costs come in the form of either reduced income or increased expenditures (or both) for individuals, businesses and governments. They are all related by the fact that they affect national *income*, either the amount of income generated by the economy or the way in which that income is spent to meet private and public needs. The costs are broken into the four categories below.

- **Income costs due to impacts on human health:**

In addition to their direct welfare costs, which were discussed in Chapter 3, the human health impacts of pollution affect income and its use in various ways. People who die or fall ill from exposure to pollution are unable to contribute to the economy for as long or as fully as those who do not. Their income and that of the businesses they work for is therefore lower than it would be in the absence of pollution. In addition, there are expenses associated with the medication and medical services required



to treat those who are ill. These costs are imposed on the sick individual (costs of uninsured medication and treatments), on the government (public health care) and on businesses (coverage of insured expenses).

- **Income costs due to impacts on produced assets:** Produced assets are impacted by pollutants that travel through the air, water and soil. The primary assets at risk are buildings, factories, homes, bridges and other built infrastructure—including structures of cultural significance such as monuments and historic buildings. A highly visible result of their exposure to pollution is excess soiling, which results when pollutant particles carried by air and precipitation adhere to buildings and other structures. Such soiling requires surfaces such as windows and exterior walls to be cleaned more often than otherwise. Another less visible but potentially more serious impact is premature wearing, which occurs when pollutants cause materials to break down sooner than they would otherwise (for example, peeling of painted surfaces, corrosion of metals and weakening of plastics and stone). Premature wearing leads to additional costs for maintenance (such as more frequent painting) and reduces the useful lifespan of structures through weakening of the materials they are built from. In addition to increased costs for the maintenance of produced assets, pollution can impose increased costs on their operation. For example, drinking water treatment plants are impacted by pollution because their processes rely on raw input water of a certain quality. If raw water quality declines due to increased pollution, the cost of producing potable water may increase.
- **Income costs due to impacts on natural assets:** Natural assets like waterbodies, forests, farmland, atmosphere and soil are also impacted by pollution. The cost of this exposure comes partly in reductions of natural assets' capacities to produce goods and services that are valued by humans.⁴⁶ For example, forests impacted by acid rain are less able to produce wood for harvesting and serve as recreation sites or offer beautiful vistas. Similarly, agricultural land exposed to ground-level ozone has a lower capacity to produce crops. Fish, wildlife and plants that ingest pollutants can pass them on to humans that consume them, making them less valuable as sources as food. An excess of greenhouse gases in the atmosphere reduces its ability to regulate the earth's climate and maintain weather patterns within the range to which society

⁴⁶ In addition, there are obvious impacts beyond those of concern to humans. Non-human species that live in ecosystems can suffer significantly from the impacts of pollution, as in the case of birds, marine mammals and other aquatic life soiled following spills of oil in waterbodies. The well-being impacts on non-human lives cannot be valued in monetary terms and are, therefore, beyond the scope of this study. The cost of the efforts that human undertake to minimize the impacts of pollution on the environment and its non-human inhabitants are, however, within scope.



is adapted, which can lead, in turn, to reductions in the production of crops, timber, fish and a range of ecological services. The income costs of natural assets' exposure to pollution also come in terms of increased costs to businesses that rely on them—for example, increased fertilizer costs to farmers to boost crop production or increased harvest effort on the part of forestry companies to obtain a given volume of timber.

- **Income costs due to the need to manage pollution:** Finally, the need to limit the amount of pollution that reaches human, economic or natural receptors increases costs for businesses, governments and individuals in two ways: the costs of limiting the impact of accidental releases of pollutants; and the costs of remediating polluted sites resulting from human activities in earlier periods.

4.2 Summary of Findings – Income costs of pollution⁴⁷

The available evidence suggests that pollution imposes very significant income costs on Canadian households, businesses and governments. **Based on a thorough review of available data, the income cost of those impacts that can be measure today is estimated to have been \$3.3 billion in 2015. The full income cost of pollution is likely to have been much larger than this, as several impacts with likely very significant costs cannot be measured today. Together, these additional costs could add tens of billions of dollars annually to the \$3.3 billion identified based on available data.** Most importantly, no cost estimates were available for the following impacts:

- Lost labour output and increased health care costs due to persistent organic pollutants
- Increased maintenance of roads and other infrastructure from road salt use
- Impacts of acid rain on forests, lakes and rivers
- Impacts of ozone layer depletion on crops and households (e.g., sunscreen purchases)
- Costs of spill cleanup
- Full costs of contaminated site cleanup.

Each of the income costs of pollution in Canada is discussed briefly below and then summarized in Table 3 at the end of this section. They are discussed in much greater detail in the remainder of the chapter, where they are divided into the four categories listed above: income costs of impacts on human health (Section 4.3), income costs due to impacts on produced assets (Section 4.4), income costs due to impacts on natural assets (Section 4.5) and income costs due to the need to manage pollution (Section 4.6).

4.2.1 Summary of Findings by Income Cost

4.2.1.1 Income Costs of Impacts on Human Health

- **Health care:** Several health care-related costs are associated with illness due to exposure to pollution: salaries of doctors and other health care workers, hospital operational costs, medical equipment and pharmaceuticals to name some. These expenses are incurred by individuals, businesses and governments. They are over and above the direct welfare costs of illness and death that were discussed in the previous chapter. The estimated health care-related cost due to pollution in 2015 is *at least* \$2 billion. This figure is conservative since it includes only the health care-related costs of PM_{2.5} and ground-level ozone. *The costs of other pollutants, notably persistent organic pollutants (see Text Box 10), are likely much larger—possibly in the tens of billions of dollars.* See Section 4.3.2 for further details.

⁴⁷ A specific nomenclature has been adopted to discuss uncertainty in this report. The nomenclature is not based on a quantitative assessment of uncertainty but rather on the authors' judgement derived from review of published studies. The terms in the nomenclature have the following meanings: “possibly” (< 50 per cent chance); “likely” (> 50 per cent chance); “somewhat larger” (< 100 per cent larger); “much larger” (> 100 per cent larger); “significant” (at least on the order of tens of millions of dollars); “very significant” (at least on the order of billions of dollars). In cases where order of magnitude (millions, billions) estimates can be given with some degree of certainty, they have been. This nomenclature is intended to provide readers with a rough sense of how much larger actual costs might be than those that can be measured based on available data and how likely it is that costs are this much larger. It should not be used to make quantitative estimates of missing values.



- **Lost labour output:** Illness causes people to miss work, reducing their personal incomes and the incomes of the businesses they work for. Friends and family may also miss work to care for sick relatives. **The estimated value of lost labour output due to pollution in 2015 is at least \$800 million.** This figure is conservative since it only accounts for lost labour output due to PM_{2.5} and ground-level ozone. **The lost labour output due to other pollutants, notably persistent organic pollutants, is likely much larger—possibly in the tens of billions of dollars.** See Section 4.3.1 for further details.

Text Box 10. The possible costs of exposure to persistent organic pollutants

Persistent organic pollutants: The group of widely used chemicals known as persistent organic pollutants (POPs)—which includes a number of pesticides, fire retardants and plastic additives—is suspected to be a factor in a variety of common and costly illnesses, including obesity, neurological deficiencies and diabetes. Though the income costs of exposure to most POPs cannot yet be accurately measured, scientists are moving closer to being able to value some of them. A European study found, for example, that health care-related costs associated with POPs were likely no less than \$54 billion (and could be as great as \$264 billion) annually across the European Union (not including direct welfare costs). While these results are still too tentative to apply to Canada, they provide some evidence that POPs may impose income costs in Canada that are of the same order of magnitude as the welfare costs of PM_{2.5} and ground-level ozone (tens of billions of dollars), which are currently the most significant known cost of pollution. If the direct welfare costs of POPs are also taken into consideration, the costs of POPs could well turn out to be larger than those of PM_{2.5} and ground-level ozone. See Section 4.3.3 for further details.

4.2.1.2 Income Costs Due to Impacts on Produced Assets

- **Increased maintenance costs – Acid rain and particulate matter:** Acid rain and particulate matter are the main contributors to building soiling and premature wearing of materials, both of which lead to increased maintenance costs for monuments, buildings and other infrastructure. The evidence regarding the economic cost of soiling and premature wearing of materials is inconsistent and not robust enough to allow an estimate to be made here. The data that are available for Canada suggest the cost may be relatively low, though these data refer only to the cost of soiling of houses and only from some pollutants. Estimates for France and other European countries suggest much higher costs, though they are based on data that are often old and methodologically inconsistent. At this point, the costs of building soiling and premature wearing due to acid rain and particulate matter in Canada can only be said to be possibly significant. See Section 4.4.1 for further details.
- **Increased maintenance costs – Road salt:** Bridges, buildings, vehicles and other produced assets are susceptible to deterioration due to road salt, which results in higher maintenance and replacement costs. About 7 million tonnes of road salt is applied annually in Canada. Based on a single American study from the early 1990s, an upper estimate on the cost of increased road maintenance due to salt use in 2015 in Canada is \$11 billion. The reliability of this estimate is very low and is not considered robust enough to report formally here; it is offered rather to give a sense of the order of magnitude of the possible costs, which are likely significant. See Section 4.4.1 for further details.
- **Increased operational costs – Algal blooms:** Algal blooms on freshwater lakes and rivers polluted by phosphorous and nitrogen are a concern for the households, businesses and governments that rely on them as sources of raw water. Because algal blooms can produce toxins and impart unpleasant tastes and odours to water, higher levels of treatment are required if the water is to be used for human consumption. The blooms can also clog intake pipes, increasing operational costs. Evidence from one study of agricultural, industrial, recreational (golf courses) and municipal (drinking water) users of Lake Erie water suggests that the costs arising from severe blooms currently affecting Lake Erie are about \$4 million annually, all for drinking water treatment plants (other users have not reported increased costs). No basis for extrapolating this cost to other freshwater bodies in the country is available; the costs are possibly significant. See Section 4.4.2 for further details.



4.2.1.3 Income Costs Due to Impacts on Natural Assets

- Honeybee deaths:** Overwinter bee deaths in the United States have been higher than historical norms since 2006–07, a phenomenon dubbed colony collapse disorder (CCD). To date, no evidence for a single cause of CCD has been found. Rather, scientists believe it is due to the combined effects of multiple stressors, including but not limited to pesticides. CCD has not been observed widely in Canada, though “traditional”⁴⁸ overwinter honeybee deaths did rise to historical highs in 2008 and 2009; they have subsequently fallen back to more normal levels. Health Canada has linked the use of seeds coated with neonicotinoid pesticides with bee deaths, and the Province of Ontario has regulated use of these seeds following a 58 per cent loss of bee colonies over the 2013–14 winter. The income costs of bee colony losses have not been well researched, and the link with pesticide remains uncertain, so no estimate is possible here; the costs are possibly significant. See Section 4.5.1 for further details.



“ Bees are exposed to a wide range of pesticides. Pesticides found in colonies include both those used to manage diseases or pests that directly infect bees as well as commercial agricultural pesticides. ”

- Acid rain:** Acid rain impacts aquatic and terrestrial environments in a variety of ways, including deaths of fish and other aquatic life and reduced tree growth. Despite considerable research into its ecological impacts, there has been little research into the economic costs of acid rain. These include reduced output of fisheries, both commercial and recreational, and reduced flows of forest products (timber and maple syrup). The few estimates that have been made of these costs are based on data and methods that are out of date and/or inconclusive. As such, no estimate is possible here at this time; the costs are possibly significant. See Section 4.5.2 for further details.
- Reduced agricultural output:** Ground-level ozone reduces plant growth, which in turn reduces agricultural yields. **The estimated losses due to reduced agricultural yields are \$96 million in 2015. See Section 4.5.3 for further details.**
- Ozone depletion:** Ozone depletion is the result of human emissions of “ozone-depleting substances” (ODS), such as chlorofluorocarbons, that destroy ozone found in the stratosphere. Depletion of the ozone layer results in an increase in the amount of ultraviolet radiation reaching the earth’s surface. This has various human health and ecological impacts, though there remains a considerable degree of uncertainty regarding their exact nature. Given this uncertainty, it is not surprising that the economic costs of ozone depletion are not well understood. The few studies that exist, while offering useful insight into the possible magnitude of the costs, are not sufficient to draw firm conclusions. All that can be said here is that the annual costs of ozone depletion in Canada are likely significant and possibly very significant. See Section 4.5.4 for further details.

⁴⁸ CCD differs from “traditional” bee colony deaths in a number of ways. First, it can affect very large numbers of colonies—up to 90 per cent for some beekeepers. Second, CCD-affected hives are found in unusual states in the spring, with a live queen, larvae, nurse bees and plenty of food but no worker bees in the hive and no evidence of dead worker bees nearby. Traditional colony death involves death of all kinds of bees in the colony, not just workers.



4.2.1.4 Income Costs of Pollution Management

- Spill cleanup costs:** When spills of oil and other materials occur, whether from pipelines, ships or other sources, considerable spending is devoted to limiting the spread of the material and removing it from the environment. Despite their potential ecological and economic impact, basic data on the number and volume of spills in Canada are incomplete, making it impossible to estimate of the cost of spills here. The potential magnitude of such costs is very significant, as large spills can be exceptionally costly to recover from. The total cost of the 1989 Exxon Valdez spill in Alaska is reported to have been US\$2.1 billion. The more recent (2010) blowout of the offshore Deepwater Horizon oil platform in the Gulf of Mexico has cost British Petroleum some US\$61 billion to date. Spills of this magnitude are, thankfully, infrequent. In Canada, the most serious spill in recent years was the 2014 derailment of a train carrying oil in the town of Lac Mégantic, Quebec. The resulting explosion left 47 people dead, another 2,000 homeless and the centre of the town destroyed. The human costs of this disaster are all but beyond quantification. The income costs to the Quebec government to remove the train wreck, decontaminate the area of the explosion and rebuild the downtown area had amounted to \$126 million by 2014, with another \$283 million expected to complete the work. Fortunately, spills of this magnitude are infrequent and their high costs do not reflect the costs of spills on average. As noted, this cost cannot be calculated with available data. See Section 4.6.1 for further details.
- Managing contaminated sites:** A large number of sites contaminated with residues from previous pollution emissions are found in Canada. These include the sites of former mines, industrial facilities, gas stations and military installations. Many of these sites have long been abandoned by their original owners. More than 22,000 sites fall under federal jurisdiction, with an unknown additional number falling under provincial, municipal and private responsibility. **It is estimated that average annual expenditures on sites under federal jurisdiction alone was \$283 million between 2005/06 and 2014/15.** This represents a lower bound on the cost of managing contaminated sites, as it does not include sites under provincial, municipal or private responsibility. The annual cost is likely to rise in coming years as a number of large sites move from relatively inexpensive assessment into the much costlier remediation stage. In addition to current spending on site remediation, governments acknowledge liabilities for the cost of future cleanup. The total liability for contaminated site cleanup recognized by the federal government was \$5.8 billion in 2015. An additional \$6.4 billion in liabilities was recognized by provincial governments. An unknown additional amount of liabilities is represented by sites under municipal and private responsibility. See Section 4.6.2 for further details.
- Managing low-level nuclear legacy wastes:** Low-level nuclear legacy wastes include those from the early development of Canada's nuclear industry. The largest concentration of these wastes is found in Port Hope, Ontario, which has been at the centre of the industry since its earliest days. Significant amounts of low-level wastes are also found at Atomic Energy of Canada Limited's Chalk River, Ontario and Whiteshell, Manitoba research facilities, with smaller amounts found at various other sites across the country. Responsibility for the long-term management of these wastes rests with Atomic Energy of Canada Limited through its subsidiary Canadian Nuclear Laboratories. **As of 2015, Atomic Energy of Canada Limited had recognized in its financial report plans for average annual spending on these wastes of \$121 million until the year 2164. See Section 4.6.3 for further details.**





Table 3. Summary of 2015 income costs of pollution

Category	Estimated income cost in 2015	Reliability of estimate	What is and is not covered
Income costs of impacts on human health			
 Health care	Central estimate: \$2 billion for PM _{2.5} and ground-level ozone; likely much larger for other pollutants, notably persistent organic pollutants Range: Unknown	Medium	Represents the health care-related costs due to illness from exposure to PM _{2.5} and ground-level ozone; costs due to other pollutants such as persistent organic pollutants are excluded, making this a conservative estimate.
 Lost labour output	Central estimate: \$0.8 billion for PM _{2.5} and ground-level ozone; likely much larger for other pollutants, notably persistent organic pollutants Range: Unknown	Medium	Represents lost labour output due to illness from exposures to PM _{2.5} and ground-level ozone; costs due to other pollutants such as persistent organic pollutants are excluded, making this a conservative estimate.
Income costs of impacts on produced assets			
 Increased maintenance costs: Acid rain and particulate matter	<i>Unknown</i> ; possibly significant	n/a	Represents the costs of repair and replacement of buildings, bridges and other human produced structures.
 Increased maintenance costs: Road salt	<i>Unknown</i> ; likely significant	n/a	Represents the costs of repair and replacement for assets such as bridges and vehicles.
 Increased operational costs: Algal blooms	<i>Unknown</i> ; possibly significant	n/a	Represents increased costs to operate facilities that rely on fresh surface water contaminated by algal blooms.
Income costs of impacts on natural assets			
 Honeybee deaths	<i>Unknown</i> ; possibly significant	n/a	Represents the costs associated with domestic honeybee colony morbidity and mortality due to pollution.
 Acid rain	<i>Unknown</i> ; likely significant	n/a	Represents costs associated with damage to natural assets due to acid rain.
 Reduced agricultural output	Central estimate: \$96 million Range: Unknown	Medium	Represents the costs associated with declining agricultural productivity due to ground-level ozone.
 Ozone depletion	<i>Unknown</i> ; likely significant, possibly very significant	n/a	Represents the costs associated with a depletion of the ozone layer due to ozone-depleting substances; for example, reduced agricultural output and increased need for sunscreen.
Income costs of pollution management			
 Spill cleanup costs	<i>Unknown</i> ; possibly significant, especially in the event of a large spill	n/a	Represents the costs of cleaning up spills of oil and other materials.
 Managing contaminated sites	Central estimate: at least \$283 million; possibly much larger Range: Unknown	High	Represents the costs of cleaning up polluted sites such as former mines, industrial facilities and gas stations under federal jurisdiction.
 Managing nuclear legacy wastes	Central estimate: at least \$121 million; likely somewhat larger Range: Unknown	High	Represents the costs of managing low-level nuclear wastes from early development of Canada's nuclear industry that fall under the responsibility of Atomic Energy of Canada Limited; does not include costs for other nuclear companies.



4.3 Income Costs of Human Health Impacts

In addition to its impacts on welfare, which were considered in Chapter 3, pollution also imposes costs on income when it affects human health. Humans who die or fall ill from exposure to pollution are unable to contribute to the economy for as long or as fully as those who do not. Economic production (and income) is therefore lower than it would be in

the absence of pollution. In addition, there are health care costs associated with the medication and medical services required to treat those who are ill. These costs are imposed directly on the sick individual (costs of uninsured medication and treatments), on the government (public health care) and on businesses (coverage of insured expenses).

“ People who die or fall ill from exposure to pollution are unable to contribute to the economy for as long or as fully as those who do not. ”

These costs are considered below.

4.3.1 Lost Labour Output – PM_{2.5} and ground-level ozone

Lost labour output measures the economic activity lost as people miss work due to illness. Not only do the sick miss work, but so may friends or family who care for them. Time missed from work reduces the productivity of the work force, which in turn reduces economic output and income.

To date, most efforts to measure the cost of lost labour output as a result of pollution have been directed at the health impacts of PM_{2.5} and ground-level ozone (see Text Box 1 and Text Box 2 in the previous chapter for definitions of these pollutants).

As noted in Section 3.3.1, the most recent studies dealing with the costs of these pollutants in Canada are *The Economic Consequences of Outdoor Air Pollution* (OECD, 2016) and *The Cost of Air Pollution: Strengthening the Economic Case for Action* (World Bank and Institute of Health Metrics and Evaluation, 2016). Of these, only the OECD study estimates the cost of lost labour output. It reports this to be 0.1 per cent of GDP.⁴⁹

Statistics Canada reports that 2015 GDP was about \$1,986 billion (2015 prices), which would imply costs of PM_{2.5} and ground-level ozone of about \$2 billion in terms of lost labour output using the OECD’s estimate. This figure should be taken as a lower bound on the costs of lost labour output due to pollution.

4.3.2 Health Care Costs – PM_{2.5} and ground-level ozone

The OECD also estimates the increased health expenditures imposed by PM_{2.5} and ground-level ozone. These they estimate to be 0.04 per cent of GDP, or about \$800 million for Canada in 2015.⁵⁰

⁴⁹ The OECD actually reports loss in labour output for Canada only for the year 2060, the end-point of its analytical period. It reports lost labour output for OECD countries as a whole over the entire time period (2015–2060) however. For OECD countries as a whole, there is relatively little variation in lost labour output between 2015 and 2060, so it is assumed here that Canada’s lost labour output in 2015 is the same as the OECD estimates it to be for 2060; that is, about 0.1 per cent of GDP.

⁵⁰ Again, the OECD reports health care costs for Canada only for 2060. As with lost labour costs, it is assumed here that the 2060 figure applies to 2015. It must be noted, however, that the evidence for this assumption is not as strong as in the case of lost labour costs, as the OECD report does not present an OECD-wide estimate of health care costs for the entire period 2015–2060.



4.3.3 Lost Labour Output and Health Care Costs – Persistent organic pollutants

Potentially much larger than the lost labour and health care costs of PM_{2.5} and ground-level ozone are those associated with so-called “persistent organic pollutants,” or POPs. POPs are pollutants that, when released into the environment:

- Remain intact for exceptionally long periods of time (many years)
- Become widely distributed as a result of natural processes involving soil, water and, most notably, air
- Accumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain
- Are toxic to both humans and wildlife (UNEP, n.d.a).

POPs are controlled under an international convention of the UN known as the Stockholm Convention (UNEP, n.d.b). There are currently 22 chemicals (mainly pesticides) that are banned for production and use under the convention plus another two whose production and use are restricted (including the pesticide DDT) and a further six whose unintentional production as industrial by-products must be avoided. Evaluation of other chemicals for possible control under the convention is an on-going process.

As a result of releases to the environment from human activities, POPs are now distributed globally, including in areas where they have never been used, such as Canada’s North (Environment Canada, 2013c). This extensive contamination results in the exposure of many species, including humans, to POPs for periods of time that span generations, leading to both acute and chronic health effects.

POPs concentrate in living organisms through a process called bioaccumulation. They are readily absorbed in fatty tissue, where concentrations can become magnified by up to 70,000 times background environmental levels. Fish, predatory birds, mammals and humans are high up the food chain and so absorb the greatest concentrations.

Health effects of POPs can include cancer, allergies and hypersensitivity, damage to the central and peripheral nervous systems, reproductive disorders, birth defects, obesity, diabetes, cardio-pulmonary disease, neurobehavioral and learning dysfunctions and disruption of the immune system.

POPs force us to rethink the notion of pollution (Smith & Lourie, 2009). Most people tend to think of pollution as smoke billowing from factories or automobile tailpipes. Though some POPs are released from “traditional” sources like these, human exposure to them comes more from the use of everyday products, including plastics, cosmetics, furniture and food.

In spite of their widespread nature and the seriousness of their health consequences, the evidence for causal relationships between exposure to POPs and specific health outcomes remains incomplete. As a result, evaluation of the economic costs of POPs in terms of health impacts is not nearly as advanced as for better studied pollutants like PM_{2.5} and ozone. One study that has attempted to do so is Trasande et al. (2015).

Trasande et al. (2015) focused on just a subset of POPs known as endocrine disrupters, which are noted to cause many of the health effects listed in Text Box 11. Their study considered the economic costs of endocrine-disrupting compounds (EDC) in European Union countries for the three health effects for which the most substantial evidence exists for EDC attribution: obesity/diabetes, male reproductive health and brain development effect. Probabilities of causation⁵¹ were determined by panels of experts who were asked to consider available dose-response relationships from the epidemiological literature and other scientific information relevant to determining links between EDC exposure and specific health effects. The panels found probabilities of causation of greater than 20 per cent for all

⁵¹ Probabilities of causation are the certainty with which a certain EDC can be assumed to cause a certain illness.



EDCs and all diseases studied except for the group of chemicals known as flame retardants⁵² and their relation to testicular cancer. The panel considering brain development effects estimated a 70–100 per cent probability that 59,300 additional cases of intellectual disability occurred each year in the Europe Union due to EDCs. The male reproductive effects panel found that exposure to phthalates⁵³ had a 40–69 per cent probability of causing 618,000 additional assisted reproductive technology procedures annually in Europe. The obesity/diabetes panel identified a 40–69 per cent probability of phthalate exposure causing 53,900 cases of obesity and 20,500 cases of diabetes in older women annually.

Text Box 11. Endocrine-Disrupting Compounds

The endocrine system includes: the ovaries; testes; thyroid, parathyroid, adrenal, pituitary and pineal glands; pancreas and hormone-releasing cells in the gastrointestinal tract, kidney, heart and placenta. It produces the hormones that coordinate and regulate essential bodily functions in humans and other animals:

- Growth and maturation
- Behaviour
- Reproduction and embryo development
- Production, use and storage of energy
- Balance and maintenance of water and salt in the body
- Reaction to stimuli (e.g., fright, excitement).

Any disruption to the endocrine system can cause changes in reproduction, development, growth and behaviour. Certain substances, both naturally occurring and artificial, can disrupt the system, including POPs. The number of substances believed to act as endocrine disruptors is wide and varied. They may be present in the environment at very low levels but still have the potential to cause effects.

Endocrine disruptors are found in industrial solvents, lubricants and their by-products, including polychlorinated biphenyls (PCBs), polybrominated biphenyls (PBBs) and dioxins. Other examples of known or suspected endocrine disruptors include bisphenol A (BPA), dibutyl phthalate and butyl benzyl phthalate (plastic additives); DDT, dieldrin, lindane, atrazine, trifluralin, permethrin, tributyltin, vinclozolin (pesticides); and diethylstilbestrol and ethynyl estradiol (artificial hormones). Some metals such as cadmium, mercury, arsenic, lead, manganese and zinc also disrupt endocrine systems. Many consumer products (cosmetics, personal care products and cleaners, especially those that are fragranced), contain chemicals with endocrine-disrupting properties. Some, but not all, of these substances are controlled under the Stockholm Convention on persistent organic pollutants (UNEP, n.d.b).

“ POPs concentrate in living organisms through a process called **bioaccumulation**. They are readily absorbed in fatty tissue, where concentrations can become magnified by up to 70,000 times background environmental levels. Fish, predatory birds, mammals and humans are high up the food chain and so absorb the greatest concentrations. ”

⁵² Flame retardants, or polybrominated diphenyl ethers, are a group of substances added to various products, such as computer housings, household appliances, furniture, automotive/aircraft seating and interiors and a variety of electrical and electronic components to reduce their flammability (<https://www.ec.gc.ca/toxiques-toxics/Default.asp?lang=En&n=98E80CC6-1&xml=5046470B-2D3C-48B4-9E46-735B7820A444>).

⁵³ Phthalates are a group of compounds added to plastics to make them more flexible. They are used to produce a wide range of products including flooring, food packaging, imitation leather, rainwear, footwear, upholstery, wire and cable, tablecloths, shower curtains, soft squeeze toys, balls, blood storage bags, medical tubing and gloves (<http://www.carexcanada.ca/en/phthalates/>).



The study considered the economic costs in terms of impacts on market income only (expenditures for hospitalization, physician services, nursing home care, medical appliances and related items along with the value of the lost output of workers). *It did not include direct welfare effects, which are likely to be much larger.*

Using the mid-points of the estimated probabilities of causation provided by the panels, the study found a 90 per cent chance that the annual costs of EDCs in terms of obesity/diabetes, male reproductive health and brain development disorders in 2010 were at least 32 billion euros (2010 prices) or about \$54 billion (2015 prices) after currency conversion. Their central estimate this cost was 157 billion euros (\$264 billion). This number is likely an underestimate of the full cost of POPs, as it considered only a subset of POPs (EDCs), a subset of the health impacts of EDCs and a subset of the economic costs of those impacts. Importantly, the study did not consider the direct welfare costs of EDC health impacts.

In a study looking specifically at Canada, Muir and Zegarac (2001) considered the economic costs of POPs in terms of their impacts on four health effects: diabetes, Parkinson's disease (PD), brain development effects and hypothyroidism and intellectual disability. As their study was published more than a decade before Trasande et al.'s, Muir and Zegarac had less scientific evidence to base probabilities of causation on. They therefore made the simplifying assumption that POPs are responsible for 10 to 50 per cent of the burden of these four diseases. Like Trasande et al., they considered only impact on market income (health care costs and lost output); direct welfare costs were not considered. This resulted in estimated costs for Canada in 1999 of \$46 billion to \$52 billion (1999 prices), or about \$1,510 to \$1,710 per person (\$2,060 to \$2,330 per person in 2015 prices).

Though they are the best currently available in the literature, neither the Trasande et al. (2015) study nor the Muir and Zegarac study provide sufficient evidence to draw firm conclusions about the costs imposed on Canadians by POPs. They do, however, provide evidence that these costs may be very high—possibly on the order of tens of billions of dollars annually. Both studies point to costs of this order of magnitude even though they considered only a subset of POPs and/or a subset of their probable health impacts and neither study took into consideration the impacts of POPs on human welfare. *All of this suggests that POPs may impose direct welfare and income costs on Canadians equal or greater in magnitude to PM_{2.5} and ground-level ozone (sections 3.3.1.1, 4.3.1 and 4.3.2).* Further study to develop more credible and complete estimates of the costs of POPs should therefore be considered a high priority.

4.4 Income Costs of Impacts on Produced Assets

Pollutants can reduce the capacity of produced assets to generate income in economic production processes. The primary produced assets at risk are buildings, factories, homes, bridges and other built infrastructure—including structures of cultural significance such as monuments and historic buildings. Impacts of pollutants on produced assets include:

- Excess soiling, requiring surfaces to be cleaned more often than otherwise
- Premature wearing, leading to additional costs for maintenance
- Increased operational costs to deal with polluted raw materials, especially air and water.

These costs are considered below.

4.4.1 Excess Soiling and Premature Wearing

4.4.1.1 Acid Rain and Particulate Matter

Acid rain and particulate matter (see Section 4.5.2 and 3.3.1 respectively for definitions) are the main contributors to soiling and premature wearing resulting in material deterioration.



Acid rain accelerates the corrosion of materials such as limestone, sandstone, mortar and many metals, causing particular problems for older buildings, outdoor sculptures and monuments. Acid rain damages stonework in part simply by dissolving the calcium carbonate that is the principle material of much building stone. It also causes stone to crumble through a repeated process of deposition and dissolution of crystals of nitrate, chloride and sulphate in the pores of the stone. The gradually accumulating crystals exert enormous pressure on the stone, causing it to eventually crumble. Acid rain can also wash away the protective green layer of copper sulphate and carbonate copper-roofed buildings, replacing it with a more porous crust that traps acid rainwater and further exacerbates the deterioration. Thus, homes and other buildings, roads, paint, sculptures and other man-made structures can be aesthetically and functionally damaged by acid rain (Weaver, 1991).

Particulate matter is mainly a concern from an aesthetic point of view, as it coats outdoor surfaces and discolours them. It leads to additional costs for window washing and cleaning of other surfaces, including cleaning of historical buildings and monuments that have become blackened from exposure over many years (Text Box 12).

The costs of the damages caused by acid rain and particulate matter are difficult to calculate, in part because the proportion of soiling and wear due to pollution cannot easily be estimated from what would occur in any case. The issue has been studied most in Europe, though most of the studies available are out of date and reflect a period (1970s to 1980s) when both acid rain and particulate matter were more serious concerns than they are today. A recent study by the Senate of France (Commission d'enquête, 2015) suggested the cost of building soiling from air pollution due to transportation activity alone might be as high as 3.4 billion euros in 2000. Older studies in Europe provide a wide range of values that are difficult to compare because of differences in time period, units of measure and measurement scope (Tidblad et al., 2010).

In Canada, there are few data available on the cost of soiling and premature wearing due to air pollution. The issue has been addressed mainly in several cost-benefit analyses undertaken by the federal government in recent years in support of the development of new environmental regulations. One such analysis (Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations, 2012) considered the benefits of regulations to reduce air emissions from coal-fired generating stations. It found that the regulations would reduce the cost of soiling of houses (soiling or premature wearing of other assets was not considered) by a total of \$11.2 million (2010 prices) over the period 2015–2035. A similar analysis for regulations related to emissions from road vehicles

Text Box 12. Repairing pollution damage to Canada's parliament buildings

The stonework of the West Block of Canada's parliament buildings is a blend of locally quarried Nepean sandstone combined with smooth, finely finished Ohio Berea sandstone and distinctive red Potsdam stone. Unfortunately, 150 years of pollution have darkened the stones, obscuring their colour and architectural detailing and threatening their stability.

Traditionally, the stones have been cleaned with abrasive techniques using air, water or steam. This invasive approach can actually damage them through over-cleaning and water saturation, destroying their protective layer and details, and exposing them to further deterioration.

Today, the stones are being cleaned using highly focused, powerful lasers that allow the stonemasons to simply vapourise the dirt without any physical contact. Unlike wet methods that require careful sequencing to avoid re-soiling previously cleaned stones, laser cleaning allows surfaces to be cleaned at any time and any location. This approach is now a standard tool in the stonemason's kit (Public Services and Procurement Canada, 2016).





(Regulations Amending the On-Road Vehicle and Engine Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999, 2015) reported \$19.8 million (2013 prices) in benefits from reduced soiling of houses (again, soiling or premature wearing of other assets was not considered). It is important to point out that neither of these figures represents the full cost of soiling due to pollution in Canada. They ignore the costs of soiling of commercial and institutional buildings and monuments, and they reflect only the costs of the soiling caused by the pollution reduced by the proposed regulations—not all pollution. It is not possible to say what the total costs of all soiling from all air pollution is based on these results. Nor do they offer any insight into the costs of premature wearing of materials.

The relatively high costs of soiling reported by the French Senate for France stands in contrast to the relatively low costs of soiling reported in the Canadian regulatory cost-benefit analyses. Even if the cost-benefit analyses do not reflect the cost of all soiling in Canada, it is hard to imagine how that cost could approach the kind of value reported for France. Of course, France and Canada are different countries, and it might be reasonably assumed that the costs of soiling in France would be higher than in Canada, given the larger population, smaller land mass and greater share of historical buildings in France as compared to Canada. Again, even taking these differences into account, there appears to be a wide gap between the figures reported for France and those for Canada. Which, if either, of the values is more reasonable is unclear. Comparing the Canadian figures with values from other studies is difficult because of the differences in time period, units of measure and measurement scope noted above. For now, estimating the cost of soiling and premature wearing of produced assets from pollution in Canada remains a matter for further research.

4.4.1.2 Road Salt

Road salt is commonly used in Canada to melt snow and ice on roads to make them safer for driving. While this has obvious benefits in terms of reducing the number of traffic accidents, corrosion caused by salt cause considerable damage to vehicles, bridges, roads and other produced assets (not to mention its impacts on ecosystems, as outlined in Text Box 13). Dissolved road salt can penetrate and deteriorate concrete on bridge decking and parking garage structures and damage concrete reinforcing rods, compromising structural integrity. Road salt application is the single biggest determining factor in the life of bridge decks and other infrastructure, from concrete pavements to sign and light posts (Fitch, Smith, & Clarens, 2013)

Text Box 13. The ecological consequences of road salt use

In addition to its impacts on produced assets, road salt can also severely impact freshwater bodies, even those far removed from urban centres. Salt runs off highways and roads as snow melts and accumulates in nearby lakes (McDiarmid, 2017). A recent study (Dugan et al., 2017) found that 44 per cent of 371 lakes assessed suffered from increased salinity, and estimated that at least 7,770 lakes in North America are at risk from salinization due to road salt.

Salt has a number of impacts on freshwater lakes, affecting fish, amphibians and plant life. Environment Canada considered listing salt as a toxic substance in 2001, but instead introduced a voluntary code of practice in 2004 (Mittelstaedt, 2010). Human health concerns also arise as salt levels in freshwater increase. Dissolved chloride cannot be filtered out of drinking water and can present problems for people with kidney disease or hypertension (Guarino, 2017).

Though the physical impacts of road salt on produced assets are well documented, few estimates of the costs of damages caused by road salt to these assets are available. A frequently quoted study is Vitaliano (1992), who estimated costs of US\$803/ton of salt for repair and maintenance of roads and bridges, vehicle corrosion cost (plus loss of aesthetic value due to roadside tree damage) in the United States. Anecdotal evidence places the total cost of corrosion damage and protection practices for highways and automobiles in the United States as high as US\$16–19 billion dollars a year (New Hampshire Department of Environmental Services, n.d.).

In Canada, a well-known case of infrastructure damage caused by road salt is that of Montreal's Champlain bridge. The bridge, which spans the St. Lawrence River and opened in the 1950s with an expected lifespan of 100 years



or more, has deteriorated much more quickly than expected. While road salt is not the only factor in the bridge's premature demise, it is a leading factor. The bridge is now being replaced after just half of its expected operating span at a cost of \$3 to \$5 billion (Kay, 2014). See Section 5.4.3 for discussion of the cost of this situation in terms of lost asset value.

Another infamous case is that of the Algo Centre Mall in Elliot Lake, Ontario. Partly as a result of damage caused by road salt (along with design and construction flaws and negligence on the part of those who owned and operated the mall), the mall's rooftop parking garage collapsed on June 23, 2012 onto the two floors below, sending tons of concrete, steel, drywall, glass, and one vehicle down. The collapse took the lives of two people and left 19 people injured (Bélanger, 2014).

According to Environment and Climate Change Canada (2012), about 7 million tonnes of road salt was sold in Canada in 2009, the most recent year for which data are available. If Vitaliano's 1992 damage cost figure of US\$803/ton is adjusted for exchange rates, inflation and conversion from imperial tons to metric tonnes, it becomes approximately \$1,650/tonne in 2015 prices. Obviously, a figure this old must be used with caution, especially when there is very little other evidence available to corroborate it. If it were accurate, it would imply costs for repair and maintenance of roads and bridges, vehicle corrosion and loss of aesthetic value of roadside trees of over \$11 billion annually in Canada.

This figure is likely an overestimate of the impact of roadside salt on produced assets for at least two reasons. First, roads and road vehicles are better built today than they were in 1992 when the study was done and less prone to damage from road salt. Second, the number includes damage to roadside trees, which are not produced assets. By how much this figure overestimates the actual costs of road salt damage is not clear. But as the cases of the Champlain Bridge and the Algoma Centre Mall indicate, road salt clearly takes a toll on produced assets and leads to costs that can be reasonably claimed to be in the billions of dollars annually.

4.4.2 Increased Operational Costs

There is little evidence available concerning the increased costs that companies or governments face in operating equipment or other production processes because of pollution. Such costs are no doubt significant, since both air and water are commonly used as inputs into production processes. As well, depending on the process, they are required to be free from contaminants to varying degrees.

In a study of the impact of algal blooms on Lake Erie (Midsummer Analytics and EnviroEconomics, 2015), Environment and Climate Change Canada considered the costs imposed by the blooms on a variety of operations that rely on Lake Erie as a source of raw water (see Sections 3.3.2.2 and 5.2.1 and 5.3.1 for further discussion of the algal bloom issue on Lake Erie and its costs). These users included seven golf courses, two food processing plants, 18 farms and 17 drinking water treatment facilities (five small private systems and 12 municipally operated plants). The presence of the blooms on the lake imposes potential additional costs on these users to filter and treat water contaminated with algal biomass (possibly including the liver toxin *Microcystin*) and to unclog water intakes submerged in the lake.

Little evidence was found of cost increases due to the blooms for golf courses, farms or food manufacturers. Drinking water plants, in contrast, reported significant additional costs to increase testing of raw water quality and the level of raw water treatment in order to meet drinking water standards. The study estimated these costs to amount to \$4 million annually (2015 prices). It is important to note that these are additional costs imposed on water users due to the emergence of the algal bloom issue on Lake Erie in recent years and not the total costs imposed by all water pollution. Much of these costs are already built into "normal" costs of operation and are not easily measured separately.



Extrapolating from this study of Lake Erie to estimate the income costs imposed by algal blooms, let alone other forms of water pollution, on water users across the country is not possible. Given the relatively small costs imposed on water users around Lake Erie, it is possible that these costs are not significant in comparison to other costs of pollution.

4.5 Income Costs of Impacts on Natural Assets

The natural assets impacted by pollution are the waterbodies, forests, farmland, atmosphere, soil and other parts of the environment into which pollution is directly released or eventually settles after being transported by air or water currents.

The cost of this exposure comes partly in reductions of natural assets' capacities to produce goods and services valued by humans.⁵⁴ For example, forests impacted by acid rain are less able to produce wood for harvesting and serve as recreation sites or offer beautiful vistas. Similarly, agricultural land exposed to ground-level ozone has a lower capacity to produce crops. Fish, wildlife and plants that ingest pollutants can pass them on to humans that consume them, making them less valuable as sources as food. An excess of greenhouse gases in the atmosphere reduces its ability to regulate the earth's climate and maintain weather patterns within the range to which society is adapted, which can lead, in turn, to reductions in the production of crops, timber, fish and a range of ecological services.

The income costs of natural assets' exposure to pollution also come in terms of increased costs to businesses that rely on them—for example, increased fertilizer costs to farmers to boost crop production or increased harvest effort on the part of forestry companies to obtain a given volume of timber.

4.5.1 Honeybee Decline and Pesticides

Colony collapse disorder (CCD) is the name given to a particular form of honeybee colony death that has been witnessed chiefly in the United States. Beginning in the winter of 2006–2007, some U.S. beekeepers noticed unusually large numbers of colonies failing to survive from fall to spring. While this was not unusual in and of itself, as beekeepers normally expect about 15 per cent overwinter loss of colonies. What made the deaths observed beginning in 2006 different was the number of affected colonies (about 30 per cent nationally and up to 90 per cent for some beekeepers) and the unusual condition in which many of the hives (about 50 per cent) were found in the spring: a live queen, larvae and nurse bees with plenty of food but no worker bees in the hive and no evidence of dead worker bees nearby (EPA, n.d.a).

Though overwinter bee colony deaths occur in Canada, as they do everywhere bees are kept, Canadian beekeepers have not noticed colony deaths that exhibit the unusual characteristics of CCD. The overwinter colony deaths seen by Canadian beekeepers in recent years are in line with historical norms in which bees starve, freeze or simply emerge from the winter too weak to survive into the summer (Boucher et al., 2012).

A number of factors are thought to be associated with CCD, including parasites and pathogens, poor nutrition, pesticides, bee management practices, habitat fragmentation and agricultural practices. No single factor or pattern of factors has been proven to be “the cause” of CCD (US Department of Agriculture, 2012).

Bees are exposed to a wide range of pesticides. Pesticides found in colonies include both those used to manage diseases or pests that directly infect bees as well as commercial agricultural pesticides. A survey of U.S. bees, honey

⁵⁴ In addition, there are obvious impacts beyond those of concern to humans. Non-human species that live in ecosystems can suffer significantly from the impacts of pollution, as in the case of birds, marine mammals and other aquatic life soiled following spills of oil in waterbodies. The well-being impacts on non-human lives cannot be valued in monetary terms and are, therefore, beyond the scope of this study. The costs of the efforts that human undertake to minimize the impacts of pollution on the environment and its non-human inhabitants are, however, within scope.



and honeycomb performed in 2010 did not find any pattern of exposure that correlated with CCD incidents. The pesticides most commonly detected were those used by beekeepers to control parasites that infect bees. Other studies indicate that pesticides may interact with other pesticides, with honeybee parasites or with pathogens in ways that significantly increase bee mortality. Yet other studies show that certain pesticides can have sub-lethal negative effects on bees, though it is not clear that a colony's ability to pollinate crops, produce honey and maintain itself are compromised by these effects on individual bees (US Department of Agriculture, 2012).

Since 2006, the rate of overwintering loss of bee colonies in the U.S. has fluctuated but has not surpassed the maximum level of about 36 per cent seen in 2007/08 (Figure 15) (Steinhauer et al., 2016). In all years, though, it has been considerably higher than what beekeepers have indicated as an “acceptable” level of overwinter loss given things like temperature, moisture and food supply. About one third of the overwintering losses are attributable to CCD (US Department of Agriculture, 2012). Summertime colony losses, which have only been tracked since 2010/11, add considerably to total annual losses, which reached nearly 45 per cent of all colonies in 2015/16 based on preliminary data.

In Canada, the share of overwinter colony deaths appears to have declined in recent years vis à vis the historically high rates seen in 2007 to 2009. Recent Canadian rates have been closer to the generally accepted rate of overwintering loss of 15 per cent. As noted, Canadian beekeepers have not noticed cases of colony death that could be described as CCD, so all Canadian cases are of the more typical sort involving starvation, freezing and overall colony weakness (Canadian Association of Professional Apiculturists, 2016). The number of commercial bee colonies has increased in both Canada (Statistics Canada, 2016e) and the United States (USDA, 2016) in recent years.

Considerable attention has been paid to the possible link between a relatively new category of pesticides known as neonicotinoids and CCD. Though that link remains a subject of considerable debate, there is clearer evidence of a link between individual honey bee mortality and neonicotinoids during non-winter months. According to Health Canada, dust generated during the sowing of corn and soybean seeds treated with neonicotinoids contributed to reported bee mortalities in 2012 and 2013. Of dead bees collected during the corn and soybean planting periods in 2012 and 2013 in Canada, 70 per cent had neonicotinoid residues present. In response, Health Canada implemented a series of measures to reduce exposure of bees to dust during the planting season (Health Canada, 2014). The Province of Ontario went a step further, implementing regulations to reduce the number of acres planted with neonicotinoid-treated corn and soybean by 80 per cent by 2017. This regulation was implemented after winter bee deaths in Ontario hit their highest recorded level of 58 per cent in 2013–2014 (Government of Ontario, 2014).

Though there has been some effort to assess the economic costs of honey bee declines in the U.S. (Carman, 2011; Rucker & Thurman, 2012; Desin, 2014), the studies have all focused on the costs of CCD and not of honeybee declines more broadly. CCD, as already noted, seems not to exist in Canadian honeybee colonies, so the existing studies are of little relevance in Canada. Moreover, the results of the studies are somewhat contradictory, with one (Carman, 2011) finding substantial costs of California almond farmers and the other two (Rucker & Thurman,

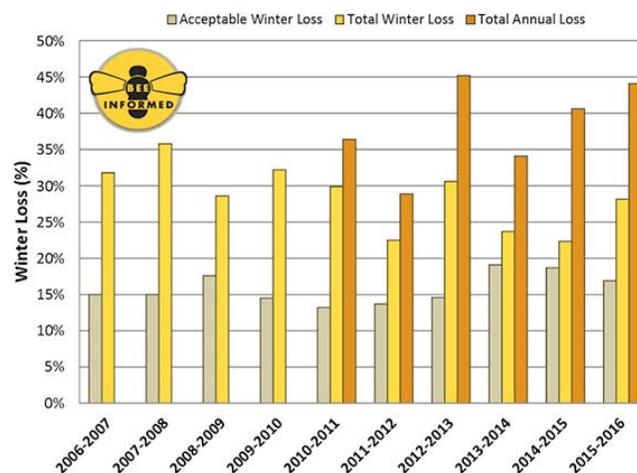


Figure 15. Losses of U.S. honeybee colonies, 2006/07–2015/16

Source: Steinhauer et al., 2016.



2012; Desin, 2014) downplaying those costs. Even if the studies were in agreement regarding the economic costs of CCD and CCD were to be an issue in Canada, there is still no scientific consensus regarding the role of pesticides in CCD. Attribution of CCD costs to pesticide use would, thus, be uncertain in any case. For these reasons, no estimate of the economic cost of pesticides in regard to honeybee declines is possible here.

4.5.2 Acid Rain

“Acid rain” is the name commonly used to refer to any kind of liquid or solid atmospheric deposition on land or water that contributes to the acidification of soil or water (that is, the lowering of soil or water pH below normal levels). Acidic deposition results from the transformation of SO_2 and NO_x into sulphuric acid, ammonium nitrate and nitric acid. Both SO_2 and NO_x can be transported over distances of thousands of kilometres, so it is possible for acidic deposition to fall in areas far removed from pollution sources. Wet acidic deposition, when acidic deposition falls in the form of rain, snow, sleet or hail, is true “acid rain”. Dry acidic deposition takes place when acidic particles are directly deposited or absorbed onto surfaces without first being dissolved in water. The particles are converted into acids when they subsequently contact water (Environment Canada, 2013b). From here on, the term “acid rain” is used to describe all wet and dry acidic deposition for the sake of simplicity.

4.5.2.1 The Ecological Impacts of Acid Rain

Acid rain has a variety of both short- and long-term impacts on ecosystems. Aquatic and terrestrial ecosystems can be affected.

Freshwater ecosystems that have been acidified cannot support the same variety of life as healthy ones. As water becomes more acidic, crayfish and clam populations are the first to disappear, followed by various types of fish. In southern Nova Scotia, for example, rivers were so acidified in the 1980s that salmon stocks were cut in half (Watt, 1987). Acidified lakes and rivers do not become totally dead however. Some life forms actually benefit from increased acidity. Lake-bottom plants and mosses, for instance, thrive in acidic lakes, as do blackfly larvae (see below for further discussion of the impact of acid rain on aquatic animals). Moreover, not all fresh water exposed to acid rain becomes acidified. In areas where there is plenty of limestone rock, fresh water is better able to absorb acid. In areas where rock is mostly granite, such as the Canadian Shield of Eastern Canada, lakes are less able to neutralize acid (Environment and Canada, 2013b).



Evidence is mixed regarding the degree to which acidified lakes can recover if acid rain diminishes, as it has over much of North America (see Text Box 14). Sudbury, Ontario, a notorious hotspot for acid rain, where some 7,000 lakes were once acidified, has seen widespread improvements thanks to reduced emissions of SO_2 and NO_x . Nonetheless, many lakes remain acidified, and biological recovery was still at an early stage in 2007. Of 202 Canadian lakes studied since the early 1980s, 33 per cent have reduced levels of acidity while 56 per cent have shown no change and 11 per cent have actually become more acidic (Environment and Climate Change Canada, 2013b). Improvement has been the slowest in Atlantic Canada, even though lakes in this region were never as highly acidified as those in Ontario and Quebec (Environment Canada, 2013b). The pattern of recovery indicates that the recovery of acid-damaged lakes is closely linked to the effects of other major environmental stressors, such as climate change (Keller Yan, Gunn, & Heneberry, 2007).



Text Box 14. Latest acid rain trends

Despite great strides in reducing emissions of SO_2 and NO_x since the height of the problem in the 1970s and 1980s, acid rain continues to negatively impact the Canadian environment. In 2012, the most recent year for which data are readily available, wet sulphate deposition on the acid-sensitive forests of the Canadian Shield was generally below 15 kg sulphate/hectare/year (Figure 16), well below levels seen in earlier decades. Even at this reduced rate of deposition, however, there were still many areas in Canada with a high probability (75 per cent or greater) of “critical load”^{*} exceedance, most notably in the southern parts of Ontario and Quebec, in the Vancouver area of British Columbia and parts of northern Alberta, Saskatchewan and Manitoba. Critical loads for wet sulphate deposition in eastern Canada range from 8 to 20+ kg of wet sulphate/hectare/year (Canadian Council of Ministers of the Environment, 2013). No data on actual critical load exceedance are available for Canada, but estimates for the United States show that 27 per cent of nearly 4,900 lakes modelled were in exceedance of critical loads in 2010–2012 (down from 42 per cent in 2000–2002) (International Joint Commission, 2014a).

^{*} A “critical load” is a measure of how much pollution an ecosystem can tolerate; in other words, the threshold above which pollutant load harms the system’s functioning. Critical loads for acid rain are defined as the amount of sulphate that can be deposited on a region and still maintain 95 per cent of the lakes in the region at or above a pH of 6 (Canadian Council of Ministers of the Environment, 1998).

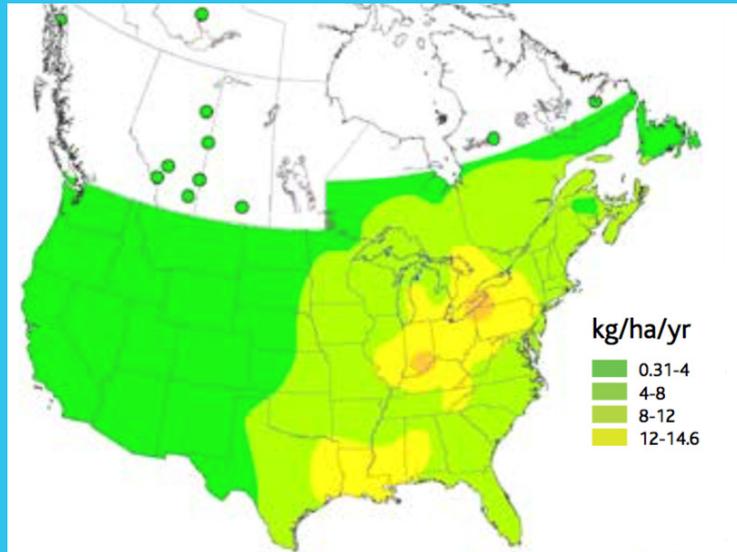


Figure 16. Wet sulphate deposition (kg SO_4^{2-} /hectare/year), 2012

Source: International Joint Commission, 2014a.

Recent research (Hadley et al., 2015) suggests that lake acidification may result in long-term ecological effects even if lake pH levels recover. For example, crayfish in some Ontario lakes have not returned in spite of the reduction in acidity of these lakes in recent years. The reason appears to be significant declines in calcium concentrations as a consequence of acid deposition as well as other stressors (such as timber harvesting). These low calcium concentrations are expected to hamper recovery from lake acidification and to have cascading effects throughout aquatic ecosystems (Jeziorsk & Smol, 2016).

Looking at *forest ecosystems*, the primary effects of acid rain include toxic impacts on trees and other plants, nutrient deficiencies, aluminum mobilization in soil and decreased productivity. The impacts range from minimal to severe, depending on the region of the country and on the acidity of the rain. Acid rain damages the surfaces of leaves and needles, reducing the ability of trees to withstand cold and inhibiting regeneration. Acid rain also depletes important nutrients (e.g., calcium and magnesium) and increases the concentration of aluminum in soils, interfering with the uptake of nutrients by the trees. This lack of nutrients can cause trees to stop growing altogether. Trees exposed to acid rain may also have more difficulty withstanding other stresses, such as drought, disease, insect pests and cold weather (Environment Canada, 2013b).

The ability of forests to withstand acidification depends on the ability of the forest soils to neutralize acid. This is determined by the same factors that affect the sensitivity of lakes to acidification. Consequently, the threat to forests is largest in those areas where lakes are also seriously threatened: central Ontario, southern Quebec and the Atlantic provinces—home to most of Canada’s iconic sugar maple forests (Environment Canada, 2013b). The effects of acid rain on the sugar maple—famed both as the source of maple syrup and for the beautiful foliage so many people associate with autumn in eastern North America—are discussed in Text Box 15.



While the forest soil damage caused by acid rain may be reversible, it would take many years—in some areas hundreds of years—for nutrients to be replenished even if it were eliminated completely. For now, forests where acid rain exceeds critical loads are using the pool of minerals accumulated since the last ice age, and monitoring indicates that some forests are already deficient in minerals, threatening their long-term viability. As much as half of Canada’s eastern boreal forests could eventually be impacted (Environment Canada, 2013b).

Text Box 15. Sugar maples and acid rain

The sugar maple is arguably the most ecologically and economically important hardwood tree species in eastern North America. Ecologically, sugar maples provide nutrient-rich litter for forest soils, help build up soil and reduce the leaching of nitrate into groundwater, not to mention their role in shaping the overall diversity of plant and animal communities. Economically, the tree provides the raw material for the maple syrup industry so important in Quebec and other provinces, durable hardwood for furniture and flooring and all but defines the concept of “autumn” for tens of millions of North Americans.

Some evidence suggests that growth of sugar maples on acid-sensitive soils in Ontario began to decline in the 1960s (Hall et al., 1998). However, data from the *North American Maple Project*, a cooperative project among the Canadian provinces and U.S. states that ran from 1988 to 2007, do not show evidence of change in the condition of sugar maples in the monitored region. Except for the first year of the program, the share of “healthy” sugar maples remained around 90 per cent for the entire period (North American Maple Project, n.d.). At the same time, more recent data suggest that the majority of sugar maples in the Adirondack Mountains of the United States exhibited declining growth in the last several decades. These results were unexpected, given recent warming and increased moisture availability, as well as reduced acid rain, all of which should have favoured growth. Further study is called for to determine whether declining growth is evident more widely across the sugar maple’s range (Bishop et al., 2015).

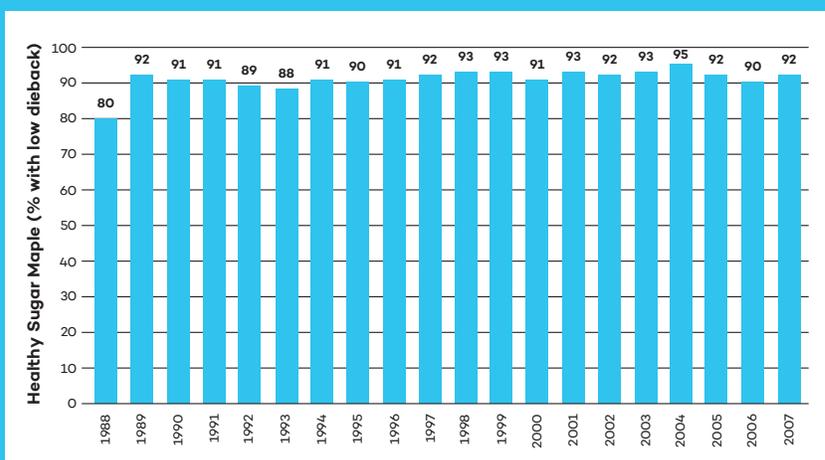


Figure 17. Sugar maple health status, North American Maple Project, 1988–2007

Source: North American Maple Project, n.d.



An early concern regarding acid rain was that it would negatively affect the maple syrup industry in Quebec, Ontario, Vermont and elsewhere (CBC Digital Archives, 1984; Goldberg, 1985). Yet the available statistics from the Quebec Federation of Maple Syrup Producers do not necessarily support this conclusion. According to their latest economic data (Bellegarde & Rouillard, 2015), total maple syrup production in the province has, with expected yearly variations, grown steadily since 1985. This growth in output cannot be attributed simply to an increased number of taps, since the average annual production per tap has, again with expected variations, remained quite steady over time.

Assuming that the efficiency of the maple syrup industry has improved since 1985 through the introduction of improved collection and sap boiling systems, the fact that syrup production per tap has not increased is, perhaps, a sign that Quebec sugar maple trees have become less productive since the onset of acid rain, and that the value of production would have increased even more than it did in the absence of acidification. Determining whether this is true would require additional research.



Aquatic animals can also suffer from acidic rain (Table 4). Impacts of acidification include increased morbidity and mortality of sensitive species, changes in species composition and declines in species richness. As noted above, crayfish and clams are often the first to be affected as fresh water is acidified, followed by fish. Some kinds of fish such as smallmouth bass, walleye, brook trout and salmon are more sensitive to acidity than others and tend to disappear early as well. Even aquatic species that appear to survive may suffer in a number of different ways, including spawning failures, weak hatchlings, decreased growth, difficulty regulating body chemistry and increased susceptibility to disease (Environment Canada, 2013b).

Table 4. Impacts of acid rain on aquatic animals

As water pH approaches...	Effects
6.0	<ul style="list-style-type: none"> • Crustaceans, insects and some plankton species begin to disappear.
5.0	<ul style="list-style-type: none"> • Major changes in plankton communities • Less desirable species of mosses and plankton may begin to invade • The progressive loss of some fish populations is likely, with the more highly valued species being generally the least tolerant of acidity.
Less than 5.0	<ul style="list-style-type: none"> • Lakes largely devoid of fish • Lake bottoms covered with non-decayed plant material • Near shore areas may be dominated by mosses • Terrestrial animals dependent on aquatic ecosystems for food (such as waterfowl) are affected.

Source: Environment Canada, 2013b.

In spite of the well-documented ecological impacts of acid rain (see above), relatively little effort has been put into assessing the related economic costs, particularly in Canada. As recently as 2004, no study had ever attempted to estimate the total costs of acid rain in the Adirondack region of New York State, even though most of U.S. policy on acid rain emanates from concerns during the 1970s and 1980s about the impacts on Adirondack forests (Banzhaf, Burtraw, Evans, & Krupnick 2006). In only a few instances is there a well enough understood link between acid rain and ecosystem quality to value the impacts. The few studies that have been conducted are mainly old (dating from the 1980s and 1990s), discuss a limited range of costs (mainly recreational fishing impacts), are of questionable quality in some cases and are mainly focused outside of Canada. Moreover, while damages to ecosystems sparked the initial concern about acid rain, most of the economic benefits from reducing it are reported to be linked to human health improvements from lower SO_x and NO_x emissions. Effects of acidification that have not been quantified include loss of forest aesthetic value, effects on forest recreation, reduced values to non-users and reduced biodiversity (Seip & Menz, 2002; Chestnut & Mills, 2005).

The World Bank and the State Environmental Protection Administration (2007) has estimated the partial cost of acid rain in China, arriving at values of 30 billion renminbi in crop damage (1.8 per cent of the value of agricultural output) and 7 billion renminbi in material damage (approximately \$11 billion and \$2.6 billion respectively) annually (2003 prices). Banzhaf et al. (2004) have estimated the total value of the expected benefits from additional reductions in acid rain in the Adirondacks to be between US\$338 million and US\$1.1 billion (approximately \$427 million and \$1.4 billion; 2004 prices).

In one of the few studies focused on the costs of acid rain in Canada, Crocker and Forster (1986) suggested that the loss of commercial timber production could be \$197 million annually and that a further \$1.29 billion might be lost annually in recreational opportunities and wildlife habitat values (1981 prices) assuming a 5 per cent reduction in forest productivity.



Talhelm et al. (1987) found that that under severe acid loadings simulated over 50 years, 5 per cent of lakes in the Muskoka region of Ontario would eventually provide no fishing, and fishing quality would significantly change in another 20 per cent. As a result, the annual amount of fishing in the region would decline by 1 per cent (6,000 angler-days). The present value of this cumulative loss over 50 years was estimated to be \$6.6 million (1981 prices; approximately \$17 million in 2015 prices).

More recently, Environment Canada (2010) has reported that “hundreds of millions of dollars” worth of timber are being lost from forests in Atlantic Canada due to acid rain and likely much more in Ontario and Quebec, “though data to verify this assumption is not currently available” (n.p.).

Phillips and Forster (1987) reported that the total impact of acid rain on the Quebec maple syrup industry could be \$89 million (1986 prices), though it is not clear over what period. As noted in Text Box 15, the value of Quebec maple syrup production has increased more or less steadily since 1985, and productivity per tap has remained essentially stable. Whether production would have increased more in the absence of acid rain is a question that could only be answered with further research.

Considerable concern was expressed by fishing lodge operators in the 1980s that the decline in freshwater fish due to acid rain would damage their businesses (CBC Digital Archives, 1985). Recreational fishing statistics compiled by Fisheries and Oceans Canada (2017) (J. Hosein, Fisheries and Oceans Canada, personal communication, February 2, 2017) provide some evidence that their concerns were valid. Expenditures by all anglers⁵⁵ in New Brunswick and Ontario—both provinces affected by acid rain—declined more quickly (-2.6 per cent and -2.1 per cent annually respectively) than for the nation as a whole (-0.7 per cent annually) from 1975 to 2010 (Table 5). These declines were largely the result of fewer anglers taking part in recreational fishing rather than of changes in spending per angler. Recreational fishing expenditures in New Brunswick were about \$50 million lower in 2010 compared to 1975 after taking inflation into account (2015 prices). In Ontario, the drop was more than \$1 billion. Whether the relatively steeper declines in New Brunswick and Ontario were the result of damage to lakes and rivers due to acid rain in those provinces or just part of the overall national trend away from recreational fishing is uncertain.⁵⁶

“ Some kinds of fish such as smallmouth bass, walleye, brook trout and salmon are more sensitive to acidity than others and tend to disappear early as well. ”



⁵⁵ Anglers include both resident and non-resident adults who fish in the province except in the case of Quebec where statistics on non-resident anglers are not available.

⁵⁶ The data for Quebec, which is also subject to acid rain damage, show an increase in recreational fishing expenditures from 1975 to 2010 (though a steep decline between their peak in 1985 and 2010). However, these figures reflect only Quebec resident anglers and not all anglers as in other provinces. As a result, the trend in Quebec is not directly comparable with that for other provinces.

**Table 5. Recreational fishing expenditures by province, 1975–2010 (thousand chained 2015 CAD)**

	1975	1980	1985	1990	1995	2000	2005	2010
NL	64,088	57,311	79,350	83,997	74,550	57,056	60,663	37,634
PE	5,374	5,097	4,700	3,668	2,872	2,678	2,850	3,408
NS	35,594	35,225	34,619	35,561	27,497	28,414	25,974	23,814
NB	82,816	60,568	54,703	38,054	39,160	31,903	29,624	33,237
QC	294,485	559,645	1,180,171	789,427	832,524	622,516	448,299	514,296
ON	2,050,666	1,464,389	2,141,565	1,804,960	1,484,676	1,315,136	1,220,480	991,919
MN	139,740	138,516	182,822	126,241	112,650	159,360	125,737	106,192
SK	153,348	120,480	157,712	125,064	137,863	143,543	142,020	145,422
AB	163,477	179,987	293,348	210,847	181,037	153,781	158,474	186,563
BC	470,567	536,027	819,948	668,255	729,473	626,368	673,965	668,054
YK	10,493	12,195	12,132	11,057	14,009	13,035	14,281	12,309
NT/NU	21,272	28,164	32,241	12,640	22,593	31,567	15,546	15,008
Total	3,491,920	3,197,604	4,993,311	3,909,771	3,658,903	3,185,357	2,917,913	2,737,856

Source: J. Hosein, Fisheries and Oceans Canada, personal communication, February 2, 2017.

While the various costs of acid noted above are significant, the fact is that they are based on data and methods that are largely out of date and/or are inconclusive regarding the link with acid rain. For this reason, they are not reliable enough to use as a basis for estimating the overall economic impact of acid rain in Canada for this study. Given the importance of acid rain as an environmental issue, both in the past and for the future, estimating this cost should be seen as a priority.

4.5.3 Reduced Agricultural Output

Tropospheric ozone has a direct toxic effect on plants. High levels of ozone cause damage to leaves and foliage, reduced chlorophyll content, decreased photosynthesis, increased respiration, altered carbon allocation, water-balance changes, and damage to epicuticular wax. In forests, high levels of ozone result in changes to the canopy structure and reduced productivity of trees. Sensitivity to ozone is variable across plant species. Evergreen trees tend to be more robust than deciduous species, and annual plants tend to be the most sensitive (EPA, 2011). For agricultural lands, high concentrations of ground-level ozone (see Text Box 1) reduce crop yields and thus agricultural output.

Sawyer et al. (2007) estimated \$36 million in lost agricultural output in Canada associated with ground-level ozone due to transportation emissions alone in 2000. This does not represent the full cost of ground-level ozone impacts, since their study considered transportation-related emissions only.

Transportation was responsible for about 53 per cent of NO_x and 22 per cent of VOC emissions in 2014, not including open sources (Environment and Climate Change Canada, 2017b). Given transportation's share of these precursor emissions to ground-level ozone, a conservative factor by which to adjust the cost of that reduction to account for other emissions sources would be 2. Using this factor, the total cost of reduced agricultural output due to ground-level ozone in Canada would be \$72 million (2000 prices). Adjusting this for inflation gives a figure of about \$96 million in 2015, or about 0.6 per cent of value added in the crop farming industry. This figure is in the same range as findings of other studies (Adams, Hamilton, & McCarl, 1986; Adams, Glycer, Johnson, & McCarl, 1989; Murphy, Delucchi, McCubbin, & Kim, 1999; OECD, 2016).



4.5.4 Ozone Depletion – Costs of increased UV-B radiation

Ozone (O₃) depletion is the term commonly used to describe the thinning of the ozone layer in the stratosphere. Ozone depletion occurs as a result of human emissions of “ozone-depleting substances” (ODS)—long-lived chemicals like chlorofluorocarbon refrigerants—that make their way to the stratosphere where they destroy some of the ozone naturally found there.

Ozone depletion was first raised as a concern by scientists (who later were awarded the Nobel Prize) in the 1970s.

The global community famously took action to limit the emissions of ODS through the Montreal Protocol, a global agreement to limit the production and use of ODS. Since the protocol’s coming into force in 1989, worldwide use of controlled ODS has fallen dramatically (Figure 18).

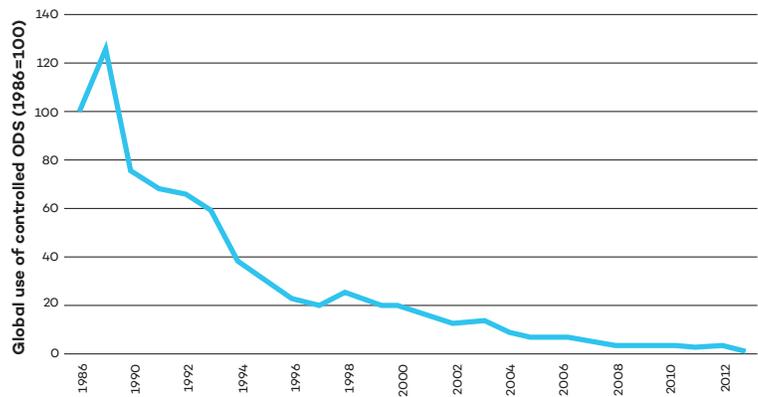


Figure 18. Index of global use of ozone-depleting substances, 1986–2013

Source: European Environment Agency, 2017.

The reduction in global ODS emissions has had a positive impact on the health of the ozone layer, though improvements have been slow to emerge. It was not until 2016 that scientists were able to declare (Solomon et al., 2016) that the annual summertime hole in the ozone layer over Antarctica had begun to show signs of definite improvement after many decades of steadily growing each year. Still, 2015 saw one of the largest and longest-lived holes ever recorded, partly due to the eruption of Chile’s Mount Calbuco in April 2015 (Figure 19). It is not expected that the ozone layer will fully recover until 2050 at the earliest (Hand, 2016).

4.5.4.1 The Health and Environmental Impacts of Ozone Depletion

Depletion of the ozone layer increases the amount of ultraviolet radiation (UV-B) that reaches the planet’s surface. This has a variety of consequences for humans, ecosystems and the economy, the full extent and direction (positive or negative) of which is not yet understood (UNEP, 2015). For example, the same organism in different bodies of water in different parts of the ocean may respond differently to UV-B increases. Furthermore, stress to organisms and ecosystems from increased exposure to UV-B is affected by other stresses, such as lack of water or nutrients (NASA, n.d.). Given this complexity, the discussion of the impacts of UV-B radiation below should be taken as indicative of the range of effects rather than an exhaustive listing.

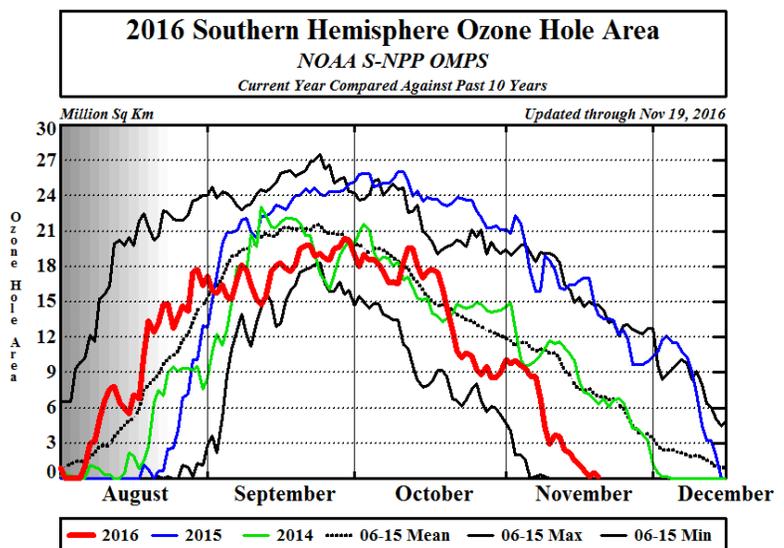


Figure 19. Antarctic ozone layer hole area, recent years and 2006–2015 trends

Source: National Weather Climate Prediction Centre, 2016.



Human health impacts of increased UV-B radiation:

- Short-term impacts of excessive UV-B radiation exposure are sunburn and eye inflammation. Long-term regular exposure can lead to melanoma and non-melanoma cancers and cataracts. A benefit of exposure for humans is synthesis by the body of vitamin D, which is critical in maintaining bone health, cell growth, neuromuscular and immune system function and reduction of inflammation (National Institutes of Health, n.d.).

Ecosystem impacts of increased UV-B radiation:

- The effects of UV-B radiation on plants are complex and can be both positive and negative. Productivity and hardiness of plants, including agricultural crops, can be both improved and decreased depending on the location and type of plants. Rates of decomposition of plant litter in forests can be affected, though uncertainty exists regarding its significance.
- Interactions between climate change and UV radiation are having strong effects on aquatic ecosystems. Higher air temperatures are increasing surface temperatures of lakes and oceans, decreasing the depth of the upper mixed layer and exposing the organisms that live there to greater amounts of UV-B radiation. Scientists have demonstrated a direct reduction in phytoplankton production—the foundation of aquatic food chains—due to increases in UV-B (EPA, n.d.b). Ocean acidification from climate change also interferes with the ability of zooplankton (and other organisms important in marine food chains) to form exoskeletons (shells), making them more susceptible to damage from UV-B radiation. In freshwater lakes, climate change is increasing turbidity (due to increased organic matter growth), limiting UV-B penetration, benefiting UV-sensitive species, including invasive species and pathogens.
- UV radiation is an essential driver in the formation of ground-level ozone. Perversely, there is a concern that recovery of the ozone layer will actually lead to increases in ground-level ozone. This is because UV radiation also contributes to formation of so-called “hydroxyl radicals” in the atmosphere that play a role in its self-cleansing. Fewer hydroxyl radicals may lead to higher concentrations of ground-level ozone.
- The role of UV radiation in creating “microplastic” particles in the oceans from the weathering of plastic litter on beaches is an emerging concern. These particles, which can concentrate toxic chemicals dissolved in seawater, are ingested by zooplankton, a main food source for animals further up the food chain. This is a potential mechanism for bio-concentration of toxics.

Economic impacts of increased UV-B radiation:

- Exposure to excessive UV-B radiation reduces the size, productivity and quality of many of the crop plant species that have been studied (among them, rice, soybeans, winter wheat, cotton, and corn) (NASA, n.d.).
- Many materials used in the economy, particularly plastics and rubber, are adversely affected by UV-B radiation. Though today’s materials can be protected from UV-B by special additives, increased UV-B levels accelerate their breakdown, limiting their useful lifetimes.

4.5.4.2 Economic Costs of Ozone Depletion

Given the uncertainty regarding the impacts of ozone depletion on human health, ecosystems and the economy, it is not surprising that information on its economic consequences is also limited. The few studies that exist, while offering useful insight into the possible magnitude of the costs, are not sufficient to draw conclusions about the cost of ozone depletion to Canada’s economy. All that can be said is that the annual cost of ozone depletion in Canada may range from hundreds of millions of dollars to perhaps an order of magnitude more, with a high degree of uncertainty around the exact value.



In a cost-benefit analysis of regulations to ban the use of ODS as propellants in medical inhalers (e.g., for treating asthma), Environment Canada (Regulations Amending the Ozone-depleting Substances Regulations, 2001) estimated the net present value (5 per cent discount rate) of the net benefits of avoided ODS emissions over a 60-year period of about \$900 million (2000 prices). In equivalent annual terms and taking inflation into account, this amounts to about \$64 million in annual benefits (or avoided costs) in 2015. The analysis used estimates for the benefits per tonne of avoided ODS emissions from the U.S. EPA that considered impacts on human health, aquatic ecosystems, crop production and materials. The ODS emissions avoided by the ban were estimated to be about 231 tonnes per year from 2001 to 2015.

In a study of the possible costs of increased incidence of cataracts in the U.S. due to ozone depletion, West et al. (2005) estimated that with 5–20 per cent ozone depletion, there would be 167,000–830,000 additional cases of cortical cataracts between 1980 and 2050. At a 2003 cost of US\$3,370 per cataract operation, this increase could represent an excess cost of US\$563 million to US\$2.8 billion, or US\$8 million to US\$40 million annually on average (2003 prices). This would not include the value of direct welfare impacts of pain and suffering associated with the disease, which could be considerably higher.

In a 1999 study of the cost of applying sunscreen to avoid possible health damages from excess UV-B radiation, Murdoch and Thayer (1990) reported that the net present value (5 per cent discount rate) of the cost of sunscreen over the 50-year period 2000–2050 and assuming a 17.05 per cent increase in UV-B radiation was US\$198 billion (1985 prices), or about US\$10 billion in equivalent annual terms. If reasonable as a cost of ozone depletion, this is clearly a very large figure. Converting it to the Canadian context given the differences in population size and opportunities for outdoor activities would not be valid.

In a 1990 study of the possible impacts of ozone depletion on agricultural output, Adams and Rowe found that a 15 per cent decrease in the concentration of stratospheric ozone depletion may have caused agricultural crop losses of between US\$1.3 and US\$2.5 billion in 1982. The estimates, which are clearly large, were labelled “preliminary” given their high degree of uncertainty.

“ It was not until 2016 that scientists were able to declare (Solomon et al., 2016) that the annual summertime hole in the ozone layer over Antarctica had begun to show signs of definite improvement after many decades of steadily growing each year. ”



4.6 Income Costs Due to the Need to Manage Pollution

The final category of income costs considered in this chapter is costs related to efforts to limit the amount of pollution that reaches human, economic or natural receptors. These efforts increase costs for businesses, governments and individuals in two principal ways:

- The costs of limiting the impact of accidental spills of pollutants (Section 4.6.1)
- The costs of remediating polluted sites resulting from human activities in earlier period (Section 4.6.2 and Section 4.6.3).

In addition, households, governments and businesses spend considerable sums to prevent pollution from occurring in the first place by managing sewage, municipal garbage and other wastes. Though not, strictly speaking, costs of pollution, these costs are presented here as supplementary information since they are clearly related to society's concerns about pollution's costs (Section 4.6.4).

4.6.1 Spill Cleanup Costs

When materials such as crude oil are accidentally spilled there can be serious consequences for environmental quality, especially when the spill is large as in the famous cases of the Exxon Valdez tanker spill in Prince William Sound, Alaska (1989) and the Deepwater Horizon offshore platform blowout in the Gulf of Mexico (2010).

To limit the consequences of spills, both large and small, considerable effort is put into limiting the spread of the material over the land and water and removing it from the environment. These activities are expensive and, especially in the case of large spills, represent a significant cost of pollution. The total cost to Exxon of dealing with the Exxon Valdez disaster is reported to have been US\$2.1 billion (Exxon Valdez Oil Spill Trustee Council, n.d.) while British Petroleum (BP) has now spent over US\$61 billion relating to the Deepwater Horizon blowout—the largest oil spill to date globally—for response, cleanup, economic claims, government payments, settlements and restoration (BP, n.d.).

Though Canada has not seen spills of the magnitude of the Exxon Valdez or the Deepwater Horizon and has, therefore, not faced the kinds of containment and cleanup costs associated with them, the country nonetheless has its share of spills. The most serious of these was the 2013 Lac Mégantic disaster, in which a Montreal, Maine and Atlantic Railway train derailed and exploded on the evening of July 5, 2013 in the town of Lac Mégantic, Quebec. The ensuing blaze and explosions left 47 people dead. Another 2,000 people were forced from their homes, and much of the downtown core was destroyed. About 6 million litres of petroleum crude oil was released. (Transportation Safety Board of Canada, n.d.). The cost of this disaster in terms of human suffering is, needless to say, beyond quantification. As for the costs of containment and cleanup, by 2014, costs incurred by the Quebec government had amounted to \$126 million, with another \$283 million in expected costs to complete the process.

Data on spills in Canada are lacking. There is no single source that provides comprehensive information on the types and quantities of materials spilled. The data that do exist are incomplete in important ways. The Transportation Safety Board (2016) provides on-line data on spills for the air, marine, rail and pipeline transport industries. Only for the pipeline industry do the data provided include information on the type and quantity of material spilled. For the other industries, only qualitative data indicating whether a spill occurred and whether dangerous goods were involved are available. No data on spills from the truck transport industry are available at all. Even the available pipeline data appear to be significantly incomplete. For example, of six major pipeline spills that occurred in Alberta between 2011 and 2014 (CBC News, 2015), none appears to be included in the Transportation Safety Board's database for pipeline accidents. According to the information found in that database, a nearly inconsequential 1.01 m³ (about 6 barrels) of crude oil was spilled in total in Alberta in 2011 and there were no negative environmental effects associated with the spills. Yet 2011 was the year in which the largest Alberta pipeline



spill in 35 years occurred, spilling some 28,000 barrels northeast of Peace River (CBC News, 2011). Why such a large spill would be so obviously missing in the Transportation Safety Board database is unclear.

As for spills from industries other than transportation, Environment and Climate Change Canada's National Pollutant Release Inventory (NPRI) is the only available source. This is problematic, as the NPRI is known to have significant shortfalls from a statistical perspective, including exemptions from reporting for certain industries, inadequate systems and practices to assess data quality and verify that all facilities required to report are doing so and difficulty in comparing data over time due to changes in estimation methods and reporting thresholds (Commissioner of the Environment and Sustainable Development, 2009). It is doubtful, therefore, that the NPRI provides an accurate assessment of the types and quantities of materials spilled.

For all these reasons, it is not possible to offer an estimate of the cost of limiting the impact of spills in Canada.

4.6.2 Managing Contaminated Sites

One of the legacies of Canada's economic development is a large number of sites where land and/or water are contaminated with residues from previous pollution emissions. These sites include former mine sites, industrial facilities, gas stations, urban developments, military installations and others. Many of these sites are abandoned, meaning that their former owners are no longer willing or able to accept responsibility for them. In such cases, the responsibility and cost of managing and remediating the sites fall to government.

The federal government has established an inventory of over 22,000 sites with suspected or actual contamination that fall under its custodianship, as well as non-federal sites for which it has accepted responsibility (Treasury Board of Canada Secretariat, n.d.a). Federal contaminated sites range in size and type from small sites contaminated by just one substance to very large sites contaminated by a range of substances. Of the sites in the federal inventory, remediation has been completed or deemed unnecessary at more than 15,000 that have been permanently closed.

The federal inventory does not cover sites controlled by Crown corporations, so-called "shared-responsibility" sites for which responsibility is shared with another level of government, such as the Sydney Tar Ponds in Sydney, Nova Scotia, or nuclear legacy sites (Parliamentary Budget Office, 2014). In addition, an unknown number of sites under the jurisdiction of provincial/territorial and municipal governments also exist. Private businesses (Text Box 16) and homeowners are also custodians of contaminated sites, sometimes without even knowing it. No reliable estimate of the total number of sites in the country is available, though a figure of 40,000 estimated by the National Round Table on the Environment and the Economy (NRTEE, 2003) is often cited.

Of the thousands of contaminated sites in Canada, only the cost of managing those under federal responsibility is known with any certainty. Table 6 provides an overview of the number of sites listed in the federal inventory and the associated spending since 1995/96. Both the number of sites under assessment and/or remediation and the

Text Box 16. Contamination at former Nortel plant sites

For decades before its closure in 2009, Nortel manufactured electronics at plants around Ontario. These sites, in Belleville, Brockville, Kingston and London, Ontario are now known to be contaminated with chlorinated solvents (such as trichloroethylene) and other chemicals. At some sites, such as Belleville, the chemicals have leached into groundwater, carrying them further from their source (Ireton, 2017).

Given Nortel's bankruptcy, it is unclear who will pay to clean up its former plant sites. One possibility is that the costs will be passed onto various levels of governments and ultimately paid by the public—as has been the case in numerous other instances of industrial contamination (see Text Box 17). A total of \$315 million is being sought through Nortel's bankruptcy proceedings for remediation of the former sites by the Ontario Ministry of Environment and Climate Change, the City of Belleville, Ontario and the Algonquin and Lakeshore Catholic District School Board in Napanee, Ontario (Ireton, 2017). Whether these claims will ultimately be successful remains to be seen.



related expenditures jumped dramatically in 2005/06, the year the Federal Contaminated Sites Action Plan (FCSAP)⁵⁷ came into being (Federal Contaminated Sites Portal, 2016a). Spending has gradually crept up since the start of FCSAP, as more sites have moved from the relatively inexpensive assessment stage into the often very expensive remediation stage. Between 2005/06 and 2014/15, the average expenditure on federal sites was \$283 million annually. This figure is expected to climb as more “big” sites shift from assessment into active remediation in the coming years (Text Box 17 provides further details).⁵⁸



Table 6. Federal contaminated site under assessment/remediation and associated spending, 1995/96–2014/15 (CAD)

Year	Number of sites	Remediation expenditures	Other expenditures*	Total expenditures
1995/96	11	261,301	2,749	264,050
1996/97	40	193,066	0	193,066
1997/98	35	443,988	20,000	463,988
1998/99	39	185,434	91,605	277,039
1999/00	63	356,357	4,500	360,857
2000/01	279	1,333,995	17,212	1,351,207
2001/02	268	6,622,688	950,115	7,572,803
2002/03	198	1,058,500	21,000	1,079,500
2003/04	74	376,279	13,700	389,979
2004/05	97	550,400	42,066	592,466
2005/06	10,217	103,098,578	28,476,699	131,575,277
2006/07	18,699	150,476,846	70,255,231	220,732,077
2007/08	18,912	178,898,253	56,204,379	235,102,631
2008/09	19,345	199,734,556	39,449,642	239,184,198
2009/10	16,931	257,596,483	64,334,169	321,930,652
2010/11	16,746	331,564,145	70,089,216	401,653,360
2011/12	17,115	225,895,802	23,296,278	249,192,080
2012/13	16,148	270,569,004	20,305,916	290,874,920
2013/14	11,450	383,879,875	18,997,565	402,877,440
2014/15	9,617	318,014,525	21,524,522	339,539,047

* Other expenditures include those for assessment, care and maintenance, and monitoring of sites.

Source: Treasury Board Secretariat, n.d.b.

⁵⁷ FCSAP is a 15-year, \$4.54 billion program established in 2005 by the Government of Canada to reduce environmental and human health risks from known federal contaminated sites.

⁵⁸ Three very large sites are slated to enter remediation in the coming years: the Faro mine in the Yukon, the Giant mine in the Northwest Territories and the Goose Bay Air Base in Labrador.



In addition to the costs currently incurred for managing contaminated sites, estimates are available of the future financial liability for the federal government. The total liability for the remediation of contaminated sites, as reported in the Public Accounts of Canada, increased from \$4.8 billion for 2,500 sites as of March 31, 2014 to \$5.8 billion for 2,400 sites as of March 31, 2015. This increase in liabilities can be attributed to several factors. As assessment activities are completed and the full scope of the required remediation is determined, new liabilities will enter the books. Estimated remediation costs can change as better information becomes available at sites (Federal Contaminated Sites Portal, 2016b). It is worth noting that the Parliamentary Budget Office (PBO) (2014) found that the federal government's reported liabilities for clean up of contaminated sites in the "general inventory" were too low by more than half. The Public Accounts of Canada recognized a liability of \$1.8 billion for these sites, whereas the PBO found the liability to be \$3.9 billion.

In addition to the federal government, provinces and territories are also obliged by public sector accounting standards⁵⁹ to estimate the liabilities associated with contaminated site cleanup in their jurisdictions. British Columbia, for example, acknowledges a financial liability to the province of \$400 million, in addition to \$390 million accrued by British Columbia Hydro and Power Authority and \$92 million accrued by British Columbia Railway Company (British Columbia Ministry of Finance, 2016). The province notes in its 2013/14 public accounts, that "possible net liabilities of approximately \$1,278 million [exist] for sites the province does not own. Many other sites remain to be evaluated; the future liability for all environmental cleanup costs is not currently determinable" (British Columbia Ministry of Finance, 2014: p. 74).

Reported contaminated site liabilities for all provinces/territories are presented in Table 7. In total, some \$6.4 billion in liabilities are currently recognized by provincial/territorial governments, the vast majority in Quebec and Ontario. The provinces of Prince Edward Island and Alberta recognize the lowest liabilities.

⁵⁹ See for example, Government of Saskatchewan (2015).



Table 7. Reported contaminated site liabilities, provinces and territories - Most recent year

Province / Territory	Contaminated site liability														
Newfoundland and Labrador	\$110 million (Province of Newfoundland and Labrador, 2016)														
Nova Scotia	\$172 million Includes \$70.8 million for the remaining liability associated with the Sydney Tar Ponds that will be used for further decommissioning, demolition and remediation activities, long-term maintenance and monitoring at the site (Province of Nova Scotia, 2016).														
Prince Edward Island	\$2.1 million (Province of Prince Edward Island, 2016)														
New Brunswick	\$41 million (Province of New Brunswick, 2016). Does not include an additional environmental liability of \$14 million accrued by the New Brunswick Power Corporation.														
Quebec	\$3.2 billion (Province of Quebec, 2016)														
Ontario	\$1.8 billion (Province of Ontario, 2016) Does not include an estimated additional contingent liability of \$365 million for sites where the likelihood of the government becoming responsible for the site is not determinable or the amount of the government liability cannot be estimated or both.														
Manitoba	\$290 million (Province of Manitoba, 2016) Manitoba's public accounts also recognize that Manitoba Hydro will incur future costs associated with the assessment and remediation of contaminated lands and facilities for the phase-out and destruction of polychlorinated biphenyl-contaminated mineral oil from electrical equipment. However, a reasonable estimate of the associated costs, not already recognized as asset retirement obligations, could not be made at time of reporting.														
Saskatchewan	\$293 million (Government of Saskatchewan, 2016)														
Alberta	No consolidated figure is available from Alberta's public accounts. Individual estimates are available from government department annual reports: <table border="0" style="margin-left: 40px;"> <tr> <td>Agriculture and Forestry</td> <td>\$2.7 million</td> </tr> <tr> <td>Culture and Tourism</td> <td>\$7.2 million</td> </tr> <tr> <td>Environment and Parks</td> <td>\$14 million</td> </tr> <tr> <td>Infrastructure</td> <td>\$175 thousand</td> </tr> <tr> <td>Transportation</td> <td>\$3.6 million</td> </tr> <tr> <td>Energy</td> <td>\$0*</td> </tr> <tr> <td>Total</td> <td>\$15.1 million (AOAG, 2015)</td> </tr> </table> <p>Also, the Alberta Office of the Auditor General (AOAG) reviewed the Mine Financial Security Program (MFSP) and found that, as of December 31, 2014, \$1.57 billion of corporate security is being held in the program in comparison to estimated reclamation liabilities of \$20.8 billion (AOAG, 2015). The AOAG concluded that "there is a significant risk that asset values calculated by the department are overstated within the MFSP asset calculation, which could result in security amounts inconsistent with the MFSP objectives. The MFSP asset calculations do not incorporate a discount factor to reflect risk, use a forward price factor that underestimates the impact of future price declines, and treat proven and probable reserves as equally valuable."</p>	Agriculture and Forestry	\$2.7 million	Culture and Tourism	\$7.2 million	Environment and Parks	\$14 million	Infrastructure	\$175 thousand	Transportation	\$3.6 million	Energy	\$0*	Total	\$15.1 million (AOAG, 2015)
Agriculture and Forestry	\$2.7 million														
Culture and Tourism	\$7.2 million														
Environment and Parks	\$14 million														
Infrastructure	\$175 thousand														
Transportation	\$3.6 million														
Energy	\$0*														
Total	\$15.1 million (AOAG, 2015)														
British Columbia	\$400 million (British Columbia Ministry of Finance, 2016) Does not include a \$390 million liability for BC Hydro and \$92 million for BC Rail.														
Yukon	\$32 million (Government of Yukon, 2016)														
Northwest Territories	\$50 million (Government of Northwest Territories, 2016) (Includes \$2.994 million for the territory's share of the remaining liability for the Giant Mine.) (Does NOT include \$11.468 million for liabilities associated with NT Hydro and \$7.085 million for NT Hydro's asset retirement obligations.)														
Nunavut	\$8.4 million (Government of Nunavut, 2016)														

* According to the annual report of the Alberta Ministry of Energy, "As at March 31, 2016, the AER [Alberta Energy Regulator] is not responsible, nor has it accepted responsibility, for performing remediation work at contaminated sites. As at March 31, 2016, the AER's liability for contaminated sites was \$nil."



Text Box 17. Abandoned mines – The “giants” of Canada’s contaminated sites

Most contaminated sites in Canada are small in size and contaminated by pollutants that are relatively easily dealt with (such as spilled fuel). A few sites are very large and complex however. Of these, the majority are abandoned mines. They account for by far the largest share of current federal spending and future liabilities for contaminated site remediation. The story of how Canadian taxpayers ended up bearing the enormous remediation costs associated with the most infamous of these sites—Yellowknife’s Giant gold mine—is worth recounting.

The Giant mine is located a few kilometres from downtown Yellowknife on the shores of Great Slave Lake. It produced its first gold in 1948 and operated until 2005 when it was finally abandoned. During its life, the mine was a major engine of economic growth for Yellowknife. At various points, it was owned by Falconbridge, Pamour, Royal Oak Mines and Miramar Mining. It was under the control of Royal Oak Mines (1990–1999), however, that the mine saw its infamous final years and its beginning as one of Canada’s greatest contaminated site liabilities (Sandlos & Keeling, 2012).

Early in Royal Oak’s tenure, a protracted and violent labour dispute over wage reductions and layoffs led to the murder of nine replacement mine workers. Miner Roger Warren was convicted of placing a bomb in a mineshaft that killed the workers. After 18 bitter months, the labour dispute ended by order of the (then) Canada Labour Relations Board (Sandlos & Keeling, 2012).

The same weak economic conditions that led to the labour dispute (high costs and low revenues forced Royal Oak Mines to seek concessions from the miners’ union) eventually forced Royal Oak to declare bankruptcy in 1999. Because the Giant mine is located on land that belonged at the time to the Crown, the then-federal Department of Indian Affairs and Northern Development (DIAND) was obliged to assume responsibility for the heavily contaminated mine site and its cleanup (Sandlos & Keeling, 2012). Under an agreement with DIAND, Miramar Mining (which operated another gold mine in Yellowknife) operated the mine in a reduced capacity without smelting after 1999, but mining ceased for good in 2005 (Sandlos & Keeling, 2012).

The contamination at the Giant mine is the result of smelting gold-containing arsenopyrite ore, which creates highly toxic arsenic trioxide dust as a by-product (Aboriginal Affairs and Northern Development Canada [AANDC], 2013). Though this dust was simply discharged to the atmosphere in the mine’s early years, resulting in at least one human death—a Dene child who succumbed to arsenic-contaminated drinking water along with an unknown number of illnesses (Sandlos & Keeling, 2012)—pollution-control equipment was installed to collect the dust beginning in the early 1950s. The collected dust was stored in the empty underground cavities (stopes) from which the ore had been mined, as well as in purpose-built chambers. In the 1950s, scientists and government agencies believed that this was a feasible long-term solution for storage of the waste. They felt that when the mine closed permanently, the natural permafrost in that area would re-establish around the storage vaults and seal in the arsenic trioxide. For a variety of reasons, not least concerns about thawing of permafrost, this solution is no longer viable (AANDC, 2013).

Over the life of the mine, some 237,000 tonnes of arsenic trioxide dust were created and stored in the underground vaults. It is the cost of dealing with this enormous toxic legacy that the Canadian public now bears. Between 2005 and 2016, assessment, maintenance and remediation of the Giant mine site cost the federal government about \$325 million (Treasury Board of Canada Secretariat, n.d.c). The total cost is expected to reach \$1 billion by the time remediation is “complete” (Foster, 2015), though the proposed solution (permanent freezing of the storage vaults) actually has no end date—it must be carried out in perpetuity (Giant Mine Remediation Project, 2004).

The Giant mine is not the only large abandoned mine for which the federal government has assumed responsibility.

Cleanup of the former Colomac gold mine north of Yellowknife in the Northwest Territories was recently completed at a cost of at least \$93 million* (Treasury Board of Canada Secretariat, n.d.d). Like the Giant mine, Colomac was owned by Royal Oak Mines at the time of its abandonment in 1999. Unlike Giant, which operated for decades, the Colomac mine had been in sporadic operation for just seven years when it closed (DELCommnic, 2013).

Remediation at the massive Faro lead/zinc mine in the Yukon has yet to begin. When it closed after 30 years of operation in 1998 (again due to bankruptcy of its owner), it left 70 million tonnes of tailings and 320 million tonnes of waste rock to be cleaned up. Between 2005 and 2016, the federal government spent about \$270 million assessing and maintaining the site, without starting cleanup (Treasury Board of Canada Secretariat, n.d.-d). The cleanup itself, which is expected to start in 2023, could cost a further \$1 billion (Giovannetti, 2013).

Partly as a result of the legacy of these and other abandoned mines, in 2002, the federal government developed mine site reclamation policies for the Northwest Territories and for Nunavut. These policies ensure there are provisions in water licenses, land leases and land use permits requiring mining companies to provide adequate financial security to cover the costs of environmental remediation at any point through the life cycle of a mine. But these assurances are typically based on cost estimates provided by mining companies, which have incentives to underestimate potential remediation costs. Governments sometimes do not verify the estimates either. For example, one Ontario mining company estimated its reclamation costs at \$551,000. When it couldn’t pay, the Ontario Ministry of Northern Development and Mines ended up footing what turned out to be closer to a \$9 million bill (McClean, 2009).

** The federal contaminated sites inventory only includes costs incurred since 2005, after the Colomac remediation began. Total costs have been reported to be as high as \$135 million (Vela, 2011).*



4.6.3 Low- and Intermediate-Level Nuclear Wastes

Low- and intermediate-level (L&ILRW) nuclear wastes includes all non-nuclear power plant fuel wastes arising from nuclear electricity generation, nuclear research and development and from the production and use of radioisotopes in medicine, education, research, agriculture and industry.

Low-level radioactive waste (LLRW) contains materials with generally limited amounts of long-lived radioactivity. It typically does not require significant isolation during handling and interim storage but requires isolation for up to a few hundred years in permanent storage (or longer for wastes containing radium and uranium). LLRW includes materials contaminated from use in nuclear facilities, such as rags and protective clothing. It also includes contaminated soil and related legacy wastes from the early operations of Canada's nuclear industry in the 1930s and 1940s.

Intermediate-level radioactive waste (ILRW) includes wastes with sufficient levels of radioactivity to require isolation during handling and interim storage as well as permanent storage (Canadian Nuclear Laboratories, 2015).

Text Box 18. Port Hope's nuclear history

The historic LLRW located at various sites in the vicinity of Port Hope, Ontario are the consequence of historical refining of radium and uranium by the federal Crown corporation, Eldorado Nuclear Limited, and its private sector predecessors. These waste materials contain radium-226, uranium, arsenic and other contaminants resulting from the refining process. Uranium ore was transported from the Northwest Territories through the "Northern Transportation Route" to Port Hope, where it was refined to produce radium for medical purposes and, later on, for nuclear fuel and military applications, including for the United States' nuclear weapons program. The town continues to be at the centre of Canada's nuclear industry, as Cameco Corporation (the name given to the new company formed when the federal government sold Eldorado Nuclear in 1988) still operates large uranium processing and nuclear power plant fuel-rod manufacturing facilities there.



The 2013 inventory of LLRW in Canada was about 2.4 million m³, most (1.7 million m³) of which was contaminated soil from early activities of the nuclear industry around the town of Port Hope, Ontario. Responsibility for managing these historic wastes rests with Atomic Energy of Canada Limited (AECL), with the exception of small amounts managed by the Government of Ontario and the Region of Peel near Toronto. Nearly all of the remaining LLRW is associated with current nuclear industry operations and falls under the responsibility of the relevant operator. Most of this is associated with operations at the Chalk River research facility operated by AECL.

The 2013 inventory of ILRW was about 35,000 m³, almost all of which was waste associated with current industry operations. About half of this waste was under the responsibility of AECL at Chalk River. Most of the remainder was under the responsibility of Ontario Power Generation at various nuclear power plants in the province. Map 1 shows the locations of L&ILRW across the country in 2013 (Canadian Nuclear Laboratories, 2015).

Between 2006 and 2015, the Canadian government conducted the Nuclear Legacy Liabilities Program (NLLP) with the objective of managing the historic LLRW that falls under the government's responsibility at AECL's Chalk River research facility, as well as the former AECL Whiteshell Laboratories in Pinawa, Manitoba and smaller sites at Douglas Point, Ontario, Rolphton, Ontario and Bécancour, Quebec (the former Gentilly 1 nuclear demonstration reactor).

The NLLP was the beginning of what will be a multi-decade strategy to deal with nuclear legacy wastes (Natural Resource Canada, 2011). Decommissioning and waste management programs will need to be delivered at AECL-managed sites over at least the next 70 to 100 years (Receiver General for Canada, 2016).



In total, the federal government spent \$520 million on the first phase of NLLP (2006/07 to 2011/12). A further \$687 million was spent between 2012/13 and 2015/16 when the program ended (Natural Resources Canada, 2013, 2014 and 2015). **On average, \$121 million was spent annually on the program over its 10 years.**

Following the wind-up of the NLLP, responsibility for the long-term management of Canada’s historic LLRW was transferred to a new subsidiary of AECL named Canadian Nuclear Laboratories (CNL). CNL will continue AECL’s research work at Chalk River and carry out the on-going management of both historic LLRW (including the large amount of contaminated soil in Port Hope, Ontario) and newly created LLRW from the decommissioning of facilities at former AECL sites.

As of March 31, 2015, CNL’s financial statement recorded planned future expenditures of more than \$18 billion (adjusted for inflation) for the associated activities spanning a period of 149 years (Canadian Nuclear Laboratories, 2016). **This amounts to average annual planned expenditures of \$121 million for the next century and a half.**



Map 1. Low- and intermediate-level nuclear waste sites, 2013

Source: Canadian Nuclear Laboratories, 2013.



4.6.4 Supplementary Information – Costs of efforts to minimize the quantity of pollution that enters the environment

Governments, businesses and households spend a great deal of money every year to prevent waste materials from entering the environment. While not strictly speaking a cost of pollution (since the point of the expenditures is to prevent pollution in the first place), these costs are nonetheless related to pollution and its harmful impacts. A plausible argument can be made that the cost of managing these wastes must be at least as great as the cost they would impose on society as pollution if they were allowed to enter the environment. The cost of their management is therefore presented here as supplementary information; it is not included in the estimated cost of pollution (see Text Box 19).

Text Box 19. The cost of preventing pollution

Governments, especially municipal governments, spend a great deal to manage the solid wastes and sewage produced by households and businesses. The latest figures available for current and capital spending on solid waste management put the cost at \$3.7 billion in 2012 (Statistics Canada, 2015a), or an estimated \$4 billion in 2015 after accounting for inflation and growth in population. The latest figures available for current and capital spending on sewage treatment put the cost at \$4.3 billion in 2008 (Statistics Canada, 2009), or an estimated \$5.1 billion in 2015 after accounting for inflation and growth in population.

In addition to municipal spending, an unknown additional amount is spent by the federal government and provincial/territorial governments on pollution prevention. These amounts are likely to be considerably less than at the municipal level, as the main responsibility for waste management in Canada lies with local governments.

Businesses also spend a great deal of money to prevent pollution. Statistics Canada measures these costs through its Survey of Environmental Protection Expenditures. According to the latest survey results (Statistics Canada, 2015b), businesses with 20 or more employees engaged in resource extraction, manufacturing industries, electric power generation and transmission and natural gas distribution spent a total of \$8.2 billion in 2012 on current and capital expenditures for pollution prevention, or an estimated \$9 billion in 2015 after accounting for inflation and growth in economic output (as measured by real GDP). These estimates do not include spending on pollution prevention in the agriculture industry or in the service sector of the economy (e.g., by hospitals).

Households also spend to prevent pollution, in particular for anti-pollution equipment on automobiles. The International Council on Clean Transportation estimates that the incremental cost of pollution control equipment to meet U.S. Tier 2 emission standards is about US\$405 (2010 prices) for a four-cylinder gasoline automobile with a 2.3L displacement (Sanchez et al. 2012). This rises to US\$2,086 for a four-cylinder diesel vehicle with a 3.0L displacement. Combining these estimates (adjusted for exchange rates and inflation) with data on new car and truck sales for 2015 from Statistics Canada (2017b) and assuming that 3 per cent of new motor vehicle sales in Canada are diesel powered (Lussenhop, 2015) yields a figure of about \$1.5 billion as the cost of motor vehicle pollution control equipment in 2015. In addition to this amount, households also spent an unknown additional amount on other pollution prevention activities; for example, operation of private septic tanks and private management of solid wastes in apartment buildings that are not serviced by municipal workers.

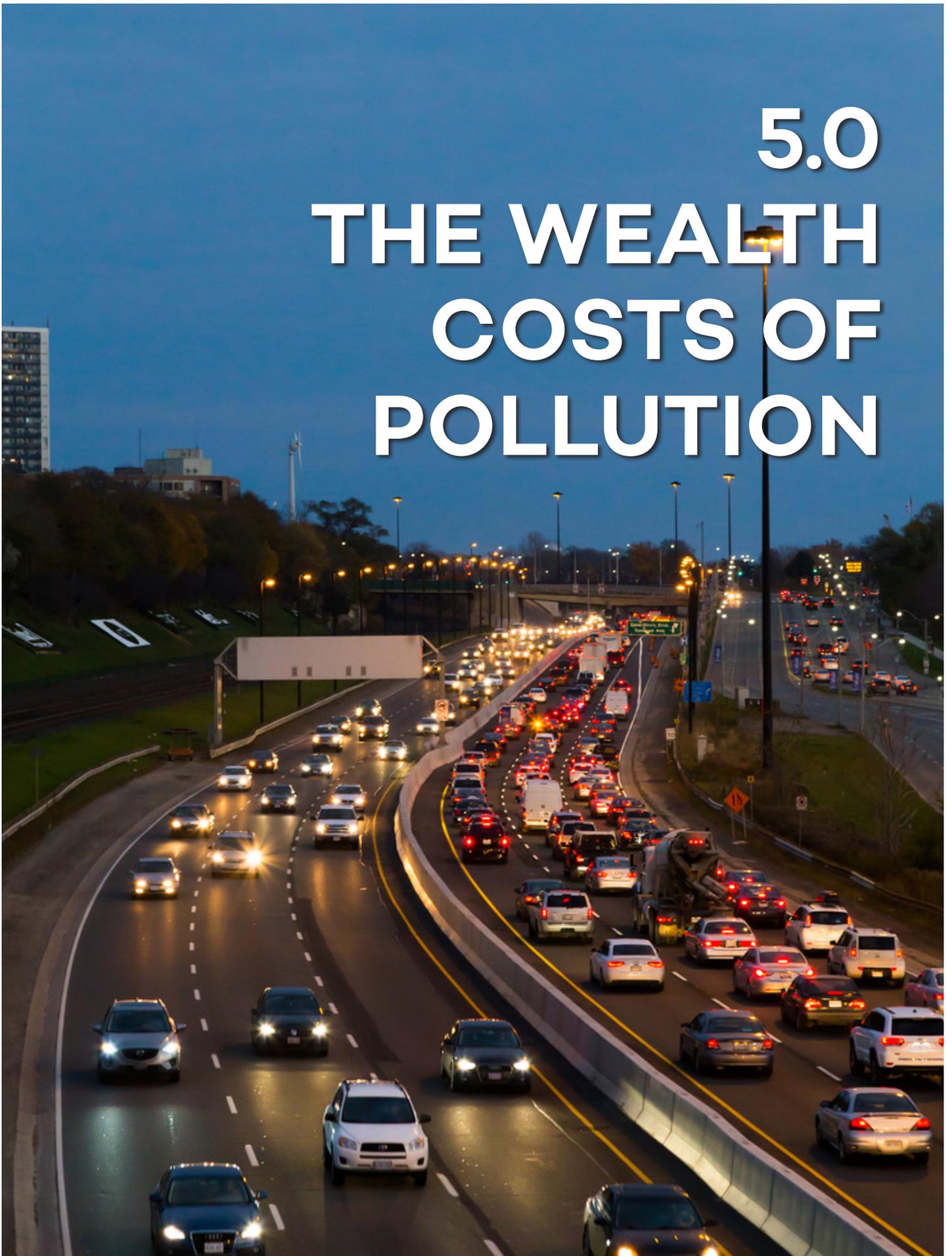
The amounts above are summarized in Table 8. As can be seen, total estimated expenditures on pollution management amounted to some \$19.6 billion in 2015. This figure does not include the unknown additional amounts spent by the federal and provincial/territorial governments, by businesses in the agriculture and service industries, and by households on pollution prevention activities other than motor vehicle pollution control equipment.

Table 8. Supplementary information - Pollution prevention expenditures, 2015

Sector and expenditure type	Estimated expenditures (\$billion)
Municipal governments, solid waste management	4.0
Municipal governments, sewage management	5.1
Businesses (other than the agriculture and service industries), pollution prevention	9.0
Households, motor vehicle pollution control	1.5
Total	19.6

Source: This review.

5.0 THE WEALTH COSTS OF POLLUTION





5.0 The Wealth Costs of Pollution

5.1 Introduction

In this chapter, the third and final way in which pollution imposes costs on Canadians is considered: reductions in the value of the assets that underpin wealth.⁶⁰ These assets comprise the stocks of natural and produced capital required to generate income and, ultimately, well-being for Canadians. Pollution impacts both assets that are bought and sold in the marketplace, such as our homes and infrastructure, as well as assets that are not valued in the market, such as ecosystems.

Pollution impacts assets in two ways. First, it can degrade their functioning so that they become less effective at delivering the services on which humans rely. For example, a forest affected by acid rain is still a forest but it is less capable of growing trees and, therefore, is of lower value as a source of timber or as a site to enjoy nature. This can be thought of as a loss in the *quality* of the forest. Acid rain can also impact produced assets like bridges and buildings by corroding the materials they are made from. Corrosion reduces the lifespan of structures and/or decreases their aesthetic value (the latter being particularly important in the case of buildings and monuments of cultural or historical significance).

Pollution also impact assets by reducing their *size*, or physical extent. Taking forests as an example again, the loss of huge areas of lodgepole and jack pine forest to the mountain pine beetle⁶¹ in British Columbia and Alberta is effectively a reduction in the size of that forest asset (Natural Resources Canada, 2016). For all intents and purposes, that forest is gone, along with all of its services, until such time as the trees regenerate.

Pollution can indirectly impact the value of assets even in cases where they are not themselves touched by pollution but are tied to others that are. For example, the value of a recreational home such as a cottage on the shore of a pristine lake will be negatively affected if the lake becomes congested with algal blooms due to excess nutrient loadings. Similarly, the value of cropland is contingent upon the capacity of the climate system to provide appropriate levels of warmth and moisture, both of which are subject to disruption by climate change.

Beyond degradation, the impacts of pollution on assets can extend to their outright destruction. An example of this is the “death” of some freshwater lakes from acid rain. Severely acidified lakes are unable to support most aquatic life (Environment Canada, 2013b), which, for all intents and purposes, amounts to their “death” as lakes—even if the water they contain remains in place. Yet another example is the pollution of lakes by phosphorus and nitrogen, leading to excessive plant growth (or eutrophication). An infamous case of this was Lake Erie in the middle part



“ Pollution impacts both assets that are bought and sold in the marketplace, such as our homes and infrastructure, as well as assets that are not valued in the market, such as ecosystems. ”

⁶⁰ Wealth and income are closely related. Wealth can be thought of like savings in a bank, whereas income is the value of the interest that is earned off those savings each year. At the national level, wealth is the value of all assets and income is the money that people and businesses earn by using those assets.

⁶¹ The unprecedented mountain pine beetle infestation is partly the result of warmer winters brought on by climate change (Natural Resources Canada, n.d.) and is, therefore, included here as an example of a pollution impact.



of the last century, when eutrophication of the lake from phosphorus loadings became so bad that the lake was considered by some to be “dead” in the 1970s (International Joint Commission, 2014b).⁶²

Today, the effects of climate change mean that pollution—more specifically, greenhouse gas emissions—threatens the existence of a much wider range of produced and natural assets. Among climate change’s many impacts are increases in the frequency and intensity of extreme weather events. When produced and natural assets like houses, power grids, roads and forests are found in the path of such events, they can be destroyed. Climate change, especially prolonged drought and high temperatures, can also lead to conditions that favour wildfires. Though the attribution of any single extreme weather event to climate change is difficult, progress in this direction is being made (National Academics of Sciences, Engineering and Medicine, 2016).

Estimating the loss in asset value associated with pollution is far from straightforward. The cost of acid rain in terms of the lost value of a freshwater lake, for example, is uncertain because understanding of both the extent of the loss and the ecosystem services that disappear is incomplete. Estimating the lost value of a cottage property adjacent to that same lake is more straightforward, as the extent of the loss and its value are readily measured in principle. In the case of assets that are outright destroyed by pollution, estimating the loss in value is straightforward if the asset has a market price (a house, for example) and more difficult when there is no market price (a forest, for example). Difficulty in estimation does not make these costs any less real, however, just harder to reveal.

5.2 Summary of Findings⁶³

The available evidence suggests that pollution likely imposes significant wealth costs on Canadian households, businesses and governments. However, **based on a thorough review of available data, it is not possible to place a value on those costs for Canada today.** There are little data available to estimate the loss in asset values in Canada due to pollution, as the majority of research on the costs of pollution has been focused on either direct welfare (Chapter 3) or income (Chapter 4) costs. This means that most of what can be said about losses in asset value due to pollution is speculative and only a sense of the magnitude of asset value at risk from pollution can be given here.

What is known about each of the possible wealth costs of pollution in Canada is discussed briefly below and then summarized in Table 9 at the end of this section. They are discussed in much greater detail in the remainder of the chapter, where they are divided into wealth costs due to impacts on natural assets (Section 5.3) and wealth costs due to impacts on produced assets (Section 5.4).

5.2.1 Summary of Findings by Wealth Cost

5.2.1.1 Wealth Costs Due to Impacts on Natural Assets

- **Freshwater algal blooms:** With respect to ecosystem assets, the only impact that could be valued for this study is loss in the value of Lake Erie due to the algal blooms that currently plague the lake (see Section 3.3.2.2 and Section 3.4.1 for further details). Based on a study of the lake’s capacity to function in its degraded condition, the losses in its value as a non-market (ecosystem) and market asset have been

⁶² Regulations imposed in the 1970s to control phosphorus loadings to Lake Erie from wastewater treatment plants were successful in reducing eutrophication, and the lake had regained much of its health by the 1990s. It is facing another crisis today, worse than that of the 1960s, this time as a result of phosphorus loadings from fertilizers applied to cropland in the lake’s basin. Whether it will recover again is an open question at this point.

⁶³ A specific nomenclature has been adopted to discuss uncertainty in this report. The nomenclature is not based on a quantitative assessment of uncertainty but rather on the authors’ judgement derived from the review of published studies. The terms in the nomenclature have the following meanings: “possibly” (< 50 per cent chance); “likely” (> 50 per cent chance); “somewhat larger” (< 100 per cent larger); “much larger” (> 100 per cent larger); “significant” (at least on the order of tens of millions of dollars); “very significant” (at least on the order of billions of dollars). In cases where order of magnitude (millions, billions) estimates can be given with some degree of certainty, they have been. This nomenclature is intended to provide readers with a rough sense of how much larger actual costs might be than those that can be measured based on available data and how likely it is that costs are this much larger. It should not be used to make quantitative estimates of missing values.



estimated to be \$3.8 billion and \$4 billion respectively. Unfortunately, no basis exists to extrapolate from these figures to estimate losses in asset values of all degraded surface water bodies in Canada; such losses are likely much larger. See Section 5.3.1 for further details.

- **Forests and farmland:** No estimate of the loss of the value of forest and farmland assets was possible for this report, but an indication of what is at risk can be found in Statistics Canada’s estimates of the value of Canada’s commercial forests and farmland. In 2015, the agency estimated these to be worth, respectively, \$158 billion and \$376 billion. These are clearly very valuable assets, and they are both at risk from the impacts of pollution in the form of climate change, ozone depletion, acid rain and others. Given their substantial value and the fact that losses due to pollution are likely significant, further research is required to explore the linkage between pollution—particularly the impacts of climate change—and the value of these assets.
- **Fossil fuels:** Even more valuable than Canada’s farmland and timber are its deposits of fossil fuels. Here too there is a potential link to pollution, though less direct. As the world confronts climate change, the development of alternatives to fossil fuels in the form of solar, wind, hydro and other renewable forms of energy is rapidly increasing. BP has recently predicted that renewables will be “the fastest growing fuel source, quadrupling over the next 20 years, supported by continuing gains in competitiveness” (BP, 2017, p. 7). One consequence of this may be that world oil prices, which have dropped significantly in recent years, will continue to face downward pressure. If so, high-cost oil producers, like Canada, may find it increasingly difficult to sell their oil at a profit. Declining oil prices have already driven the value of Canada’s fossil fuel assets down by 95 per cent from their peak of \$1.1 trillion in 2008. If oil prices do not recover, this loss of wealth (about 13 per cent of Canada’s total net worth) could be permanent. If that were to happen, it would be at, least in part, an impact of pollution manifesting itself through climate change. See Section 5.3.2 for further details.

5.2.1.2 Wealth Costs Due to Impacts on Produced Assets

- **Waterfront properties:** One area where partial estimates of the wealth costs of impact on produced assets are possible is the relationship between house values and the quality of freshwater ecosystems. As noted in the introduction, waterfront property is more desirable when the quality of the nearby water bodies is good. Water clarity is often used as a surrogate for water quality, and there is ample evidence that property values decrease along with water clarity. Based on the



same study of the impact of algal blooms on Lake Erie mentioned above, the value of residential properties along the lake’s Canadian shoreline has been reduced by \$712 million as a result of the blooms. There is insufficient evidence to extrapolate from this study to all lakefront property in Canada; however, the losses are likely significant. See Section 5.4.1 for further details.

- **Extreme weather:** As with fossil fuel assets, climate change also presents risks for Canada’s produced assets. The number and severity of extreme weather events are increasing as the climate changes and so too is the value of insurance payouts for damaged and destroyed property. Payouts for insured losses due to storms, floods and wildfires, including the 2016 Fort McMurray fire, have increased substantially since the 1980s, even after accounting for inflation and increases in the size of the insured asset base. Payouts for



insured losses have been above \$1 billion annually every year since 2009 with the exception only of 2015. Prior to 2009, they had been greater than \$1 billion only twice since 1983. Of course, severe weather is not solely attributable to climate change, but scientific understanding of the share of extreme weather events that can be attributed to the changing climate is improving. Nonetheless, climate change appears to be imposing significant and growing costs on Canada’s produced asset base, and the losses are likely very significant. See Section 5.4.2 for further details.

- **Road salt:** Another area where a partial estimate is possible is the case of road salt impacts on highway infrastructure. Montreal’s Champlain bridge is currently being replaced 50 years ahead of time in part because of excessive and unpredicted damage from road salt. The cost of this early replacement can be estimated by considering the interest that might have been earned by investing the funds required to replace the bridge in some other use for 50 years. Depending on the final cost to build the bridge, this loss of interest could amount to \$10 billion to \$17 billion. Overall, the losses due to impacts on all produced assets are likely very significant. See Section 5.4.3 for further details.

Table 9. Summary of 2015 wealth costs of pollution

Category	Estimated wealth cost in 2015	Reliability of estimate	What is and is not covered
Wealth costs of impacts on natural assets			
 Freshwater algal blooms	Central estimate: \$3.8 billion and \$4.0 billion for the loss in the value of Lake Erie alone as an ecosystem asset and market asset respectively due to algal blooms; likely much larger for other freshwater bodies in the country. Range: Unknown	Medium	Represents the loss in the value of Lake Erie as an ecosystem and market asset due to the presence of algal blooms on the lake. The loss in the value of other freshwater bodies in the country due to algal blooms and other effects of eutrophication is unknown.
 Forests and farmland	<i>Unknown</i> ; Likely very significant (hundreds of billions of dollars of assets at risk), especially with increasing impacts from climate change	n/a	Represents the loss in the value of forests and farmland as ecosystem and market assets due to the impacts of climate change, ozone depletion, acid rain and other pollutants.
 Fossil fuels	<i>Unknown</i> ; Possibly very significant (hundreds of billions of dollars of assets at risk)	n/a	Represents the loss in the value of fossil fuel assets if climate change policies put downward pressure on the prices of oil, natural gas and coal.
Wealth costs of impacts on produced assets			
 Waterfront properties	Central estimate: \$0.712 billion for the loss in the value of waterfront properties on Lake Erie alone; likely much larger for properties on other freshwater bodies in the country. Range: Unknown	Medium	Represents the loss in the value of waterfront homes along the Canadian shore of Lake Erie due to the presence of algal blooms on the lake. The loss in the value of properties on other freshwater bodies in the country due to algal blooms and other effects of eutrophication is unknown.
 Extreme weather	<i>Unknown</i> ; Likely very significant (hundreds of billions of dollars of assets at risk); annual payouts for insured losses have generally been above \$1 billion since 2009, though not all these can be attributed to extreme weather induced by climate change.	n/a	Represents the loss in value of produced assets (houses, buildings and other infrastructure) due to damage and destruction from extreme weather induced by climate change.
 Road salt	<i>Unknown</i> ; Likely very significant (hundreds of billions of dollars of assets at risk).	n/a	Represents the loss in value of roads, bridges and other infrastructure due to degradation of materials from road salt.



5.3 Wealth Costs of Pollution's Impacts on Natural Assets

Natural assets comprise all the *land, ecosystems and sub-soil resources* found within the country. While pollution has no direct impact on *sub-soil resources*⁶⁴ (though see Text Box 19 for a discussion of possible indirect impacts), it can and does impact both *land* and *ecosystems*.

As a natural asset, *land* can be thought of simply as space. Space has value because it is limited; there is only so much good farmland, so many lakefront properties with western exposures and so many downtown neighbourhoods.

Pollution can impact the value of land (that is, space) by reducing the aesthetic and other qualities that make it valuable. A penthouse condominium, for example, is worth less if its mountain view is obscured by smog. Likewise, an industrial site will become less valuable for a brewery if a formerly pristine spring becomes contaminated by pesticide runoff.

Ecosystems are structured groupings of living organisms and non-living matter that, given an on-going supply of solar energy, remain intact over long periods of time and yield continual flows of ecological goods and services. Ecosystems can be affected both qualitatively and quantitatively by pollution.

Qualitative impacts on ecosystems occur when pollution changes the ability of the living and non-living elements of ecosystems to play their normal roles in the overall functioning of the system. For example, excess nutrient loadings in aquatic ecosystems can cause plants to grow far out of proportion to their normal state, disrupting the ability of other organisms in the ecosystem to thrive.

While *qualitative* impacts of pollution on ecosystems are common, *quantitative* impacts are less so. In the past, nutrient runoff in waterbodies (eutrophication) and air emissions of sulphur and nitrogen oxides (acid rain) were the only pollutants widespread and damaging enough to quantitatively reduce ecosystems on a broad scale (see the introduction to this chapter).

Climate change is changing this, however. The catastrophic loss of forests due to wildfires or pest infestations induced by climate change are examples of how climate change can threaten entire ecosystems. Another would be the loss of glaciers in the North due to Arctic warming. Yet another would be the permanent loss of wetlands due to a shift to a drier rainfall regime.

5.3.1 The Impacts of Eutrophication on Freshwater Lakes

A serious consequence of water pollution is excess growth of plant life, a process known as *eutrophication*. Nitrogen and phosphorus—common components of sewage and agricultural runoff—are key nutrients for plant growth. Under natural conditions, nitrogen and phosphorus are in limited supply, and aquatic plant growth is kept in check. When excess nitrogen and phosphorus make their way into to surface waters as a result of pollution flows, aquatic plant growth can greatly exceed its natural level.

The consequences of eutrophication are numerous:

- Excess plant growth can lead to a situation known as hypoxia, in which dissolved oxygen levels in water fall as a result of the decay of dead plant material. Lowered oxygen levels make water unsuitable as habitat for fish and other aquatic animals, leading to “dead zones” where little life is found.

⁶⁴ Given that groundwater and surface water are directly connected through surface and underground water flow, groundwater is considered part of aquatic ecosystems rather than as a sub-soil resource. An exception to this is so-called “fossil groundwater,” which is groundwater that is effectively cut off from all surface flows. Pollution of fossil groundwater could, then, be considered pollution of a sub-soil resource.



- In some cases, the plants that are encouraged to grow by excess nutrients can cause illness in animals that live in, on or around the water and in humans that use the water for swimming, boating or as a source of drinking water or food (e.g., shellfish). This is particularly the case with various forms of “algae” that produce compounds toxic to humans and animals. These include so-called “blue-green algae,” cyanobacteria that form in large masses—or blooms—in freshwater lakes. Lake Erie is particularly affected by this issue at the moment, with large blooms of *Microcystis aeruginosa* and other cyanobacteria forming in lake’s western basin every summer since the late 1990s. This blue-green algae produces the liver toxin *Microcystin*, the symptoms of which can include skin irritation, nausea, vomiting and, in rare cases, acute liver failure. Algal blooms are also responsible for the so-called “red tides” that affect offshore areas of oceans. An unprecedented red tide containing the neurotoxin domoic acid formed in the summer of 2015 from central California to the Alaska Peninsula, resulting in significant impacts to coastal resources and marine life (National Ocean Service, 2016). See Section 3.3.2.2 for discussion of the impact of algal blooms on human health.
- Even when eutrophication does not result in dangerous conditions like hypoxia and toxic algal blooms, excessive plant growth can be a simple nuisance. Lake Erie is again a current example. The lake’s western basin suffers from dense bottom-resting mats of *Lyngbya*, a non-toxic but odourous cyanobacteria. In the eastern basin, large shoreline blooms of the filamentous algae *Cladophora* are a serious problem. These blooms foul recreational beaches with dense covers of dead algal “muck”, clog municipal and industrial water intakes, impair water quality and, in certain cases, pose microbial health risks⁶⁵ to wildlife and humans.

The eutrophication of Lake Erie has serious consequences for the value of the lake as an ecosystem asset. A study carried out in 2015 for Environment and Climate Change Canada considered the economic costs of algal blooms on Lake Erie in terms of lost flows of ecosystem goods and services (EGS) from the lake (Midsummer Analytics and EnviroEconomics, 2015). The study put the total annual cost of lost EGS at \$236 million annually. Table 10 presents the breakdown of these costs by category.

As can be seen, the major impact of Lake Erie algal blooms was found to be direct losses of welfare (utility) for individuals who use Lake Erie for recreation and for those who derive value from the knowledge that the lake is in a healthy state (non-users). The losses of recreational and non-use services enjoyed by these individuals amounted to an estimated \$115 million in 2015. In addition, reduced flows of recreational services cost the tourism industry \$110 million in terms of lost value added. Smaller costs were also noted for commercial fishing (\$5 million in lost value added due to reduced fish quantity/quality) and industrial water users (increased costs of \$4 million for drinking water treatment plants). The study found that costs at these levels will be imposed for the indefinite future unless action is taken to reduce the phosphorous loadings to the lake that cause the algal blooms.



“Eutrophication from inadequately treated sewage became so bad that the lake (Erie) was considered “dead” in the 1970s.”

⁶⁵ Though nuisance algae do not produce toxins, they can harbour pathogenic bacteria.

**Table 10. Costs of Lake Erie Algal blooms, 2015**

Ecological good/service	Annual cost (\$million)	Costs considered
Tourism	110	Reduced value added of the tourism industry due to lost business as a result of reduced numbers of visitors to the lake.
Non-users	94	Reduced utility due to reduced well-being associated with knowledge of the lake's condition.
Recreational users	21	Reduced utility due to reduced enjoyment from beach activities, fishing, boating, birdwatching and hunting.
Commercial fishing	5	Reduced value added due to reduced flows or quality of freshwater fish and/or increased costs to harvest fish.
Water users	4	Increased capital and operating costs due to reduced raw water quality for industries (principally municipal drinking water treatment plants) that use water from the lake.

Source: *Midsummer Analytics and EnviroEconomics, 2015.*

These annual losses can be converted to a loss in the value of Lake Erie as an ecosystem asset by calculating the discounted present value of an indefinite future stream of annual losses. Since direct welfare (non-market) costs and market costs are conceptually distinct, the losses of Lake Erie's value as non-market and market asset are calculated separately. Assuming a 3 per cent discount rate for this calculation, as recommended by Environment and Climate Change Canada (Yves Bourassa, Environment and Climate Change Canada, personal communication, February, 2015), the loss in Lake Erie's value as a *non-market asset* amounts to approximately \$3.8 billion and the loss in its value as *market asset* amounts to approximately \$4 billion. It should be kept in mind that these two values are not directly comparable.

As Lake Erie is just one lake among many affected by algal blooms in Canada (see Section 3.3.2.2), this figure underestimates the total costs of freshwater eutrophication on Canada's water assets, likely by a significant margin. Unfortunately, there is little evidence to build upon in extrapolating from these results to estimate the impacts of eutrophication on the value of freshwater lakes for Canada as a whole.

5.3.2 Loss in the Value of Other Natural Assets – What could be at stake

Of course, eutrophication is the not pollution's only impact on natural assets. As discussed above, acid rain was a significant concern in the past, and the evidence suggests that lake ecosystems have been slow to recover in spite of reduced levels of acid rain (Keller, Gunn, & Yan, 1998; Wright et al., 2005). Toxic pollutants also impact ecosystems in a variety of ways (Sánchez-Bayo et al., 2011). The greatest threat to ecosystems from pollution today is, however, most likely to come from climate change induced by human emissions of greenhouse gases. The expected changes in temperature and precipitation regimes associated with climate change will stress ecosystems' abilities to adapt, possibly resulting in significant disruption to their production of ecological goods and services.

Valuing the impact of pollutants on natural asset values is difficult. This is largely because the valuation of natural assets is, itself, still in its infancy. Statistics Canada has made progress in this direction (it is, in fact, an international leader) but its valuations remain largely focused on natural capital that provides flows of market goods and services: sub-soil resources, timber and agricultural land. Ecosystems are not currently valued by Statistics Canada, though they are measured in quantitative terms to some extent.⁶⁶

To give a sense of what is at stake in terms of market natural assets at risk from pollution impacts, Statistics Canada's estimates of the value of Canada's farmland and timber assets were \$376 billion (Statistics Canada, 2016f) and \$158 billion (Statistics Canada, 2016g) respectively in 2015. Clearly, these are very valuable assets,

⁶⁶ Statistics Canada has recently published a significant research study of ecosystems, but it remains far from being able to value them comprehensively and regularly (Statistics Canada, 2013).



both of which are at risk from climate change and other impacts of pollution. And, it must be emphasized, they are not the only market natural assets at risk. Even more valuable than Canada's farmland and timber are the nation's fossil fuel assets. Though not at risk themselves of damage by pollution, these assets face an uncertain economic future in part because of the roles they play in creating pollution in the first place. The world is increasingly seeking alternatives to fossil fuels out of a desire to avoid the negative consequences of fossil fuel use in terms of smog, spills and—especially—climate change. Text Box 20 outlines what is at risk for Canada in terms of the value of its fossil fuel assets.

Unfortunately, other than the study of algal blooms on Lake Erie referenced above, no studies were found that would permit more than speculation about the change in the value of other natural assets (either market or non-market) due to pollution. This must remain a topic for future research.

Text Box 20. Climate change and the value of Canada's fossil fuel assets

One of the consequences of climate change is an increase in the urgency with which the world views the need to shift from fossil fuels to alternative forms of energy. Though other impacts of fossil fuel production and use would provide an impetus to find alternatives even in the absence of climate change, climate change adds considerably to this impetus given the pervasive nature and scale of its expected effects. While efforts to avoid climate change will not mean the abandonment of fossil fuels any time soon (Morgan, 2016), they do mean the world is increasingly turning to alternatives. China, for one, plans to invest US\$361 billion in renewables in just the next five years (Reuters, 2017). India, for its part, plans to produce 60 per cent of its electricity from non-fossil fuels by 2027.

It is impossible to predict what the world's move toward renewable energy will mean for fossil fuels. It does seem likely, however, that as producers and consumers move to alternatives, the first fossil fuel-producing regions to be affected will be those with relatively high costs of production. Canada sits near the top of the list of high-cost producers, with an average barrel of oil costing about three times more to produce than in the lowest cost countries (Wall Street Journal, 2016). Given this, Canada's fossil fuel industry could be reasonably characterized as being at greater risk from climate change than many of its competitors. As the Chief Economist of British Petroleum, one of the world's largest energy companies, remarked during the release of the company's 2017 *Energy Outlook* (BP, 2017) "I think it is increasingly likely that there will be technically recoverable oil reserves which will never be extracted" (Ward, 2017). BP's *Outlook* predicted that lower-cost oil producers in Russia and the Middle East would capitalize on increased global energy reserves and falling global demand to increase their share of global fossil fuel production at the expense of higher-cost producers like Canada. It also predicted that renewables will be "the fastest growing fuel source, quadrupling over the next 20 years, supported by continuing gains in competitiveness" (BP, 2017, p. 7). Oil may well be "in its dotage" (Mortished, 2017).

At their peak in 2008, when global fossil fuel prices and demand were high, Canada's fossil fuel assets (that is, coal, oil and natural gas reserves) were worth about \$1.1 trillion. By 2015, this value had dropped by more than 95 per cent to just \$56 billion as a result of declining prices—a loss in wealth of more than \$1 trillion. To put this in context, Canada's total net worth* in 2008 was about \$7.5 trillion (Statistics Canada, 2016h).

Of course, this loss in the value was for the most part not caused by the move away from fossil fuels in response to climate change. Rather, it was the result of price declines driven by other forces. The concern, however, is that climate-change motivated moves toward alternatives will prevent fossil fuel prices from climbing back to where they were in 2008.

If that happens and prices remain low, much of the wealth that has disappeared from Canada's fossil fuel assets may not return. This would represent a massive loss in wealth, at least partly as a result of the world's need to address greenhouse gas pollution.

* Statistics Canada defines net worth as "[t]he value of all the assets (non-financial and financial) owned by an institutional unit or sector less the value of all its outstanding liabilities." See http://www.statcan.gc.ca/eng/nea/gloss/gloss_n#Networth.



5.4 Wealth Costs of Impacts on Produced Assets

The primary produced assets at risk from pollution are buildings, factories, homes, bridges and other built infrastructure—including structures of cultural significance such as monuments and historic buildings. Pollution can both degrade these assets—for example, by soiling them or causing premature deterioration of their structures—or destroy them outright, as in the case of extreme weather events like tornadoes and floods. Pollution can also reduce the value of produced assets indirectly by reducing the value of natural assets on which their value is contingent. The value of a cottage property, for example, is a function of the quality of the surrounding natural environment. If that environment is degraded by pollution—perhaps by an algal bloom on a freshwater lake (see Section 3.4.1)—the value of the cottage will decline proportionally. These impacts are discussed further below.

5.4.1 Impacts of Water Pollution on Housing Values

Many studies have shown that the value of property located along water bodies is influenced by the quality of the adjacent water body. Clean water is more aesthetically pleasing than contaminated water, and waterfront property has significantly greater value with increased quality (Krysel, Boyer, Parson, & Welle, 2003; Dodds et al., 2009). Waterfront properties in the United Kingdom, for example, have been found to be worth 10-40 per cent more than equivalent non-waterfront properties (Wood et al., 1999;). These effects have been found to apply at distances of up to 1.2 kilometres from the shoreline (Dornbusch, Barrager, & Abel, 1973).

In a comprehensive review of the U.S. literature on the impact of water quality, the U.S. Environmental Protection Agency (2015) found that a 1-metre decrease in the clarity of water led to a decrease in adjacent residential properties of anywhere from 1 per cent to 78 per cent. One study of Lake Erie (Ara et al., 2006) evaluated the impact of water clarity on house prices near 18 Lake Erie beaches in Ohio. At the average distance of these properties from the shoreline (12.6 kilometres), a 1-metre change in Lake Erie water clarity was associated with a 1.93 per cent change in home value. The value of homes closer to the lakeshore changed more than those further away.

In the same study of the impact of algal blooms on Lake Erie mentioned above (Midsummer Analytics and EnviroEconomics, 2015), Environment and Climate Change Canada conservatively assumed that declines in water quality due to algal blooms would lead to either a 2, 4 or 6 per cent decrease in the value of all residential property within 1 kilometre of the Canadian shoreline, depending on the severity of the bloom. Using these figures, the study arrived at a value of \$712 million as the loss in residential property asset value due to the lake's deteriorated quality. Using similar assumptions, an International Joint Commission study of impacts on the residential property on the U.S. side of the lake arrived at a figure of US\$242 million for the relatively less populated western basin of the lake only (Bingham, Sinha, & Lupi, 2015).

It is difficult to extrapolate from these results water pollution's impacts on the value of residential property for Canada as a whole. As discussed earlier, (Section 3.3.2.2), evidence suggests that algal blooms are affecting an increasing number of freshwater lakes in Canada. Many of these lakes host seasonal and permanent homes whose values are at risk from declines in water quality. Though the total loss in residential property value cannot be estimated, it seems safe to suggest that it would be on the order of billions of dollars.

In addition to the impact of surface water quality on house values, proximity to contaminated sites (Greenstone & Gallagher, 2008; McCluskey & Rausser, 2003) and sources of noise, such as airports and roads (Palmquist & Smith, 2008; Levesque, 1994), as well as poor air quality (Harrison & Rubinfeld, 1978; Ridker & Henning, 1967) are known to be relevant. No studies were found that would permit estimation of the impacts on house values across Canada of these forms of pollution.



5.4.2 Impacts of Extreme Weather on Produced Assets

One of the expected consequences of climate change is an increase in the frequency and severity of extreme weather events. A warming climate is expected to increase the extremes of temperature, wind speed and precipitation, potentially leading to increased numbers of heat waves, tornadoes, hurricanes, ice storms, heavy snow, floods and wildfires (Field et al., 2014). All of these have the capability to damage and even destroy natural and produced assets.

Consistent with the expected impacts of climate change, the Insurance Bureau of Canada (IBC, 2015) reports that insurance payouts for damage to produced assets (homes, buildings, infrastructure) due to extreme weather events are increasing in Canada. Since the 1980s, such payouts have doubled every five to ten years. With \$3.4 billion in payouts due to floods in Alberta and Toronto, an ice storm in eastern Canada and other extreme weather, 2013 was a record-breaking year (IBC, 2015). It was surpassed in 2016 by a single event, however. The Fort McMurray Wildfire is estimated to have caused \$3.58 billion in insured property losses (IBC, 2016a). The wildfire was by far the largest single payout for a natural disaster in Canada, more than doubling the \$1.74 billion figure for the Alberta floods in 2013.

As noted, these record-setting events are part of an increasing trend in insurance payouts due to extreme weather. Six straight years of insurance losses exceeding \$1 billion (2015 prices) were witnessed in Canada from 2009 to 2014 (IBC, 2016b; Feltmate & Moudrak, 2016). Insured losses averaged only \$400 million a year between 1983 and 2008 and only two years saw losses exceeding \$1 billion (Figure 20). The Insurance Bureau of Canada notes that storms previously expected only once every 40 years are now expected every six years (IBC, 2013). While severe weather is not, of course, solely attributable to climate change, it is increasingly possible to link the two, particularly in the case of heat waves (see Section 3.3.7 for further discussion). However, scientists cannot yet estimate with confidence what share of extreme weather-related insured losses can be attributed to climate change, so no estimate of the cost of climate change in terms of loss of produced assets is given here.

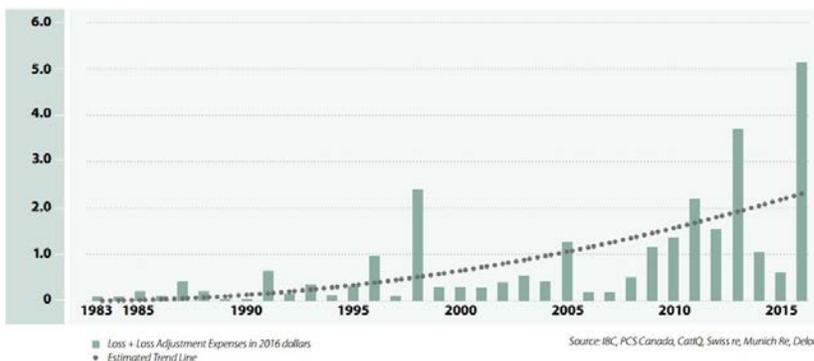


Figure 20. Catastrophic insured losses from natural disasters, Canada, 1983–2016
 Source: Insurance Bureau of Canada, 2017.

The data in Figure 20 have been adjusted to take account of inflation, a factor that could lead to an increasing trend in insured losses even in the absence of increased extreme weather. Another factor is that over time there are more insured assets in the economy to be found in harm’s way when extreme weather strikes. Munich Re, a global reinsurance company, has studied this factor and found that adjusting insurance losses for changes in the scale of the economy limits the impact of extreme weather at the global level; that is, after “normalizing” for growth in insured assets, the trend in increased insured losses from extreme weather is less evident (Figure 21). At the same time, the normalized data for insured losses due to thunderstorms in North America retain their upward trend, suggesting that extreme weather is having a clear impact on produced assets, at least in this region (Figure 22). To use Munich Re’s words, “the earth is hotting up” and “despite year-to-year variability, a long-term upward trend [in insured losses due to extreme weather] is clear” (Munich Re, 2016).

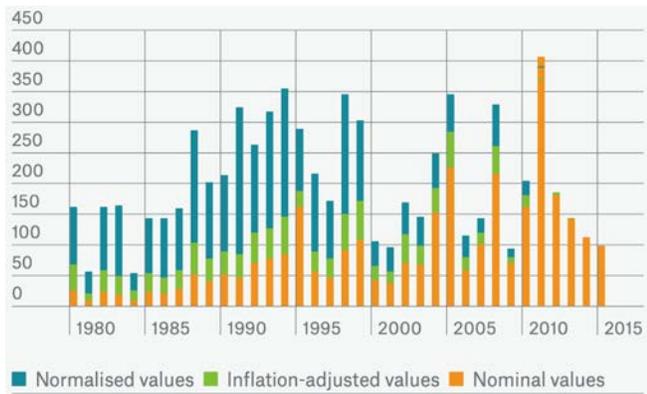


Figure 21. Nominal, inflation-adjusted and normalized trends in global insured losses due to natural disasters, 1980–2015

Source: Munich Re, 2016.

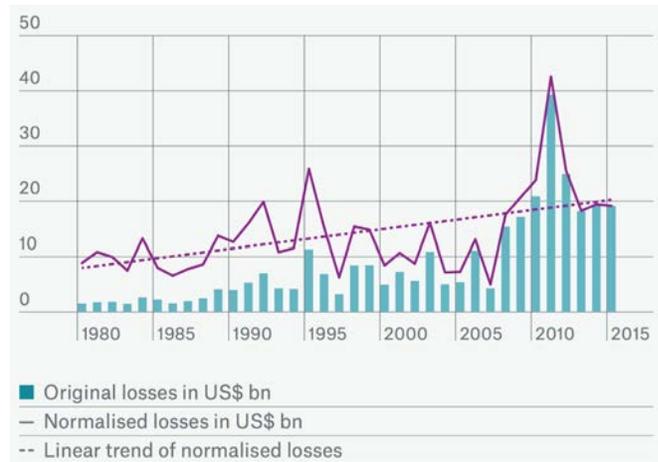


Figure 22. Nominal and normalized insured losses due to thunderstorms in North America, 1980–2015

Source: Munich Re, 2016.

5.4.3 Other Impacts on Produced Assets

Little information is available to assess other impacts of pollution on the value of produced assets. Though the relationship between degradation of infrastructure and pollution is well-established in some cases (for example, acid rain and road salt), there has been little effort to quantify the costs in terms of lost asset values.

One case where this might be tentatively attempted is the damage to the Champlain Bridge over the St. Lawrence River in Montreal, Quebec. As noted in Section 4.4.1.2, road salt applied to the bridge over many years is responsible in part for the bridge’s earlier-than-anticipated deterioration. Rather than lasting 100 years, as its designers intended, the bridge is being replaced today, some 50 years ahead of schedule, at a cost of some \$3–5 billion (Kay, 2014). Had the bridge lasted its intended lifespan, this expenditure would have not been required until 2065. A sense of the impact on Canada’s wealth as a result of this unanticipated expenditure can be given by the interest that could have been earned by investing the funds required to reconstruct the bridge in some other socially beneficial use for the next 50 years. Assuming a 3 per cent annual return on such an investment, this interest amounts to \$10 billion to \$17 billion depending on the actual cost of building the new bridge.



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APPENDIX A. RESEARCH METHODOLOGY

The research methodology used in this review is based on an approach known as *systematic review*. Systematic review aims to provide a transparent and replicable approach to the review of large amounts of information/literature/test results. This methodology aims to reduce subjective aspects brought in by the review's authors in material selection and assessment. The methodology originated in health sciences and has recently been applied to the review of large amounts of information in the environmental domain. Such reviews have included, for example, studies of adaptation efforts in the Arctic, national climate change mitigation strategies and project documentations on vulnerability reduction.

The systematic review methodology provides a structured process covering all aspects of literature review, from material selection to summarization of key trends identified in the literature. The first step in the methodology is to identify types of materials that will be considered in the review. This is followed by literature collection, screening and classification and, finally, analysis and synthesis of the key findings.

A summary of the four key methodological steps and sub-steps as applied in our review of the cost of pollution literature is listed in Text Box A1. Each of these four steps is described in detail in the sections below.

Text Box A1. Review methodology comprised of four main steps with specific sub-steps

1. Literature collection

- a) Develop search keywords based on the screening criteria
- b) Identify on-line sources
- c) Search for and collect studies

2. Literature screening

- a) Identify key criteria relevant for the review focus
- b) Develop specific screening criteria
- c) Pilot the screening criteria using a small number of studies and revise as needed
- d) Screen collected studies according to screening criteria

3. Literature classification

- a) Classify resultant group of studies according to "organizing" classifications
- b) Conduct targeted search(es) as needed to close gaps in literature

4. Analysis and synthesis

- a) Analyze studies individually
- b) Consolidate, synthesize studies' findings
- c) Produce aggregated estimates of the cost of pollution

A1.1 Literature Collection

The first step of the methodology relates to how the reports and studies used in this analysis were identified and gathered. It uses a rigorous searching process to ensure that a wide net is cast and a broad and diverse set of potentially useful studies is collected.

A number of individual key words were identified and, after some experimentation using Google, were combined. The combination of search terms was found to be targeted enough to identify highly relevant reports and studies, but also broad enough to pick up studies that may have only tangential connections to the cost of pollution.



Advanced Search

Find pages with...		To do this in the search box
all these words:	<input type="text" value="pollution cost pdf"/>	Type the important words: tricolor rat terrier
this exact word or phrase:	<input type="text"/>	Put exact words in quotes: "rat terrier"
any of these words:	<input type="text" value="environment health economic estimate model"/>	Type OR between all the words you want: miniature OR standard
none of these words:	<input type="text"/>	Put a minus sign just before words you don't want: -rodent, -"Jack Russell"
numbers ranging from:	<input type="text"/> to <input type="text"/>	Put 2 periods between the numbers and add a unit of measure: 10..35 lb, \$300..\$500, 2010..2011

Figure A1. Google Advanced Search Terms

A general search was done in Google using the above search criteria. In addition, a number of other specific on-line search engines were explored. First, scholarly portals were searched in order to gather relevant peer-reviewed studies. The portals used included Google Scholar, Bielefeld Academic Search Engine, and EconLit. The resources and websites of specific institutions known to have produced research on the topic of the cost of pollution were also consulted (see Table A1 below). In some cases, the search terms above were used in combination with a specific institution’s name, while in other cases institutions’ websites were directly explored to try to identify relevant materials.

When doing general Google searching, the first 250 search “hits” were reviewed. Any and all studies that appeared relevant to this analysis were collected in a database. For the scholarly search engine, the first 500 hits were reviewed and when searching for institution specific results, the first 100. These figures were chosen based on experimentation that determined the approximate point at which no further relevant results were being found in each respective source. In addition, an entirely separate search was done with each search engine using the search criteria presented above but with the word ‘Canada’ also included in the search string. This helped to ensure that both relevant international studies and important Canada-specific studies were picked up in the search. A total of 211 studies were collected through this process.

Table A1. Overview of Literature Collection

On-line sources used: Google Advanced Search, Google Scholar, Science Direct

Specific publishers considered:

Government sources: Canada (AAFC, Health Canada, Environment and Climate Change Canada, Statistics Canada) US (US EPA, US Department of Health and Human services); Europe (European Environment Agency, Public Health Europe)

Multilaterals: WHO, FAO, World Bank, UNEP, OECD

Non-governmental organizations (NGOs): Sustainable Prosperity, Pembina Institute, Canadian Public Health Association, Public research organizations, Canadian Medical Association, Ontario Medical Association, Canadian Association of Physicians for the Environment

A2. Literature Screening

With the studies collected, the second step of the analysis focused on their screening. The goal of this step was to use a defined set of criteria to narrow the focus to those studies deemed most relevant to this review.

To develop credible reviews on specific issues such as cost of pollution it is critical to define the boundaries of the studies to be included and excluded. To decide on these boundaries, it is important to account for aspects critical for the research. For example, the year of publication may be important, as older studies may use different methodologies and assessment methods that may not be comparable with more recent ones. The publisher of the



study may also be relevant; “grey” literature published by groups with policy interests, for example, may show biased results that could influence the quality of the assessment.

In this review, there were two screening stages (see Table A2). The first stage included three criteria based on study year of publication, type of publisher and country focus. The second stage used just one criterion based on study focus and methodology. Within each criterion, we specified sub-criteria to score studies higher that were more relevant for this review; for example, how recent the study is, whether it was peer-reviewed by credible agencies and whether its country context was relevant to Canada.

Table A2. Overview of Screening Criteria

Criteria	Sub-criteria	Score given to the collected material
Criteria for First Screening		
Year	2010 or after	5
	2005–2009	4
	2000–2004	3
	1990–1999	2
	Pre-1990	1
Type of Study	Tier 1 – Multilateral (World Bank, OECD, etc.) or academic journal	5
	Tier 2 – Grey literature from public research organization	4
	Tier 3 – Grey literature from private company / NGO	2
	Tier 4 – Grey literature from book / thesis	1
Country focus	Canada	5
	US – similar climate/ecological zone	4
	OECD country – similar (similar climate/ecological zone and similar level of development)	3
	OECD country – relevant (different climate/ecological zone but similar level of development OR similar climate/ecological zone but different level of development)	1
Criteria for Second Screening		
Focus and methodology	Primary research	5
	Meta-study	4
	Uses secondary sources	2
	Tangential focus	1

A simple Excel database was created to score the collected studies using the screening criteria. For the first screening stage, all studies collected were classified according to their year, type and country focus. For each criterion, a numerical score was given to reflect the relevance of the study. For example, studies focused on Canada and using primary data were given a higher scoring compared to those focused on other regions and/or using secondary sources. Details of the scoring are listed in Table A2.

Once scores were assigned to a study across the first three criteria (year, type of publisher, country/regional focus) an average score was calculated. All studies with an average score of 4 or greater were then subject to the second round of screening. In total, 102 studies were passed to the second round of screening.

While the three criteria in the first screening stage were focused on basic characteristics of the studies, the second screening stage looked at the specific methodological approach used in the study. Here we distinguished between those that actually provided an account of specific research and/or used secondary sources. Studies whose main focus was not to estimate pollution costs but still referenced the cost of pollution were scored the lowest as they are least relevant for our focus.



Determining the methodology used in a given study requires a more intensive scan of the study, so this criterion was addressed in a second screening stage rather than as part of the first screening stage. This was done to reduce the workload during the initial screening process. Rather than screening all the collected literature, only the 102 studies that passed the first screening stage were subjected to the second, more demanding screening stage.

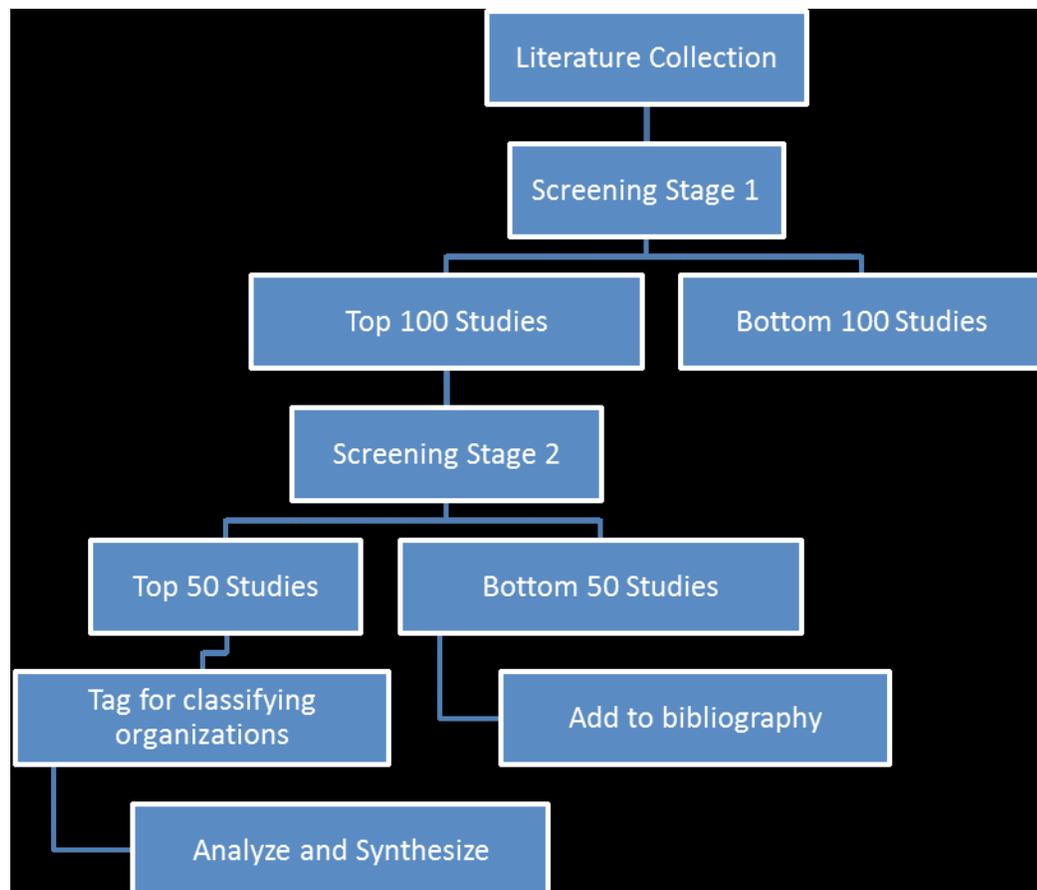


Figure A2. Decision tree for systematic review methodology

For the second screening stage, numerical scores were again assigned to the 102 prioritized studies that emerged from the first screen, but now on the basis of an additional criterion—their focus and methodology (see Table A2. Overview of Screening Criteria). Whereas the first screen was accomplished with only a cursory review of each study, the second screen required closer review of the prioritized studies. The numerical score assigned to a given study in the second screening was the average of the study’s score from the first screen and its score from the second screen. All 72 studies with an average score of 4 or greater were then selected as core studies to be reviewed (see Figure A2).

Overall, the numerical scoring used in the literature review favoured original research and meta-analyses. Studies that addressed cost of pollution only by referencing other studies were ranked lower. Any study where the sources or methods were not clear was removed from the analysis.

In addition, the bibliographies of the 72 studies were also reviewed to ensure that there were not any commonly cited studies the literature review failed to identify. Any additional collected literature was included in the database and tagged according to the screening and organizing classifications discussed above. The bibliography review



resulted in an additional 65 studies being collected. These studies were then subjected to the same two-stage screening process as the initial 211 studies. Of the 65 additional studies, 26 received an average score of 4 or greater across the two screening stages and were selected for inclusion into the final group of studies to be reviewed. Overall, 90 studies were selected for final review.

Before proceeding with the literature search and screening as outlined above, a pilot of the screening was undertaken to ensure that it effectively captured and summarized the information found in studies. The pilot was done using a small number of known studies drawn from previous research on the topic. The pilot resulted in the following changes to the methodology: adjustment of criteria and sub-criteria and refinement of the search string used in the on-line searches.

A3. Literature Classification

The 90 studies that emerged from the screening are the core set of studies that were analyzed and synthesized in Step 4 of the systematic review. In Step 3, these 90 studies were classified into a number of categories in order to facilitate analysis. The organizing categories include pollutant(s), impact type(s), media, valuation methodology, geographical scale, attribution focus, and regional focus within Canada, if any (see Table A3). Studies were individually reviewed in detail to determine how they matched the categories and tagged in the database accordingly⁶⁷. Multi-select was permitted for all the organizing classifications. No numerical scores were assigned at this stage since the intent was only to make the database easily searchable and navigable by specific topic rather than to facilitate screening.

Table A3. Organizing classification for the chosen literature

Category	Definition and sub-categories
Pollutant(s)	Types of pollutants such as GHGs, SO ₂ , NO _x , PM, CO, POPs, Dioxins and furans, Nuclear waste
Media	Types of media where the pollutant is realized/measured such as water, air, soil
Valuation methodology	Used valuations methodology for the costs of pollution such as directly observed market cost, indirectly observed market cost, stated preferences, benefits Transfer, meta-analysis
Impact type(s)	Types of economic impact of the pollutant: direct welfare cost; income cost; wealth cost
Final impact	The final socioeconomic impact of the pollutant: health, environment, agriculture/forestry/fisheries, visibility, recreation, physical damage
Geographical scale	Scales of the study: multi-national, national, provincial, regional, local
Regional focus within Canada	Focus within Canada: Northern, Western, the Prairies, Central and Atlantic Canada; applied only if relevant
Attribution focus (sectoral)	Attribution of the population source to sector: chemical, mining, oil and gas, petrochemical, fertilizer, agriculture - crop production, agriculture - livestock, fisheries and aquaculture, pulp and paper, cement, textiles, transportation, buildings, Construction, manufacturing, households, diffuse sources

Once all studies were classified it was possible to review the results to see how many addressed specific pollutants, media and impact types. If the results indicated that there were gaps in the collected literature with respect to important areas, then targeted searching was undertaken in an attempt to identify relevant literature that could fill these gaps. In the end, a good deal of targeted searching was required, as the initial systematic review results contained a number of gaps and missed some important studies that were found only following additional targeted searching. The studies listed in the bibliography of this report reflect the results of both the systematic review and the subsequent targeted searching.

⁶⁷ The criteria used in the earlier screening stage were also included in the database (study year, type, country focus and focus and methodology). However, rather than using the numerical scores, the actual values were inputted (e.g., “2014,” or “United States”).



APPENDIX B. DETAILS OF KEY STUDIES AND MODELS

This section provides a detailed overview of a number of the most important studies and models reviewed for this report.

B1. OECD 2016

Description of Method

The *Economic Consequences of Outdoor Air Pollution* (OECD, 2016) uses the impact pathway approach. Multiple steps are used to link projections of economic activity to changes in air quality, which are then linked to changes in health and economic outcomes. Seven steps are included in the process.

First, projections of economic activity are made using the OECD's ENV-Linkages model, which is a computable general equilibrium model. Projections are made at the sectoral and regional level to 2060.

Second, emissions of air pollutants are linked to the economic activities projected in Step 1. Emissions are either linked to a specific stage of the production process, such as the combustion of fossil fuels, or to the scale of production as a whole. Included pollutants are SO₂, NO_x, black carbon, organic carbon, carbon monoxide, volatile organic compounds, and ammonia. These pollutants are the main precursors of PM_{2.5} and ozone. This step establishes projections of regional pollution emissions.

Third, the emissions projections from step two are used to calculate the concentration of PM_{2.5} and ozone. An atmospheric dispersion model is used to create a gridded map of concentrations from 2010 to 2060.

Fourth, the data on pollutant concentrations are combined with concentration-response functions to determine the biological and physical impacts. Measured biophysical impacts include lost working days, hospital admissions, agricultural productivity changes and other impacts.

Fifth, the economic consequences of the health impacts are calculated for each country. Unit values for health endpoints are multiplied by the total number of each health endpoint.

Sixth, the ENV-Linkages model is used to analyze market costs, including agricultural yield changes, health expenditures, and labour productivity changes.

Seventh, non-market costs are quantified and estimated as welfare change using direct valuation studies.

Data Inputs

Air Quality Data

Air pollutant data are the output of the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model. Historic emissions of air pollutants are estimated in the GAINS model using data from international energy and industrial statistics, emission factors, and information on the implementation of environmental legislation. The results of the model are compared against national and international emission inventories.

Concentrations of ozone and PM_{2.5} are calculated using the European Commission Joint Research Centre's TM5-FASST (Fast Scenario Screening Tool) model. TM5-FASST is an atmospheric-chemistry-transport model that links emissions of precursor pollutants to concentrations of ozone and PM_{2.5}.



Population Data

Population and demographic data for health impacts were based on the UN's demographic and population projections.

Health Functions

Inclusion of health impacts was based on the recommendations of the World Health Organization under the “Health Risks of Air Pollution in Europe” review. Concentration-response functions are used to link health impacts to the population-weighted mean concentrations of PM_{2.5} and ozone.

Base-year health impacts for PM_{2.5} mortality are based on Fouzanzfar et al. (2015) and Brauer et al. (2016). Base-year health impacts for ozone mortality are based on Lim et al. (2012) and Burnett et al. (2014). These studies make use of IHME's Global Burden of Disease (GBD) database.

Morbidity impacts are based on the extrapolation of results from studies performed for the Clean Air Policy Package of the European Commission.

Economic Functions

OECD-developed VSL estimates are used to value premature mortality. The report uses a reference value of US\$3 million (2005 dollars) which is then transferred to individual countries using country-specific income and PPP exchange rates. This VSL is then applied to the estimated number of premature deaths in each country. For Canada, the applied VSL is US\$3.397 million (2005 dollars) (OECD, 2014).

The valuation of morbidity is separated into cost of illness and direct welfare costs. The direct welfare costs, as discussed earlier, are the pain and suffering associated with illness. The value of pain and suffering was derived using benefit transfer from a willingness-to-pay review in Europe. Direct welfare costs vary by health endpoint.

The illness costs of morbidity are separated into labour productivity impacts and health care costs. Both are calculated as a percent change in GDP using the ENV-Linkages model. The model uses a production function approach.

Changes to labour productivity are calculated from the number of lost working days. Labour productivity impacts are divided into four effects: the direct effect on labour, indirect effects on the labour market through wage effects and the allocation of labour, an impact on capital markets as they readjust to changes in household savings, and an impact on other components of GDP such as changes to tax revenues.

Health expenditures are estimated by multiplying the total number of a certain health outcome by the unit value of related health care. A reference value for health care costs in the OECD was taken from Holland (2014a, 2014b), which is then transferred to individual countries based on the relationship between health care expenditures and GDP per capita. The impact on GDP is estimated by viewing health expenditures as a reduction in demand. For households, increased health spending will result in reduced spending in other areas. For governments, increased health spending will be financed through additional tax revenues, which in turn have an impact on overall demand.



Table B1. Health effects included in OECD (2016)

Health effect		Quantified	Monetized
Mortality			
	Ozone mortality	Yes	Yes
	PM _{2.5} mortality	Yes	Yes
Morbidity			
PM _{2.5}	Chronic exposure adult bronchitis	Yes	Yes
	Chronic exposure child bronchitis	Yes	yes
	Hospital admissions respiratory illness	Yes	Yes
	Hospital admissions cardiovascular illness	Yes	Yes
	Restricted activity days	Yes	Yes
	Lost working days	Yes	Yes
	Child asthma	Yes	Yes
Ozone	Hospital admissions	Yes	Yes
	Minor restricted activity days	Yes	Yes

Crop Yield Changes

Included crops are rice, wheat, maize and soybeans. Crop yield changes are modelled with the TM5-FASST model based on concentrations of ozone during the growing season. Growing season and crop yield data are obtained from the Global Agro-Ecological Zones.

B2. World Bank and IHME, 2016

Description of Method

The World Bank and Institute of Health Metrics (IHME)’s report *The Cost of Air Pollution (2016)* uses the impact pathway approach to estimate health impacts and costs of ambient and indoor air pollution in countries around the world. The review was accompanied by a methodology report that provides a more in-depth review of the methodological choices made (Narain & Sall, 2016). Estimates of costs are limited to the mortality costs of PM_{2.5}. Morbidity costs were excluded due to their small magnitude in relation to mortality costs, and the uncertain methodology for their calculation. As with the OECD (2016) review, this review makes use of the IHME’s Global Burden of Disease (GBD) database

Data Inputs

Air Quality

Air pollution estimates in the GBD combines data from ground monitoring stations with satellite observations and chemical transport models. Ground-level monitoring alone is not enough to provide global coverage of emissions necessary to estimate exposure, in part due to the absence of stations in many parts of the world. Satellite observations help to fill in these gaps, but also provide useful information for areas such as Canada where monitoring stations are plentiful.

The chemical transport model Fast Scenario Screening Tool (TM5-FASST) was used to simulate pollution concentrations in 1990, 2000, and 2010. The TM5-FASST model was used to estimate population exposure to PM_{2.5}.



Health Outcomes

The risk of mortality from a number of diseases (ischemic heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, acute lower respiratory infections, and pneumonia in children and adults) was estimated using integrated exposure-response (IER) functions. The IERs combine individual response functions from the epidemiological literature.

Economic Valuation

Two approaches are used for valuing health impacts, a welfare-based approach using WTP methods, and an income-based approach that uses the present value of foregone lifetime earnings. The welfare-based approach is more useful for evaluating the total economic costs of premature mortality, which include lost consumption, leisure, and good health. A central VSL of US\$3.83 million (2011 PPP exchange) is used. This base VSL is the mean from a database of WTP studies conducted in high-income member countries of the OECD.

Country-specific VSLs are then determined by using benefit transfer. Willingness to pay for mortality risk reductions has been shown to increase with income. As a result, the benefit transfer approach used accounts for the difference between the OECD average GDP and the target countries' GDP.

B3. ICAP

Description of ICAP

The Illness cost of Air Pollution (ICAP) model was first developed by the Ontario Medical Association (OMA) in 2000 to quantify and monetize the health impacts of air pollution in Ontario. It was later developed further by the Canadian Medical Association (CMA) for application to all of Canada (CMA, 2008). The ICAP model uses a damage function/impact pathway approach.

ICAP models seven individual criteria air pollutants, including PM₁₀, PM_{2.5}, ozone, NO₂, SO₂, SO₄, and CO. The model can be used to look at the combined effects of PM_{2.5} and ozone (which includes the relevant primary pollutants), or to look at the effects of each primary pollutant. Primary pollutant effects are determined by their role in the formation of PM and ozone. PM is emitted as a primary pollutant and both PM and ozone are secondary pollutants formed in the atmosphere (CMA, 2008).

The model uses an impact pathway/damage function approach to link pollutant emissions to health impacts and finally health costs. Model inputs to quantify health impacts include population data and projections, pollutant emissions data, baseline health incidence rates, and concentration-response functions. Air quality data is projected by the model itself, rather than being an input from a separate air quality model.

Health endpoints are monetized using a mixture of WTP and cost-of-illness methods. The costs of mortality are estimated using WTP methods. ICAP also uses WTP to estimate the costs associated with pain and suffering. Cost-of-illness methods are used to value health care costs and lost productivity, which are the other impacts of morbidity (CMA, 2008).

ICAP Data Inputs

Air Quality

Baseline air quality concentrations were developed using 2003 to 2006 emission data taken from the National Air Pollution Surveillance (NAPS) stations run by Environment and Climate Change Canada. Interpolation for census divisions that did not have a NAPS station was necessary. This interpolation was improved by use of US air monitoring network data taken from stations within 500 km of the Canadian border (CMA, 2008b).



The ICAP model supports future air quality forecasts. The default forecast is to hold initial air quality concentrations constant. The model also includes air quality forecasting tools that allow the user to predict future air quality. The default forecast in the model is no change in air quality. Based on expert elicitation, the national ICAP model uses $PM_{2.5}$ and ozone only, as these are highly predictive pollutants, and are also formed by other criteria pollutants (CMA, 2008a).

Population

Population data is census division-level, drawn from the census. Statistics Canada forecasts are used for population projections. The model allows the user to choose between four projections: low-growth, medium-growth – medium migration trends, medium-growth – central-west migration trends, and high growth (CMA, 2008a).

Background Incidence and Prevalence Rates

Background incidence rates vary by province, age group and illness. Incidence rates for death are drawn from the death statistics published by Statistics Canada. Hospital admissions and emergency department visit baseline rates are derived from Canadian Health Statistics provided by the Canadian Institute for Health Information (CIHI). Baseline incidence rates are for Ontario only and are derived from OHIP statistics on annual average visits. Official statistics are not available for the baseline incidence rate for minor illnesses, so the rates were derived from work by Abt Associates (2003). Baseline incidence rates for asthma symptom days are taken from the Canadian Community Health Survey (CMA, 2008b).

Health Functions

There are five broad categories of health effect included in the model (CMA, 2008a):

- Premature death: includes both acute (short-term) mortality and chronic (long-term) mortality.
- Hospital admissions: includes both cardiovascular and respiratory illnesses.
- Emergency department visits: includes both cardiovascular and respiratory illnesses.
- Minor illnesses: the least severe but most common effect of air pollution. Includes minor restricted activity days, restricted activity days, and asthma symptom days.
- Doctor's office visits: these effects could only be quantified for Ontario at the provincial level, other provincial estimates do not include doctor's office visits. The Ontario estimate is proportionally extended for the national estimates.

These categories are further broken into 20 specific health effects (see Table B2).

Economic Valuation

Economic damages fall into four categories in the model: lost productivity, health care costs, pain and suffering, and loss of life. Lost productivity, health care costs, and pain and suffering fall into the category of morbidity costs, while loss of life is mortality.

When individuals are sick and cannot go to work, they miss out on wages. Any unpaid caregivers that have to stay home from work also miss out on wages. Lost productivity is valued using the average provincial wage rate for both the patient and unpaid caregivers. Wage rates are varied by age and gender. Sick time of children is not valued in the model, although prolonged absences may have an economic impact (CMA, 2008b).

Health care costs are based on provincial daily health cost statistics and expected length of hospital stay. Health care costs vary by illness. The length of stay in hospital due to illness is linked to age. The cost of pharmaceuticals is also included as a health care cost (CMA, 2008b).



Increased pain and suffering has an economic value, as both affected individuals and those close to them may be willing to pay to increase the quality of life. Quality of life is measured using WTP methods that survey the willingness to pay to reduce pain and suffering (CMA, 2008b).

Early death is the most severe economic outcome of illness associated with air pollution. The economic value is measured by the amount that people are willing to pay to reduce the chance of early death. This measure is called the value of statistical life (VSL) (CMA, 2008b). ICAP uses a VSL of \$2.3 million (SENES Consultants Limited, 2012).

Table B2. Monetized and non-monetized health impacts in ICAP

	Health effect	Quantified	Monetized
Mortality			
Loss of life	Chronic all-cause premature mortality	Yes	Yes
	Chronic cardio-respiratory premature mortality	Yes	Yes
	Chronic lung cancer premature mortality	Yes	Yes
	Acute all-cause premature mortality	Yes	Yes
	Acute cardiovascular premature mortality	Yes	Yes
	Acute respiratory premature mortality	Yes	Yes
Morbidity			
Hospital admissions	Dysrhythmia	Yes	Yes
	Congestive heart failure	Yes	yes
	Coronary artery disease	Yes	Yes
	Asthma related hospital admission	Yes	Yes
	COPD-related	Yes	Yes
	Pneumonia related	Yes	Yes
	Hypertension	No	No
	Reproductive and developmental effects	No	No
	Myocardial infarction	No	No
	New cases of chronic bronchitis	No	No
Emergency department visits	Cardiovascular ED visits	Yes	Yes
Doctors office visits	Cardiovascular	Yes (in Ontario)	Yes (in Ontario)
	Respiratory	Yes (in Ontario)	Yes (in Ontario)
Minor illnesses	Restricted activity days	Yes	Yes
	Minor restricted activity days	Yes	Yes
	Asthma symptom days	Yes	yes
Childhood	Early childhood lung development	Yes	Yes

Source: CMA, 2008b.

B4. Air Quality Benefits Assessment Tool (AQBAT)

Description of AQBAT

The Air Quality Benefits Assessment Tool (AQBAT) was developed by Health Canada beginning in 2003. AQBAT is a computer program that models the human health benefits associated with changes to the ambient air quality in Canada. AQBAT is a successor to the earlier Air Quality Valuation Model (AQVM). The earlier AQVM was developed in a partnership between Health Canada and Environment Canada, and estimated agricultural and



visibility impacts along with health impacts. Agricultural and visibility impacts have been split into separate models developed by Environment Canada (Sawyer et al., 2007). AQBAT uses a damage function/impact pathway approach method.

There are four model input components in AQBAT: pollutants, health endpoints, geographic areas and scenario years. Concentration-response functions link pollutants and health endpoints within a geographic area. Baseline health endpoints and population counts are also included in the model (Judek et al., 2012).

AQBAT Data Inputs

Air Quality

The AQBAT model accepts changes in air quality as a data input. Baseline ambient concentration levels are taken from the National Air Pollution Surveillance (NAPS) program (Judek et al., 2012). Ambient concentration levels developed with modelling software that uses NAPS monitoring data to increase regional coverage. Transport Canada (2008) used a model called the Reduced Form Source-Receptor Tool (ReFSoRT).

AQBAT includes four gas pollutants and two particle pollutants: carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide, particulate matter, and fine particulate matter (Judek et al., 2012).

Population

Population levels are based on the census. The population is divided among 446 geographic areas based on the 2006 Census Geography. Geographic levels include the national level, provincial level, census agglomerations, census metropolitan areas and census divisions. Census metropolitan areas are a subtype of census agglomerations (Judek et al., 2012).

Health Functions

There are currently 18 health endpoints included in AQBAT, based on Health Canada's judgement that sufficient evidence exists to show a causal link between pollutants and a specific health endpoint. Mortality and morbidity health endpoints are included (Judek et al., 2012).

Some health endpoints are considered to be overlapping. For instance, chronic exposure mortality includes all other chronic mortality endpoints (cardiovascular, respiratory, cerebrovascular etc.) (Judek et al., 2012).

Concentration-response functions in AQBAT are derived from the epidemiological literature. Health endpoints are either related to short-term exposure (acute) or long-term exposure (chronic) (Sawyer et al., 2007).

Economic Valuation

Mortality is valued using the VSL. The AQBAT model uses a VSL of \$4.05 million. Morbidity is valued as the total of lost wages, cost of treatment, averting expenditures, and pain and suffering (Sawyer et al., 2007).

**Table B3. Monetized and non-monetized health effects in AQBAT**

	Health effect	Quantified	Monetized
Mortality	Chronic exposure mortality	Yes	Yes
	Acute exposure mortality	Yes	Yes
	Chronic exposure cardiovascular mortality	Yes	Yes
	Chronic exposure respiratory mortality	Yes	Yes
	Chronic exposure cerebrovascular mortality	Yes	yes
	Chronic exposure ischemic heart disease mortality	Yes	Yes
	Chronic exposure lung cancer mortality	Yes	Yes
Morbidity	Acute respiratory symptom days	Yes	Yes
	Adult chronic bronchitis	Yes	yes
	Asthma symptom days	Yes	Yes
	Cardiac emergency room visits	Yes	Yes
	Cardiac hospital admissions	Yes	yes
	Elderly cardiac hospital admissions	Yes	yes
	Child acute bronchitis episode	Yes	Yes
	Minor restricted activity days	Yes	Yes
	Respiratory emergency room visits	Yes	Yes
	Respiratory hospital admissions	Yes	Yes
	Minor restricted activity days	Yes	Yes
	Restricted activity days	Yes	Yes

Source: Sawyer et al., 2007.

B5. Air Quality Valuation Model (AQVM2)

Description of AQVM2

The Air Quality Valuation Model (AQVM2) is a software program developed by Environment Canada. AQVM2 is used to estimate the economic value of the environmental impacts associated with changes in air quality. A two-scenario approach is used, in which a baseline scenario is compared against an alternative scenario. Changes to crop productivity due to ground-level ozone, changes in visibility, and soiling of buildings are the impacts included in the AQVM2 model. Each of these impacts is separated into a module, the Value of Ozone Impacts on Canadian Crops Estimator (VOICCE), the Visibility Impacts Estimator of Welfare for Residents (VIEW) and the Soiling Cleaning Savings Impact Estimator (SCSIE).

The AQVM2 uses an impact pathway approach that connects changes in air quality to changes in outcomes using concentration-response (exposure-response) functions. Monetization is done using agricultural market prices or benefit transfer. Air quality is modelled using AURAMS (A Unified Regional Air-Quality Modelling System).

VOICCE

The Value of Ozone Impacts on Canadian Crops Estimator (VOICCE) was developed by Environment Canada to estimate the yield change impact that ozone has on Canadian crops. Average yearly 1-hour ozone concentration changes in 82 agricultural regions are used to estimate impacts associated with 19 crops.

VOICCE is a damage function model that connects changes in air quality to changes in crop yield, much like health cost models. Concentration-response functions for each crop type allows for estimates of yield change due



to air quality change. Economic values can then be estimated by calculating the reduced revenue due to lower yields (Sawyer et al., 2007). The concentration-response functions were determined by a literature review by Kulshreshtha, Sobool and Belcher (2003).

Table B4. Crops included in VOICCE

Crops	
Spring wheat	Sugar beet
Durum	Dry field peas
Winter wheat	Lentils
Canola	Dry white beans
Soybeans	Other dry beans
Corn for grain	Tomato
Corn for feed	Lettuce
Alfalfa	Onion
Hay	Potatoes

Visibility Impacts Estimator of Welfare (VIEW)

The Visibility Impacts Estimator of Welfare (VIEW) was developed by Environment Canada to examine how changes in ambient air quality, primarily PM, impact visibility and social welfare. Changes in PM concentrations are linked to visibility, which are then valued using estimates of a person’s willingness to pay for increased visibility. The WTP estimates were developed using contingent choice surveys, which force participants to repeatedly choose between various improvements at various costs (Sawyer et al., 2007).

The primary visibility endpoint is the atmospheric haze index called the deciview, which expresses changes in visibility. The deciview relates changes in haziness to human perceived visibility conditions, with one deciview representing a 10 per cent change in the extinction coefficient, which is a small scenic change (Sawyer et al., 2007).

The cost function in the VIEW model is based on a survey of people in the Lower Mainland of British Columbia (Haider et al., 2002), and may therefore be biased toward the characteristics and demographics of the area (Sawyer et al., 2007). The value used is \$12.32 for a one-unit reduction in deciviews (in 2002 CAD).

Soiling Cleaning Savings Impact Estimator (SCSIE)

The Soiling Cleaning Savings Impact Estimator (SCSIE) module is used to estimate the costs associated with cleaning houses that have been coated in particulate matter. Estimates are made only for residential houses, for all 288 census divisions. Monetization is based on the cost of cleaning associated with an annual increase of one microgram/m³ in PM₁₀ concentrations (\$3.50 in 1996 dollars). The value amount was derived from a benefit transfer of a report done by the US EPA.

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